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# Heavy Metals Pollution Risk in Roșia Montană Area. Note II: Copper, Zinc and Arsenic Soil Occurrence

**TOPAN Mircea Vasile, Bianca MOLDOVAN, Antonia ODAGIU*, Petru BURDUHOS, Cristian IEDERAN, Cristian MĂLINAȘ, Ioan BRAȘOVEAN**

*University of Agricultural Sciences and Veterinary Medicine Cluj-Napoca, Faculty of Agriculture, Calea Mănăștur 3-5, 400372 Cluj-Napoca, Romania*

* Corresponding author e-mail: antonia.odagiu@usamvcluj.ro

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**Abstract**

At the core of all green closure and reclamation efforts lies a framework of principles and practices designed to reduce environmental and community harm while maximizing economic and social benefits in the post-mining phase. The aim of the study is to develop risk matrices copper, zinc and arsenic contamination risk in Roșia Montană area Roșia Montană. Soil analysis in the Roșia Montană area identified significant heavy metal contamination, particularly near former mining operations, where concentrations of lead, copper, zinc, arsenic, and cadmium exceeded permissible limits, posing substantial environmental and health risks. Although copper, zinc, and arsenic levels in distant areas remained within acceptable limits, the overall averages across all sampling sites exceeded regulatory thresholds, underscoring the cumulative effects of both historical and ongoing mining activities. Industrial and mining waste emerged as the most critical risk factor for all three metals, necessitating prioritized intervention. Additionally, risks stemming from agricultural and industrial practices demand targeted strategies to reduce their long-term impact on soil health and community well-being.

**Keywords:** environmental restoration, management, monitoring, X-Ray spectroscopy.

## 1. Introduction

Underlying all green closure and reclamation initiatives is a set of principles and practices aimed at minimizing negative impacts on the environment and local communities, as well as optimizing post-mining economic and social benefits [1, 7].

The importance of these principles and practices is highlighted in a variety of studies and documents that address the complex challenges of sustainable post-mining mine land management. The central principle of any green closure and reclamation process is the obligation to restore environmental quality while protecting the health and well-being of local communities [3].

Mining regions are often plagued by a variety of toxic pollutants that compromise soil quality. In particular, heavy metals such as lead (Pb), cadmium (Cd), arsenic (As), zinc (Zn) and copper (Cu) have been identified as among the main chemical substances contributing to soil pollution [7, 9]. These metals are often introduced into the environment through mining and metallurgical activities, either as by-products of the ore extraction process or as residues from metallurgical processing.

Arsenic (As) is a known carcinogen, which can lead to a variety of health problems, including skin and cardiovascular system disorders. Zinc (Zn) and copper (Cu) are essential for biological processes, but in excess can become toxic [4, 6].

The mechanisms of pollution of chemicals and heavy metals are a major concern in managing the impact of human activities on the environment.

These hazardous elements can reach the soil through several routes, with serious consequences for ecosystems [2].Leaching is a process by which chemicals are transported through the soil together with the infiltrating water. This mechanism becomes particularly relevant in the context of mining operations, where acidified rain can have harmful interactions with mineral waste or unusable (barren) rocks. Rain, having a low pH due to increased acidity from atmospheric pollution, can accelerate the chemical decomposition of mined ores or rocks, releasing heavy metals or other toxic substances into the soil.

Without appropriate interventions, this process not only degrades soil quality, but also favors the migration of contaminants into groundwater or surface waters, thus expanding the scope of ecological impact [1]. Tailings dumps represent another major source of soil pollution, consisting of piles of rocks and other residual materials from mineral extraction. These materials are usually stored in surface deposits and are exposed to natural elements, such as wind and precipitation. Through the action of the wind, fine particles can be lifted and disseminated to neighboring areas, and rainwater can induce the erosion of these deposits, facilitating the dispersion of toxic substances in the surrounding area. These substances can modify the chemical composition of adjacent soils and, by extension, affect vegetation, fauna and even the quality of aquatic resources, leading to a progressive destabilization of local ecosystems [1, 5].

Soil erosion, accelerated by the improper management of tailings dumps, not only facilitates the spread of pollutants, but also reduces the capacity of the ecosystem to naturally regenerate. Excessive erosion can lead to the loss of topsoil, indispensable for plant growth, and can increase the risk of flooding by obstructing watercourses with contaminated sediments [2, 8]. The possible environmental problems caused by copper, zinc and arsenic from the water stream originating from the mines in Roșia Montană are presented in Table 1.

