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Cu AND As CONCENTRATIONS IN ARABLE LAND AND WHEAT GRAIN IN THE VICINITY OF BOR, SERBIA: IMPLICATIONS FOR SUSTAINABLE AGRICULTURE AND FOOD SECURITY

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Abstract

In this study, concentrations of Cu and As in agricultural soil and wheat (Triticum aestivum L.) in the vicinity of the Zijin Copper Bor mining complex, Serbia, were analyzed, with a focus on 6 localities: Brezonik, Veliki Krivelj, Oštrelj, Slatina, Zlot and Gornjane. Using the ICP-MS method (inductively coupled plasma - mass spectrometry), the presence of Cu and As in the soil and in wheat grains was examined, using descriptive analysis and Spearman's rho correlation. The obtained results indicate pronounced spatial variability and can represent the initial basis for extended monitoring of the quality of arable land and agricultural products in areas exposed to mining and metallurgical influences, with possible importance for sustainable agriculture and food security.

***Keywords**: arable land, wheat grain, mining exploitation, Cu and As, ICP-MS, descriptive statistics, Spearman's rho correlations*

1. INTRODUCTION

Mining and metallurgical activities represent significant sources of potentially toxic elements created by human activity in the environment. In the area of Bor, emissions from copper production, including particles containing Cu and As, are recognized as a significant source of air and surrounding soil pollution [1,2]. The disposal of flotation tailings and the atmospheric deposition of particles can contribute to the increase in the concentration of these elements in the soil and their presence in plants. Therefore, the contamination of arable land with potentially toxic elements requires continuous monitoring, especially due to the possibility of their adoption in crops and entering the food chain [2]. Continuous monitoring of arable land in areas close to the mining industry is important for achieving the goals of sustainable agriculture and food security.

Copper (Cu) is an essential trace element that participates in numerous physiological and biochemical processes in plants, including photosynthesis, respiration, antioxidant defense and signaling processes [3]. However, its elevated concentrations can cause the formation of reactive oxygen species, oxidative stress, disturbances of the photosynthetic apparatus and reduction of plant growth [3]. Arsenic (As) is a toxic metalloid that enters the soil through natural geological processes, but also through anthropogenic activities, especially the exploitation and processing of ores containing sulphide minerals [4]. Absorption and accumulation of As in edible parts of plants can contribute to its entry into the food chain and represent a potential risk for food safety [5,6].

The aim of the research was to determine and compare the concentrations of Cu and As in arable soil and wheat grain (Triticum aestivum L.) at six locations in the vicinity of Bor, determine their spatial variability and examine the relationship between concentrations in soil and grain using the Pearson correlation coefficient. The obtained results were considered as a basis for future monitoring of soil and agricultural products in areas exposed to mining and metallurgical influences.

2. EXPERIMENTAL

Sampling of soil and wheat grains (Triticum aestivum L.) was carried out at 6 locations (L1-Brezonik, L2-Veliki Krivelj, L3-Oštrelj, L4-Slatina, L5-Zlot and L6-Gornjane), which are in the vicinity of the mining and smelting complex Zi Jin Bor, Serbia. The sampling plan was prepared in accordance with the ISO 18400-101:2017 standard. All procedures were performed at the Institute of Mining and Metallurgy Bor (IRM Bor), according to ISO 18400-102:2017, ISO 18400-104:2018, ISO 18400-105:2017 and ISO/IEC 17025:2017 standards.

3. RESULTS AND DISCUSSION

Descriptive statistics, Table 1, show significant differences in soil Cu concentrations between the analyzed locations. The highest average value was registered in Slatina (L4), where mean = 568.60 mg/kg with a standard deviation of 7.65, which indicates a markedly elevated soil contamination. The next highest level of contamination is Oštrelj (L3) with mean = 376.78 mg/kg, while the values for Brezonik (L1) are moderate (216.86 mg/kg). In Veliki Krivelje - Banjica (L2) and Zlot (L5) concentrations are significantly lower (75.00 and 61.45 mg/kg), while Gornjane (L6) is the safest location with an average value of only 20.28 mg/kg. The coefficient of variation (CV) shows that the data are stable in most locations (1–4%) of soil Cu abundance, while the overall CV for all locations is 93.47%, indicating extreme differences in soil Cu contamination. Based on these results, Slatina (L4) stands out as the location with the highest measured concentration for wheat cultivation, while Gornjane (L6) is the location with the lowest measured concentration.

