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Foreword

The International Scientific and Professional Conference POLITEHNIKA 2025 represents the eighth edition of the POLITEHNIKA scientific and professional events, occurring biannually since its inaugural event in 2011. POLITEHNIKA 2025 upholds a distinguished tradition and commitment to integrating higher education and practical application across a diverse spectrum of disciplines represented by defined thematic scopes.

Organized with the patronage of the Ministry of Education of the Republic of Serbia, the Ministry of Science, Technological Development and Innovation of the Republic of Serbia, the Directorate for Occupational Safety and Health, the Office for Dual Education and National Qualifications Framework, the Chamber of Commerce of Belgrade, the Institute for Standardization of Serbia, Serbian Automotive Cluster - AC Serbia, Center for the Promotion of Science, Engineering Academy of Serbia and the Development Agency of Serbia, POLITEHNIKA 2025 stands as a collaborative platform at the intersection of academia, governmental institutions and industry.

Proudly holding its international status, the Conference POLITEHNIKA 2025 encompasses 10 thematic domains: Environment and Sustainable Development, Occupational Safety and Health and Fire Safety, Smart Management Systems, Graphic Engineering, Design, Traffic Engineering, Biotechnology, Pharmacy and Healthcare, Mechanical Engineering, Ecotourism and Rural development, and Mechatronics. By engaging experts, emerging professionals, and practitioners from these domains, the conference unifies fields of study programs of the Academy of Applied Studies Polytechnic. The thematic scopes, coupled with the structure of the compiled papers in this Proceedings, exhibit a rich diversity and multidisciplinary approach, fundamentally contributing to a holistic examination and resolution of societal and scientific challenges.

Comprising over 200 peer-reviewed contributions, the Proceedings represent a substantial intellectual asset, aligning with the conference's overarching objective of fostering the exchange of knowledge, research findings, and professional experiences among experts from industry, research institutions, and higher education establishments.

The Proceedings of the International Scientific and Professional Conference POLITEHNIKA 2025 serve as a comprehensive snapshot of the current landscape within the thematic realms of the conference, offering both insights and directives for ongoing scientific and professional development. Moreover, it offers concrete solutions to practical challenges grounded in contemporary trends and pertinent insights.

The Academy of Applied Studies Polytechnic extends its sincere appreciation to all conference supporters whose financial contributions played a pivotal role in its successful realization. Special acknowledgment is reserved for the authors of the papers, whose diligence and eagerness to present their work to a wider audience, alongside the reviewers and members of the International Scientific Committee, Program Committee and Organizational Committee, have collectively contributed to the triumph of the International Scientific and Professional Conference POLITEHNIKA 2025.

Belgrade, November 2025
EDITORS



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ECOLOGICAL RISKS OF URBAN SOILS IN BELGRADE

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Abstract: This study investigated the distribution of heavy metals (Cu, Zn, Pb, Cd, Ni, Cr) and As in urban soils of Belgrade. Analysing soil quality data from the Serbian Environmental Protection Agency (2011–2023), the most contaminated samples were located near Parking Service “25. Maj,” with significant concentrations of Cu (302 and 198 mg/kg), Zn (478 and 547 mg/kg), Cd (3.80 and 3.59 mg/kg), Ni (137 and 122 mg/kg), Cr (145 and 104 mg/kg), and Hg (1.06 and 1.20 mg/kg) at both investigated depths 10 and 50 cm in 2021. Traffic zones exhibited the highest average concentrations for Cu (37.9 mg/kg), Zn (97.0 mg/kg), Cd (0.45 mg/kg), and As (12.2 mg/kg), while Pb peaked in urban and traffic agricultural lands (67.8 mg/kg). The lowest concentrations were found in residential and agricultural zones. According to national regulations, 95.4% of the samples contained Ni above the maximum limit value; Cu exceeded limits in 27.8%, and Zn in 17.9%. Notably, Ni levels were particularly concerning, with 3% of samples surpassing remediation values, indicating anthropogenic influences on soil contamination as indicated by the co-occurrence of other heavy metals.