Table 1 Chemicals in the water of the stream originating from the mines in Roșia Montană

| Material/Element | Description | Environmental impact/Actions |
|---|---|---|
| Copper (Pb) | In sediment analyses, copper concentrations exceeded the maximum permissible limit, thus highlighting significant pollution from mining operations. | Although essential for organisms in small doses, high levels of copper can be toxic to aquatic life and disrupt the balance of aquatic ecosystems. |
| Zinc (Cd) | While zinc is considered an undesirable substance, zinc pollution has been documented in the study area. | Zinc concentrations can negatively affect aquatic organisms and contribute to deterioration of water quality. |
| Arsenic (As) | Frequently found in acidic mine waters from Roșia Montană.<br>In contact with other chemicals, heavy metals, it gives the water a reddish color. | It contributes to excessive acidification of waters, affecting the viability of aquatic organisms and the corrosivity of metals, including lead and cadmium. |

The aim of the study is to develop risk matrices copper, zinc and arsenic contamination risk in Roșia Montană area Roșia Montană.

## 2. Material and Method

The soil sampling was made in Roșia Montană area at three distinct points: near the former mining operation (Area I), within a 500 m radius (Area II), and at 1 km (Area III). Sampling took place between March 1 and March 31, 2024 [12]. The concentrations of copper, zinc, and arsenic in the soil were determined using an XRF spectrometer, which functions based on X-Ray spectroscopy principle.

To ensure accuracy, each sample was analyzed in triplicate, and the results were averaged to provide representative values for each site. These averages were then compared with the permissible limit values [12].

Risk matrices were developed for lead and cadmium, and appropriate remedial measures were proposed.

Two types of risk matrices were utilized: a 5 x 5 matrix, which evaluates probability levels (ranging from very low to very high) against impact levels (ranging from insignificant to catastrophic) [10, 13], and a second matrix that integrates probability, impact, and risk level values [10, 12, 13].

The overall risk level was calculated based on both the likelihood of pollution occurrence and the severity of its impact.

## 3. Results and Discussions

The results of the soil sample analyses identified indicate significant heavy metal contamination, especially in areas near the former mining operations. Concentrations of lead, copper, zinc, arsenic and cadmium exceeded the permissible limits in soil samples collected from Experimental Area I (ZI) located in the vicinity of the former mining operation (Table 4.1).

Deşi pentru cupru, zinc şi arsen nu se înregistrează depăşiri ale concentraţiilor maxime admise în zonele de prelevare Z II şi Z III, pe ansamblul acestora, s-au înregistrat depăşiri ale limitelor admise pentru toate metalele grele identificate (Tabelul 4.2).

Table 4.1. Average heavy metals identified in soil samples collected from the Roșia Montană area, depending on the sampling area

| Element | Concentration in soil (mg/kg) | | | Accepted limit (mg/kg) [11] |
|---|---|---|---|---|
| | Z I | Z II | Z III | |
| Copper (Pb) | 100 | 55 | 40 | 60 |
| Zinc (Cd) | 300 | 140 | 120 | 150 |
| Arsenic (As) | 20 | 9 | 6 | 10 |

Table 2. The averages of heavy metals identified in soil samples collected from the Roșia Montană area, across the entire experimental site

| Element | Concentration in soil (mg/kg) | Accepted limit (mg/kg) [11] |
|---|---|---|
| Copper (Pb) | 65.00 | 60 |
| Zinc (Cd) | 186.67 | 150 |
| Arsenic (As) | 11.67 | 10 |

Regarding the risk matrices for the 3 heavy metals identified as having polluting potential, they are compiled by following the steps necessary for their preparation, namely, risk identification, risk probability and severity assessment, to which is added risk classification, or risk level.

For copper, the identified risks are: industrial and mining waste, use of copper-containing pesticides and fungicides, emissions from copper smelting and refining processes, leaks from industrial facilities and uncontrolled waste. The risk matrices prepared for the risk of soil contamination with copper in the Roșia Montană mining area are presented in Table 3 and Table 4. For industrial and mining waste the probability of occurrence is equal to 4, i.e. high, due to continuous industrial and mining activities, and the impact is equal to 4, being classified as "major", due to the significant impact on health and the environment due to the significant impact on health and the environment. Thus, the resulting risk level is equal to 16, which corresponds to the "high" risk category.

Table 3. Risk matrix for copper pollution in the Roșia Montană mining area

| Probability \Impact | 1 | 2 | 3 | 4 | 5 |
|---|---|---|---|---|---|
| 4 | | | | | |
| 4 | | | | Industrial and mining waste | |
| 3 | | | Pesticides and fungicides | Industrial emissions | |
| 2 | | | | Industrial leaks | |
| 1 | | | | | |

Table 4. Probability, Impact and Risk Level Values for the Risk Matrix associated with copper pollution in the Roșia Montană mining area

| Risk | Probabiliy | Impact | Level |
|---|---|---|---|
| Industrial and mining waste | 4 | 4 | 20 |
| Use of copper-containing pesticides and fungicides | 3 | 3 | 9 |
| Emissions from copper smelting and refining processes | 3 | 4 | 12 |
| Leaks from industrial facilities and uncontrolled waste | 2 | 4 | 8 |

For the use of pesticides and fungicides containing copper, the probability of occurrence is equal to 3, i.e. moderate, because the use is frequent in agriculture, and the impact is equal to 3, being classified as “moderate”, due to the slow accumulation in the soil.