Table 1. *Descriptive statistics of Cu in arable land and wheat grain*

Lokacija	Mean	StDEV	Min	Max	Std. Error of Mean	CV
L1 - soil	216.860	8.500	210.85	222.87	6.010	3.920
L1 - grain	9.493	2.113	8.00	10.99	1.494	22.256
L2 -soil	75.003	1.056	74.26	75.75	0.747	1.408
L2 - grain	6.505	0.493	6.16	6.85	0.348	7.571
L3 - soil	376.782	4.242	373.78	379.78	3.000	1.126
L3 - grain	9.088	0.004	9.09	9.09	0.003	0.041
L4 - soil	568.604	7.655	563.19	574.02	5.413	1.346
L4 - grain	6.746	0.916	6.1	7.39	0.647	13.572
L5 - soil	61.450	1.169	60.62	62.28	0.827	1.903
L5 - grain	4.044	0.017	4.03	4.06	0.012	0.411
L6 - soil	20.284	0.006	20.28	20.29	0.004	0.027
L6 - grain	3.718	0.098	3.65	3.79	0.069	2.630

The results in wheat grain, Table 1, show that Cu concentrations range from 3.71 mg/kg (Gornjane - L6) to 9.49 mg/kg (Brezonik - L1). The highest values were registered in Brezonik (L1) and Oštrelje (L3) (9.49 and 9.09 mg/kg), while they were moderate in Slatina (L4) (6.74 mg/kg) and Veliki Krivelje - Banjica (L2) (6.50 mg/kg). The lowest values are recorded in Zlot (L5) (4.04 mg/kg) and Gornjani (L6) (3.71 mg/kg). The coefficient of variation (CV) shows that the data are stable at most locations (0.04–22.25%), while the overall CV for all locations is 36.67%, indicating moderate variability between locations. These results confirm that elevated Cu concentrations in the soil are not proportionally transferred to the wheat grain, but that locations with higher values in the soil (L1, L3, L4) tend to record higher values in the grain.

Descriptive statistics for As in soil, Table 2, show significant differences in arsenic concentrations between the analyzed locations. The highest average value was registered in Slatina (L4), where mean = 63.05 mg/kg with a standard deviation of 0.81, which indicates a markedly elevated soil contamination. The next highest is Zlot (L5) with mean = 31.58 mg/kg, while in Oštrelje (L3) the average value is 27.88 mg/kg. In Brezonik (L1) and Veliki Krivelje - Banjica (L2) concentrations are moderate (14.76 and 9.92 mg/kg), while Gornjane (L6) is the safest location with an average value of only 8.71 mg/kg. The coefficient of variation (CV) shows that the data are stable across all locations (1.3–4.1%), which means that values within locations are uniform. Based on these results, Slatina (L4) stands out as the most critical territory for wheat cultivation, while Gornjane (L6) is the safest location in terms of soil arsenic contamination.

Table 2. *Descriptive statistics of As in arable land and wheat grain*

Location	Mean	StDEV	Min	Max	Std. Error of Mean	CV
L1 - soil	14.757	0.511	14.4	15.12	0.361	3.461
L1 - grain	0.089	0.067	0.04	0.14	0.048	76.215
L2 -soil	9.924	0.410	9.63	10.21	0.290	4.133
L2 - grain	0.042	0.005	0.04	0.05	0.003	11.695
L3 - soil	27.885	0.407	27.6	28.17	0.288	1.459
L3 - grain	0.131	0.005	0.13	0.13	0.004	4.159
L4 - soil	63.046	0.812	62.47	63.62	0.574	1.287
L4 - grain	0.181	0.011	0.17	0.19	0.008	6.018
L5 - soil	31.581	1.005	30.87	32.29	0.711	3.183
L5 - grain	0.030	0.005	0.03	0.03	0.003	16.118
L6 - soil	8.710	0.142	8.61	8.81	0.100	1.630
L6 - grain	0.028	0.000	0.03	0.03	0.000	0.000

The results for As in wheat grain, Table 2, show that As concentrations range from 0.028 mg/kg (Gornjane - L6) to 0.1808 mg/kg (Slatina - L4). The highest values were registered in Slatina (L4) and Oštrelje (L3) (0.18 and 0.13 mg/kg), while they were moderate in Brezonik (L1) (0.088 mg/kg) and Veliki Krivelje - Banjica (L2) (0.0419 mg/kg). The lowest values are recorded in Zlot (L5) (0.0304 mg/kg) and Gornjani (L6) (0.028 mg/kg). The coefficient of variation (CV) shows that the data are stable at most locations (4–16%), while at Brezonik (L1) CV = 76.21%, which indicates a large variability within the sample. These results confirm that locations with higher As values in soil (L3, L4, L5) tend to record higher values in wheat grain, while Gornjane (L6) is the safest location both in terms of soil and grain.