Keywords: Soil Pollution, Heavy Metals, Belgrade Urban Area

1. INTRODUCTION

Intensive urbanization, expansion of industry, traffic and agricultural practices significantly contribute to environmental pollution, adversely affecting soil ecosystems by heavy metals. Their accumulation in the surface soil layers can result in soil degradation and disruption of natural ecological functions. These alterations produce detrimental consequences for both the ecosystem and public health [1]. The soil composition is critical determinant of population health, exerting both direct and indirect effects through the contamination of surface and groundwater, as well as pollution of air and food sources. The primary contributors to soil pollution are predominantly the result of human activities [2], which can be broadly categorized into three main groups; wastewater, atmosphere and solid waste. Wastewater is the consequence of the industrial, agricultural and domestic activities. Agricultural runoff include water contaminated by artificial fertilizers, pesticides, and various organic substances of similar origin. Atmospheric pollutants encompass emissions from industrial processes, emissions from the combustion of fossil fuels (including those from industrial, energy-producing, and residential sources), emissions from motor vehicles and the emissions arising from the combustion of various organic materials. Solid waste includes various sources such as: industrial, mining and agricultural waste. The fate of heavy metals and metalloids in the environment has garnered significant interest from scientists across various fields over the past few decades. This

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heightened focus has been fuelled by an increasing awareness of the environmental toxicity associated with metals.

At high concentrations, all heavy metals whether essential or non-essential for living organisms can have toxic effects on various forms of life, including microorganisms, plants, animals, and humans [3]. Most studies agree that urban soils exhibit higher concentrations of trace elements compared to natural background levels. Although their natural forms typically exist, significant contributions of various anthropogenic sources are confirmed, especially in upper soil layers [4]. Anthropogenic influence typically includes emissions from industrial plants, vehicle exhausts, thermal power stations, and waste from commercial products [5].

This article investigates potential ecological risk of the heavy metals (Cu, Zn, Pb, Ni, Cd, Cr and Hg) and metalloid (As) concentrations in soil within the urban Belgrade region. It includes monitoring the eventual extent of soil contamination, particularly in the immediate vicinity of the sanitary protection zone of the Belgrade water supply system, traffic roads, parks and children's playgrounds. The study focuses on heavy metals concentrations data related to soil pollution, while also suggesting the possible source of soil contamination.

2. MATERIAL AND METHODS

2.1 Study area

In this paper, the soil quality data from the Serbia's Environmental Protection Agency's 2011–2023 reports are analysed. 784 soil samples were examined at around 350 different locations from depths of 10 and 50 cm focusing on examination of eventual soil contamination in various critical areas, including the sanitary protection zone of the water supply system, city parks and recreational zones, soil near industrial buildings, agricultural, urban agricultural and locations adjacent to major traffic routes.

2.2 Ecological risks assessment

The soil quality assessment is usually determined by comparing the measured concentrations of observed parameters against established soil quality guidelines. For this work, the results of the element concentrations were compared with the maximum limit (*MLV*) and remediation values (*RV*) prescribed by the Regulation on limit values of polluting, harmful, and dangerous substances in soil (Official Gazette of the Republic of Serbia, No. 30/2018 and 64/2019). Exceedance of the maximum limit value of an individual pollutant indicates a level of contamination that disrupts ecological balance and additional research is to be carried out in order to determine the degree of soil contamination and develop remediation projects. Mentioned Regulation prescribes the correction of maximum limit and remediation values (*MLV*, *RV*)_{corr} for metals and arsenic in soil with the correction formula (1), depending on the type of soil so that the corrected values should be applicable to the actual soil properties, based on the measured organic matter content (OM, %) and clay content (particle size < 2 μm, %). For each soil sample the following correction formula was used and new *MLV*_{corr} and *RV*_{corr} were calculated using *A*, *B*, *C* as constants obtained in the Official Gazette:

$$(MLV, RV)_{corr} = (MLV, RV) + \frac{A + B * Clay (\%) + C * OM(\%)}{A + B * 25 + C * 10} \quad (1)$$