Thus, the resulting risk level is equal to 9, which corresponds to the “low” risk level. For emissions from copper smelting and refining processes the probability of occurrence is equal to 3, i.e. moderate, due to strict regulations, and the impact is equal to 4, being classified as “major”, due to the potential for large-scale contamination. Thus, the resulting risk level is equal to 12, which corresponds to the “moderate” risk category. For leaks from industrial facilities and uncontrolled waste, the probability of occurrence is equal to 2, i.e. low, if properly managed, and the impact is equal to 4, being classified as “major”, due to the risk of infiltration into soil and water. Thus, the resulting risk level is equal to 8, which corresponds to the “low” risk category (Table 4).

To reduce the risks of copper pollution, depending on the identified risk, we propose the following measures:

- industrial and mining waste – remediation of contaminated soil and stabilization of waste, continuous monitoring of soil and groundwater quality and implementation of advanced decontamination technologies;
- tailings and old construction materials – promotion of the use of less toxic alternatives, education of farmers on risks and good agricultural practices;
- effluents and leaks from processing facilities – installation of capture and abatement technologies, regular monitoring of copper levels in soil and air around facilities;
- contamination from natural sources – improving the management and safety of industrial facilities, regular monitoring of leaks and rapid interventions to prevent contamination.

For zinc, the risks identified are: industrial and mineral waste, use of fertilizers and agricultural fines containing zinc, emissions from galvanizing and zinc refining processes, leaks from industrial facilities and uncontrolled waste.

The risk matrices prepared for the risk of soil contamination with zinc in the Roșia Montană mining area are shown in Table 6 and Table 6. For industrial and mineral waste the probability of occurrence is equal to 4, i.e. high, due to continuous industrial and mining activities, and the impact is equal to 4, being classified as “high”, because zinc is not as toxic as other heavy metals, but can affect the soil and ecosystems. Thus, the resulting risk level is equal to 16, which corresponds to the “high” risk level (Table 6).

Table 5. Risk matrix for zinc pollution in the Roșia Montană mining area

| Probability \Impact | 1 | 2 | 3 | 4 | 5 |
|---|---|---|---|---|---|
| 4 | | | | | |
| 4 | | | | Industrial and mineral waste | |
| 3 | | | Fertilizers and aamendments | Industrial emissions | |
| 2 | | | | Industrial leaks | |
| 1 | | | | | |

Table 6. Probability, Impact and Risk Level Values for the Risk Matrix associated with zinc pollution in the Roșia Montană mining area

| Risk | Probabiliy | Impact | Level |
|---|---|---|---|
| Industrial and mineral waste | 5 | 4 | 20 |
| Use of fertilizers and agricultural amendments containing zinc | 4 | 3 | 12 |
| Emissions from galvanizing and zinc refining processes | 3 | 4 | 12 |
| Leaks from industrial facilities and uncontrolled waste | 2 | 2 | 4 |

For the use of fertilizers and agricultural fines containing zinc, the probability of occurrence is equal to 3, i.e. moderate, because the use is frequent in agriculture, and the impact is also equal to 3, being classified in the "moderate" category, due to the slow accumulation in the soil. Thus, the resulting risk level is equal to 9, which corresponds to the "moderate" risk category.

For leaks from industrial facilities and uncontrolled waste, the probability of occurrence is equal to 2, i.e. low, if properly managed, and the impact is equal to 4, being classified in the "major" category, due to the risk of infiltration into soil and water. Thus, the resulting risk level is equal to 12, which corresponds to the "moderate" risk category (Table 6). To reduce the risks of zinc pollution, depending on the identified risk, we propose the following measures:

- industrial and mineral wastes – remediation of contaminated soil and stabilization of wastes, continuous monitoring of soil and groundwater quality and implementation of advanced decontamination technologies;
- use of fertilizers and agricultural fines containing zinc – promotion of the use of less toxic alternatives, education of farmers on risks and good agricultural practices;
- emissions from galvanizing and zinc refining processes – installation of technologies for capturing and reducing emissions, periodic monitoring of zinc levels in the soil and air around the facilities;
- leaks from industrial facilities and uncontrolled waste – improvement of the management and safety of industrial facilities, periodic monitoring of leaks and rapid interventions to prevent contamination.