Table 3. *Spearman's rho correlation results*

			Soil_Cu	Soil_As	Grain_Cu	Grain_As
Spearman's rho	Soil_Cu	Correlation Coef.	1.000	.650*	.699*	.907**
		Sig. (2-tailed)	.	.022	.011	.000
	Soil_As	Correlation Coef.	.650*	1.000	.238	.487
		Sig. (2-tailed)	.022	.	.457	.108
	Grain_Cu	Correlation Coef.	.699*	.238	1.000	.690*
		Sig. (2-tailed)	.011	.457	.	.013
	Grain_As	Correlation Coef.	.907**	.487	.690*	1.000
		Sig. (2-tailed)	.000	.108	.013	.

*. Correlation is significant at the 0.05 level (2-tailed), **. Correlation is significant at the 0.01 level (2-tailed)

Instead of Pearson correlation, Spearman correlation was used, because it does not depend on normality and gives more robust results on small samples. The results of the Spearman correlation indicate significant and strong relationships between copper and arsenic concentrations in soil and wheat grain: soilCu shows a moderately strong correlation with soilAs ($\rho = 0.650$, $p < 0.05$) and with grainCu ($\rho = 0.699$, $p < 0.05$), while the correlation with grainAs is extremely strong and highly significant ($\rho = 0.907$, $p < 0.01$). These findings suggest that increased concentrations of Cu in the soil accompany the increase of As in the grain, indicating a potential connection in the process of metal accumulation in the plant. The correlations between As in the soil and metal in the grain are weaker and statistically insignificant, which emphasizes that it is Cu in the soil that is the key factor associated with the transfer of arsenic to the grain.

4. CONCLUSION

Descriptive statistics clearly show that Slatina (L4) is the most critical location in terms of Cu and As soil contamination, while Gornjane (L6) is the safest in terms of soil and wheat grains (Triticum aestivum L.). The results indicate significant differences between locations, which confirms that local conditions and sources of contamination have a decisive influence on metal concentrations in the agroecosystem. These findings are of particular importance for food safety risk assessment and agricultural production planning in the region.

Spearman's rho correlation results show that soil Cu is a key variable as it shows a strong association with both soil As and grain As. For more reliable conclusions, it would be useful to expand the number of sites or replicates, as N=6 limits the statistical power of the tests. The influence of Cu on As and vice versa cannot be reliably monitored because there are other metals in the system (eg Pb, Zn, Fe) that affect the mechanisms of accumulation and competition in the plant, and are not included in this analysis.

The obtained results can be the basis for further monitoring of the quality of arable land and agricultural products, as well as for the planning of sustainable agricultural land management measures in areas exposed to mining and metallurgical influences. However, for a reliable assessment of food safety, additional research is necessary that includes a larger number of samples, determination of chemical forms of As and assessment of population exposure.

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REFERENCES

[1] S.M. Šerbula, A.A. Ilic, J.V. Kalinovic, T.S. Kalinovic, N.B. Petrovic, (2014). Environmental earth sciences, 71(4), 1651-1661.
[2] S. Tošić, V. Mrvić, D. Jaramaz, E. Saljnikov, (2020). Glasnik Šumarskog fakulteta, 122, 107–124.

[3] G. Chen, J. Li, H. Han, R. Du, X. Wang, (2022). International journal of molecular sciences, 23(21), 12950.
[4] H. Cheng, Y. Hu, J. Luo, B. Xu, J. Zhao (2009). Journal of Hazardous Materials, 165(1–3), 13–26.
[5] F.J. Zhao, S.P. McGrath, A.A. Meharg, (2010). Annual review of plant biology, 61(1), 535-559.
[6] D. Simonović, D. Kržanović, R. Kovačević, M. Šteharnik, S. Stanković, D. Urošević, Vesna Krstić, (2026). Plants, 15, 631.