3. RESULTS AND DISCUSSION

The statistical characterization of heavy metals and arsenic concentrations in the soil samples is summarized in Table 1. The distribution of these elements across the studied soils exhibited significant spatial variability among different sampling locations, suggesting diverse origins for these elements and varying anthropogenic influences. A comparative analysis of the results from this study

and those from a prior investigation [5] indicates a significant decrease in the average metal concentrations in the urban soils of Belgrade. In 2008, the mean concentration of Pb was observed at 299 mg/kg, nearly double the mean values reported for 2003 and 2005, which were 151 mg/kg and 125 mg/kg, respectively, while this study recorded a mean concentration of 41.9 mg/kg. But, the maximum Pb concentration identified in the previous study was 238 mg/kg (2005), which is approximately seven times lower than this peak concentration of 1670 mg/kg (10 cm) and 770 mg/kg (50cm) documented at the Dorćol profile, located near a major traffic thoroughfare (Table 1) during 2011.

Table 1. The statistical description of the heavy metal concentrations in soils of Belgrade

Source: <https://sepa.gov.rs/>

		Mean	Median	Mode	Minimum	Maximum
OM	%	5.5	5.1	6.3	1.4	31.9
Clay		14.1	12.6	9.0	0.3	46.7
Cu	mg/kg	27.1	22.1	24.5	<2	302.9
Zn		77.8	63.2	102.0	<1	547.5
Pb		41.9	23.1	16.6	<5	1670
Cd		0.3	<0.4	<0.4	<0.4	5.5
Ni		52.9	45	38.9	<1	302.0
Cr		46.5	43.2	29.3	<0.5	191.0
As		11.2	9.6	8.5	2.4	83.8
Hg		0.12	<0.2	<0.2	<0.2	2.6

These discrepancies may be attributed to two primary factors. The increasing traffic density caused very high surface Pb content in 2011, while still leaded gasoline was a common practice in Serbia. Also, elevated mean Pb concentrations were probably a consequence of the seasonal timing of the sampling conducted during winter in 2008 [5], a period when emissions from heating plants may have contributed to elevated levels of pollutants. Similarly, the average concentration of Cu (Table 1) was lower than that recorded in 2005 (95.7 mg/kg) and in 2003 (53.3 mg/kg). In addition, Cu also exhibited the greatest variability among the assessed elements, with concentrations fluctuating from below the quantification limit (<2 mg/kg) to a peak of 302.6 mg/kg at a depth of 10 cm and 198.95 mg/kg at 50 cm at the same profile. The highest Cu concentrations were identified in soil samples collected from industrial areas adjacent to roadways, with elevated levels of Cd recorded concomitantly at these locations. Likewise, Zn concentrations ranged from <1 mg/kg to 547.5 mg/kg, with the maximum observed in samples also exhibiting substantial Cu content from industrial zones near traffic roads. Same as previous metals, mean Zn concentration was noticeably lower (Table 1) than those measured in 2008 (174.2 mg/kg), 2005 (152 mg/kg) and 2003 (214 mg/kg). Ni concentrations ranged from <1 mg/kg to 302 mg/kg, with the highest value noted at the same profile where elevated levels of Cd and Cr were found at Boulevard Patrijarha Pavla at a depth of 50 cm. Mean concentration (52.9 mg/kg) is in agreement with prior investigation which reported average Ni content of 61.94 mg/kg in urban area of Belgrade [6].

Arsenic concentrations varied between 2.4 and 83.8 mg/kg, with its presence detected at all monitored sites. The maximum concentrations were recorded in soil samples from park areas near traffic roads, measuring 50 mg/kg at a depth of 50 cm (Poenkareova street) and 74.98 mg/kg at a depth of 10 cm. Cd content ranged from below the limit of quantification (LoQ < 0.2 mg/kg) to a maximum of 5.5 mg/kg, with the highest concentration recorded at a depth of 50 cm on Boulevard Patrijarha Pavla. The mean concentration of 0.3 mg/kg represents a decline compared to previous studies, which reported values of 1.8 mg/kg in 2008, 1.3 mg/kg in 2003, and 1.9 mg/kg in 2005 [5]. Cr values displayed significant variability among sites, ranging from below the quantification limit (LoQ < 0.5 mg/kg) to 191 mg/kg, with the highest levels also recorded at Boulevard Patrijarha Pavla. Mercury (Hg) was generally undetectable in most samples (content <0.07 mg/kg); however, measurable

