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Research Article

Heavy Metal Contamination of Irrigated Meadow and Meadow-Alluvial Soil Agroecosystems and Its Transfer to Crop and Livestock Products

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Abstract

This article presents the results of an assessment of heavy metal (Cu, Zn, Cd, Pb) contamination in irrigated meadow and meadow-alluvial soil agroecosystems and analyzes their transfer patterns to crop and livestock products. The study was carried out at reference monitoring points across three districts over the 2021–2023 period. The results demonstrated that mobile forms of heavy metals in all studied areas remained substantially below the maximum permissible concentration (MPC) thresholds, with the chemical pollution coefficient (Kp) mostly below 0.1. The highest copper (Cu) concentration was recorded in a district with intensive chemical reclamation and mineral fertilizer application, while zinc (Zn) and lead (Pb) levels were relatively elevated in districts closer to industrial facilities. Among vegetable crops, beet exhibited the highest accumulation coefficient (Kp = 0.33), whereas tomato showed the lowest (Kp = 0.21). Heavy metal levels in dairy products remained within permissible limits, although an upward trend in background lead and cadmium concentrations was identified in one district over recent years. The findings justify the need for continuous ecological monitoring along the soil–plant–animal–human chain.

Keywords: Heavy metals, soil agroecosystem, pollution coefficient, copper, zinc, cadmium, lead, sanitary-hygienic assessment

INTRODUCTION

Globally, more than half of agricultural land is subject to moderate or severe degradation, and heavy metal contamination of soil agroecosystems is recognized as one of the major ecological threats to food safety. The migration and accumulation of heavy metals along the soil–plant–animal–human biogeochemical chain directly affects human health,

making their systematic monitoring a matter of pressing scientific and practical importance.

Soil resource protection has become a policy priority in the Republic of Uzbekistan, formalized through the Law “On Soil Protection and Fertility Improvement,” which mandates strengthened soil monitoring. The aim of this study was to determine the degree of heavy metal contamination in irrigated soil agroecosystems and to reveal the patterns governing their transfer into crop and livestock products.

METHODS

Irrigated meadow and meadow-alluvial soil agroecosystems located in three districts served as the object of the study. Three reference monitoring points were established in each district, and soil samples were collected in accordance with the agrochemical cartogram method during 2021–2023. Copper (Cu), zinc (Zn), cadmium (Cd), and lead (Pb) contents were determined using atomic absorption spectrophotometry (AAS) and electrothermal atomic absorption spectrometry (ETAAS). The chemical pollution coefficient ($K_p = S/MPC$, where S is the measured concentration and MPC is the maximum permissible concentration) was calculated to assess soil contamination levels. Statistical processing of the obtained data was performed in Microsoft Excel following the methodology of B.A. Dospekhov, and the relationship between indicators was evaluated using the Pearson correlation coefficient (r).

RESULTS AND DISCUSSION

Monitoring conducted during 2021–2025 made it possible to establish the dynamics of mobile heavy metal forms in the studied soil agroecosystems (Table 1).

Reference point	Year	Cu, mg/kg	Zn, mg/kg	Cd, mg/kg	Pb, mg/kg
Site 1	2021	0.48	0.95	0.02	0.68
Site 1	2022	0.45	0.92	0.03	0.70
Site 1	2023	0.52	0.88	0.03	0.75
Site 2	2021	0.62	1.15	0.04	0.70
Site 2	2022	0.58	1.12	0.03	0.68
Site 2	2023	0.60	1.18	0.05	0.75
Site 3	2021	0.52	1.05	0.03	0.75
Site 3	2022	0.47	0.98	0.04	0.82
Site 3	2023	0.50	1.08	0.03	0.78

Table 1. Dynamics of mobile heavy metal forms in soil agroecosystems (2021–2025).

The data show that the highest copper (Cu) concentration occurred at Site 2, located in a district with intensive chemical reclamation and mineral fertilizer use. Zinc (Zn) and lead (Pb) concentrations were comparatively higher at Sites 2 and 3, which is attributable to industrial and transport-related influences. Nevertheless, all measured indicators remained several times below the applicable MPC thresholds.

Indicator MPC,

Indicator	MPC, mg/kg	Range detected, mg/kg	Mean $\pm$ SE, mg/kg	Ratio to MPC
Zn	23.0	0.65–1.2	0.90 $\pm$ 0.07	19–35× lower
Cd	0.5	0.03–0.07	0.045 $\pm$ 0.005	7–16× lower
Pb	6.0	0.35–1.2	0.95 $\pm$ 0.20	5–17× lower
Cu	3.0	0.4–1.5	1.00 $\pm$ 0.15	2–7× lower

Table 2. Pollution coefficient and safety assessment of soil agroecosystems.

Correlation analysis revealed a moderate positive relationship between Cu and Pb ($r = 0.47$), suggesting shared sources and similar mobility mechanisms in soil, whereas the correlation between Zn and Cd was comparatively weak ($r < 0.3$).

Among crop products, vegetable crops displayed differing capacities for heavy metal accumulation. The descending order of the pollution coefficient was as follows: beet (0.33) > bitter vegetables (0.26) $\approx$ potato (0.26) $\approx$ turnip-onion (0.26) > green onion and cucumber (0.25) > radish and carrot (0.23) > cabbage (0.22) > tomato (0.21). These

differences correspond to root-system architecture and species-specific physiological uptake mechanisms.

In livestock products, particularly dairy products, heavy metal levels remained within permissible limits overall. However, a gradual increase in background lead and cadmium concentrations was identified in one district over the past 4–5 years, indicating the need for enhanced preventive control.

CONCLUSION

The results indicate that mobile forms of heavy metals in irrigated soil agroecosystems currently remain below sanitary-hygienic norms, while inter-district differences in copper, zinc, and lead levels are linked to industrial and agrotechnical factors. Among vegetable crops, beet and leafy vegetables stand out as relatively strong accumulators, warranting targeted agrotechnical and sanitary control during cultivation. The observed upward trend in background lead and cadmium concentrations in dairy products justifies the introduction of continuous monitoring along the soil–plant–animal chain. The use of certified mineral fertilizers free of heavy metal impurities is recommended for future agricultural practice.

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