For arsenic, the identified risks are: mining waste and ore processing residues, leaks and effluents from processing facilities, tailings and old construction materials and natural contamination from geological sources. The risk matrices prepared for the risk of arsenic contamination of soil in the Roșia Montană mining area are shown in Table 7 and Table 8.

For mining waste and ore processing residues, the probability of occurrence is equal to 5, i.e. very high, due to historical mining activities, and the impact is equal to 4, being classified as "major", due to the significant impact on health and the environment due to the significant impact on health and the environment.

Thus, the resulting risk level is equal to 20, which corresponds to the "high" risk level.

For leaks and effluents from processing facilities the probability of occurrence is equal to 4, i.e. high, due to the potential for uncontrolled leakage, and the impact is equal to 4, being classified as "high", due to water and soil pollution.

Table 7. Risk matrix for arsenic pollution in the Roșia Montană mining area

| Probability \Impact | 1 | 2 | 3 | 4 | 5 |
|---|---|---|---|---|---|
| 5 | | | | Mining waste and residues | |
| 4 | | | | Leaks and effluents | |
| 3 | | | Tailings dumps | | |
| 2 | | Natural contamination | | | |
| 1 | | | | | |

Table 8. Probability, Impact and Risk Level Values for the Risk Matrix associated with arsenic pollution in the Roșia Montană mining area

| Risk | Probabiliy | Impact | Level |
|---|---|---|---|
| Mining waste and mineral processing residues | 5 | 4 | 20 |
| Leaks and effluents from processing facilities | 4 | 4 | 16 |
| Tailings dumps and old construction materials | 3 | 3 | 9 |
| Natural contamination from geological sources | 2 | 2 | 4 |

Thus, the resulting risk level is equal to 16, which corresponds to the "high" risk level. For tailings and old construction materials the probability of occurrence is equal to 3, i.e. moderate, due to the constant presence, and the impact is equal to 3, being classified as "moderate", because the impact can be controlled by appropriate measures.

Thus, the resulting risk level is equal to 9, which corresponds to the "low" risk category (Table 8).

For contamination from geological sources, the probability of occurrence is equal to 2, i.e. low, because it is less frequent, and the impact is equal to 2, being classified as "minor", because the natural impact is lower compared to anthropogenic sources.

Thus, the resulting risk level is equal to 4, which corresponds to the "low" risk category (Table 8).

To reduce the risks of arsenic pollution, depending on the identified risk, we propose the following measures:

- mining waste and ore processing residues – measures to remediate and stabilize contaminated soil, continuous monitoring of soil and groundwater quality, removal and appropriate management of toxic waste;
- leaks and effluents from processing facilities – installation of barriers and leakage capture systems, improvement of infrastructure to prevent uncontrolled leakage, regular monitoring of surface and groundwater quality;
- tailings dumps and old construction materials – encapsulation or removal of tailings and contaminated materials, periodic assessment of the stability of the dumps and implementation of soil stabilization technologies;
- natural contamination from geological sources – regular monitoring to detect and manage potential increases in arsenic levels and community education on the risks associated with arsenic exposure.

## 4. Conclusions

Soil analysis in the Roșia Montană area revealed significant contamination with heavy metals, particularly in the vicinity of former mining operations (Area I). Concentrations of lead, copper, zinc, arsenic, and cadmium in this area exceeded permissible limits, posing a serious environmental and health risk. While Areas II and III did not show exceedances for copper, zinc, or arsenic, the overall averages across all experimental sites still exceeded acceptable limits for these metals. This highlights the cumulative impact of historical and ongoing mining activities.For copper, the highest risk is associated with industrial and mining waste, followed by emissions from smelting and refining, and agricultural use of copper-containing pesticides. Industrial leaks present a lower but still notable risk. Concerning zinc, the primary risks are linked to industrial and mineral waste, followed by emissions from galvanizing processes and agricultural amendments. Uncontrolled leaks pose a moderate risk but require attention. Arsenic mining waste and ore processing residues present the greatest risk, with leaks from processing facilities being the next significant source. Natural contamination poses a minor risk compared to anthropogenic sources.Copper and zinc remediation strategies include soil stabilization, advanced decontamination technologies, monitoring of soil and groundwater, use of less toxic alternatives in agriculture, and improved management of industrial emissions and waste. Arsenic remediation measures include stabilizing contaminated soil, improving infrastructure to prevent leaks, encapsulating or removing contaminated materials, and regular monitoring of both anthropogenic and natural contamination sources. For all three metals, industrial and mining waste consistently ranks as the highest risk, indicating the need for prioritized intervention in these areas. Risks from agricultural and industrial activities also require tailored strategies to mitigate their long-term impacts on soil health and community safety.

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