concentrations were identified in several monitoring profiles near traffic roads (industrial zones), exceeding 1 mg/kg, with the maximum recorded concentration at the Vrčin profile being 2.6 mg/kg. Generally, the most polluted profiles were observed near traffic roads. The most contaminated samples were detected near Parking service “25. Maj” with very high values of Cu (302 and 198 mg/kg), Zn (478 and 547 mg/kg), Cd (3.80 and 3.59 mg/kg), Ni (137 and 122 mg/kg), Cr (145 and 104 mg/kg) and Hg (1.06 and 1.2 mg/kg) at both depths, 10 and 50 cm during 2021.

Compared to Regulation on the limit values of polluting, harmful, and dangerous substances in soil, this profile exceeded the remediation values for Cu, Zn and Ni at both depths. These results indicate anthropogenic sources, traffic concretely since all elevated concentrations were detected near traffic roads. Same is also evident on the Figure 1 where the soil samples were grouped by the land use and the average concentrations of elements are presented. Cd and Hg were excluded from the figure because almost all the average values were less than LOQ values. Cu (37.9 mg/kg), Zn (97.0 mg/kg), Cd (0.45 mg/kg) and As (12.2 mg/kg) were the highest in the traffic zones while Pb (67.8 mg/kg) was most elevated in agricultural land in urban and traffic areas (65.4 mg/kg).

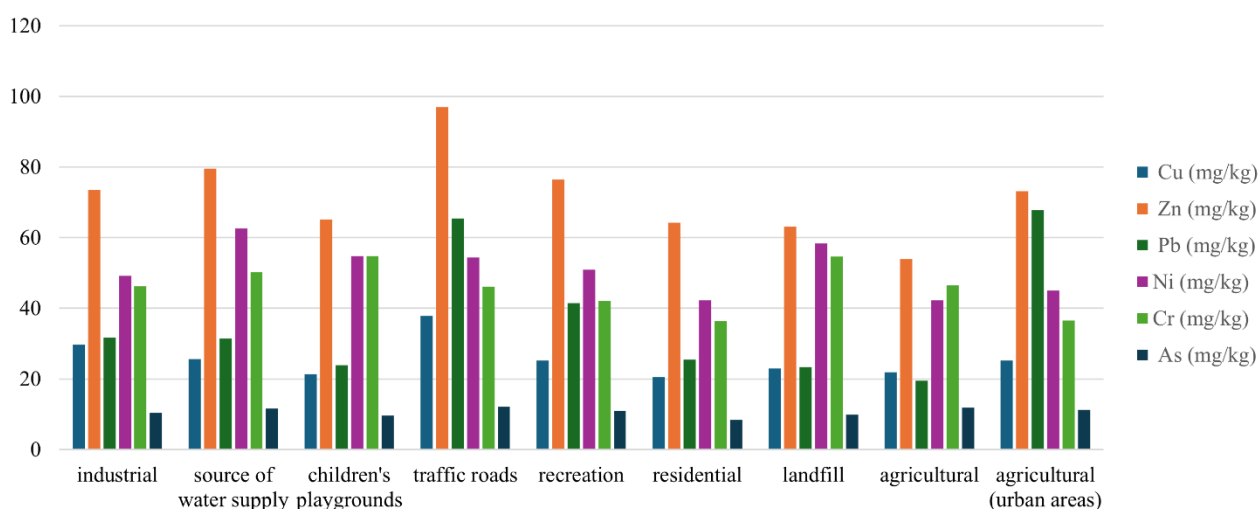


Figure 1. Mean values of element concentrations and their spatial distribution based on land use

The lowest mean concentrations of the analysed elements, particularly Pb, Zn, Cu, and Cd, were recorded in residential and agricultural zones. Conversely, soil samples collected from surrounding landfill areas indicated elevated mean concentrations of chromium (54.6 mg/kg) and nickel (58.4 mg/kg). A comparative analysis of agricultural and urban agricultural areas revealed significant discrepancies in the mean values of several elements. Notably, the most pronounced difference was observed in Pb concentrations, with mean values of 19.5 mg/kg in agricultural areas and 67.8 mg/kg in urban agricultural areas, suggesting traffic as the primary source of pollution. The other element which exhibited distinguished difference is Zn, 54.0 mg/kg in agricultural and 73.2 mg/kg in urban agricultural areas. The other monitored elements did not demonstrate substantial differences between these two types of areas.

In the context of the water supply source zone, all analysed elements exceeded the maximum limit value (*MLV*) to varying degrees. As previously noted, Ni presented the most significant concern, with 97% of all soil samples surpassing the *MLV*. This was followed by Cu and Zn, which exceeded the *MLV* in 27% and 24% of the samples, respectively, while Cr exceeded the *MLV* in 12% of the samples. The other elements analysed remained below 5% of the total soil samples. It is of great importance to monitor these areas and to prevent eventual activities which can cause a change in the natural water quality by introducing pathogenic microorganisms and/or changing its physical and chemical properties.

According to national legislation, 95.4% of the all analysed soil samples were found to contain Ni, exceeding the maximum limit value; 27.8% were contaminated with Cu, and 17.9% with Zn. Other elements exhibited contamination in less than 10% of total samples. So, based on the metals

concentrations the eventual ecological risk descends with the following order: Ni>Cu>Zn>Pb>Cr>Cd>As>Hg.

Considering the aforementioned regulation, Ni emerged as the most concerning element across all observed samples, with 95% exceeding the *MLV* and 22 samples surpassing the calculated *RV*. The high concentrations of Ni in nearly all samples at both depths indicate a geochemical source which is in agreement with Bogdanović (2007) [7]; however, anthropogenic influence was also evident at the contaminated sites, as demonstrated by the presence of other elements. Additional research is to be conducted to determine the degree of soil contamination and to develop eventual remediation and recultivation projects.

In this study correlation analysis was also done using all obtained soil quality data (Table 2). This method is employed to determine the possible sources and pathways of pollution by statistically associating the presence and concentrations of various metals with common sources, such as industrial activities or specific geological formations. Strong correlations between heavy metals suggest originating from shared sources like vehicle emissions, and a common pathway. Conversely, other metals may exhibit independent correlations or lack any relationship altogether, indicating distinct pollution sources. Here, correlation analysis revealed two strong correlations between elements. The highest correlation factors were obtained between Ni and Cr ($r^2=0.82$) and the other one between Cu and Zn ($r^2=0.72$).

Table 2. The Correlation coefficients (r^2)

	OM	Clay	Cu	Zn	Pb	Cd	Ni	Cr	As	Hg
OM, %	1.00									
Clay, %	-0.02	1.00								
Cu, mg/kg	0.51	-0.01	1.00							
Zn, mg/kg	0.50	-0.02	0.72	1.00						
Pb, mg/kg	0.27	0.08	0.46	0.59	1.00					
Cd, mg/kg	0.38	-0.07	0.56	0.66	0.43	1.00				
Ni, mg/kg	0.32	0.15	0.30	0.33	0.13	0.24	1.00			
Cr, mg/kg	0.23	0.30	0.29	0.31	0.13	0.21	0.82	1.00		
As, mg/kg	0.40	0.10	0.37	0.52	0.41	0.42	0.38	0.38	1.00	
Hg, mg/kg	0.22	-0.03	0.31	0.31	0.12	0.26	0.25	0.18	0.11	1.00

Previous study demonstrated the geogenic contents of Ni and Cr in the soils of Serbia and their elevated concentrations in all depth profiles while if they are anthropogenic origin (industry, transport, smelters and mines, mineral and organic fertilizers, pesticides, sludge) they have a tendency to accumulate in the uppermost soil layers [8]. So, additional research, including measuring Ni and Cr content in deeper layers of soil, should distinct whether these two elements have natural or anthropogenic source. Mining, smelting, and manufacturing operations can concurrently release Cu and Zn into the environment. Both Cu and Zn are applied in agricultural activities, Cu primarily through copper-based fungicides and Zn via Zn-containing fertilizers. Runoff can transport these metals into soils and aquatic ecosystems concurrently. Tire wear, brake pad degradation, and galvanic coatings on guardrails and vehicles contribute Cu and Zn to roadside soils and dust. Mixed industrial effluents and municipal or industrial solid waste may contain both metals, with processes such as electroplating introducing heavy metals into receiving water bodies and sediments [9]. Organic matter content was good correlated with Cu and Zn indicating their organic background while clay exhibited very small correlation coefficient with almost all elements.

4. CONCLUSION

All investigated metals exhibited a broad range of concentration values, which varied by location and specific sampling points. The observed high concentrations and variability indicate anthropogenic sources for these elements. Generally, the most polluted profiles were observed near traffic roads.

The most contaminated samples were detected near Parking service “25. Maj” with very high values of Cu, Zn, Cd, Ni, Cr and Hg at both depths, 10 and 50 cm during 2021. Compared to Regulation on the limit values of polluting, harmful, and dangerous substances in soil, this profile exceeded the remediation values for Cu, Zn and Ni at both depths. These results indicate anthropogenic sources, traffic concretely since all elevated concentrations were detected near traffic roads. A comparative analysis of the results from this study and those from a prior investigation indicates a significant decrease in all the average metal concentrations in the urban soils of Belgrade especially lead, copper and zinc suggesting the use of an unleaded gasoline.

From the aspect of different land use area, the lowest mean concentrations of the analysed elements, particularly lead, zinc, copper, and cadmium, were recorded in residential and agricultural zones. Conversely, soil samples collected from surrounding landfill areas indicated elevated mean concentrations of chromium and nickel. A comparative analysis of agricultural and urban agricultural areas revealed significant discrepancies in the mean values of several elements. Notably, the most pronounced difference was observed in lead concentrations, suggesting traffic as the primary source of pollution. The other element which exhibited distinguished difference is zinc, and the other monitored elements did not demonstrate substantial differences between the two types of areas.

In the context of the water supply source zone, all analysed elements exceeded the maximum limit value (MLV) to varying degrees. As previously noted, Ni presented the most significant concern following Cu, Zn, and Cr. According to national legislation, 95.4% of the all examined soil samples were found to contain Ni, exceeding the maximum limit value; 27.8% were contaminated with Cu, and 17.9% with Zn. Other elements exhibited contamination in less than 10% of total samples. Based on the metals concentrations the eventual ecological risk descends with the following order: Ni>Cu>Zn>Pb>Cr>Cd>As>Hg. Ni was identified as the most problematic element in all observed samples, with 95% exceeding the maximum limit and about 3% samples going beyond the calculated remediation values. The elevated concentrations of nickel found in nearly all samples at both depths suggest a geochemical source; nonetheless, anthropogenic influence was also apparent at the contaminated locations, as reflected by the presence of various other elements.

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The logo for PR-DC, featuring the letters 'PR-DC' in a bold, white, sans-serif font. The 'P' and 'R' are connected, and the 'D' and 'C' are also connected. The logo is set against a white, stylized shape that resembles a drone's body or a camera lens.

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A black drone is shown in flight, viewed from a low angle. The drone has four arms, each with a propeller. The background is a dark blue gradient with a faint grid pattern. The drone is positioned in the center of the frame, with its arms spread out.

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Razvijeni model sakupljanja i zbrinjavanja otpada je primenjen i organizovan po sistemu „zagađivač plaća“ u skladu sa Zakonom o upravljanju otpadom, a veliki broj renomiranih klijenata iz različitih grana industrije je tokom prethodnih 13 godina postojanja ENVIPACK doo, postalo deo ENVIPACK sistema koji uspešno rešava probleme upravljanja otpadom iz poljoprivrede, farmaceutske industrije, građevinske industrije, grafičke industrije, metaloprerađivačke industrije, drvnoprerađivačke industrije i iz drugih grana privrede.

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