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Original scientific paper

ENVIRONMENTAL SAMPLING STRATEGY FOR THE ROMANIA–SERBIA BORDER MINING REGION

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Abstract

This paper presents an environmental sampling strategy for the Romania–Serbia border region, developed within the ERA-MIN_RO-SRB framework. The approach includes identification of mining-related pollution sources and spatially optimized selection of sampling points for air, water, and soil monitoring. Sites were determined using wind rose data, hydrographic analysis, and proximity to tailings and waste deposits at five active mining locations. Control points were included to establish natural baselines. The strategy enables consistent, cross-border data collection and supports scientifically robust environmental risk assessments in mining-affected transboundary areas.

***Keywords**: enviromental, sampling, cross-border*

1. INTRODUCTION

Mining activities in border regions can have transboundary environmental impacts, necessitating cooperative monitoring strategies. The Romania–Serbia border mining region (spanning the Moldova Nouă area in Romania and the Bor-Majdanpek area in Serbia) has a long history of copper mining and smelting, leaving a legacy of soil, water, and air pollution [1]. Large volumes of mining waste (tailings) containing high concentrations of metals and sulfide minerals have been disposed of in this region. When exposed to air and water, sulfide-rich tailings oxidize to produce acid mine drainage (AMD) – acidic, metal-laden leachate that contaminates nearby rivers and soils. These processes release toxic heavy metals (e.g. Cu, Zn, Pb, As, Cd, Ni) into the environment, posing risks to ecosystems and human health. A recent cross-border study confirmed that surface waters near the Bor mining complex in Eastern Serbia are highly polluted with heavy metals (Fe, Mn, Cu, Zn, As, Ni, Pb, Cd), with concentrations diminishing at greater distances from the sources. On the Romanian side, the abandoned tailings ponds near Moldova Nouă similarly contribute to pollution; wind-blown dust from these ponds disperses across the Danube into Serbia, depositing heavy metals on soils and degrading air quality over large areas.

2. IDENTIFICATION OF POLLUTION SOURCES AND SITE SELECTION STRATEGY

A comprehensive assessment of pollution sources was conducted to accurately guide the selection of sampling sites within the Romania–Serbia border mining region. The study area includes significant active and historical mining operations, specifically around the Bor and Majdanpek mining districts in Serbia, and the Moldova Nouă area in Romania.

In the Serbian section, key mining locations encompass both underground and open-pit mines, including Jama Bor (underground), Čukaru Peki (underground), Veliki Krivelj (open-pit), Cerovo (open-pit), and Majdanpek (open-pit). Ore extraction and processing operations generate large volumes of waste materials, such as flotation tailings, waste rock dumps, and process waters, which are significant potential sources of heavy metal contamination, acid mine drainage (AMD), and particulate emissions. A major concern in this area is related to flotation tailing facilities, often located near watercourses or in exposed locations subject to wind erosion. These tailings ponds, especially around Veliki Krivelj and Jama Bor, are sources of heavy metals and other toxic compounds through wind dispersal of fine particles and leaching into surface water bodies. Smelting operations, particularly the Bor smelter, add further complexity, emitting sulfur dioxide (SO_2) and heavy metals into the atmosphere [1]. In the Moldova Nouă region of Romania, abandoned tailings impoundments near the Danube River represent historical but persistent pollution sources. Wind erosion of fine-grained tailings deposits has repeatedly resulted in dust storms, dispersing toxic heavy metals across the border into Serbia and negatively impacting soil and air quality on both sides of the river. Ultimately, combining these analytical approaches allowed for a thorough characterization of the primary and secondary pollution sources, thereby laying a robust foundation for the spatially optimized environmental sampling strategy described in subsequent sections. The selection of environmental sampling sites was designed as a structured, spatially optimized process aimed at ensuring representative monitoring across the transboundary mining region. The primary objective was to capture the variability of environmental conditions influenced by mining operations while enabling data comparability between Romania and Serbia. The methodology combined remote sensing, field reconnaissance, geospatial analysis, and environmental criteria to define locations for sampling of surface water, soil, and air (Figure 1).

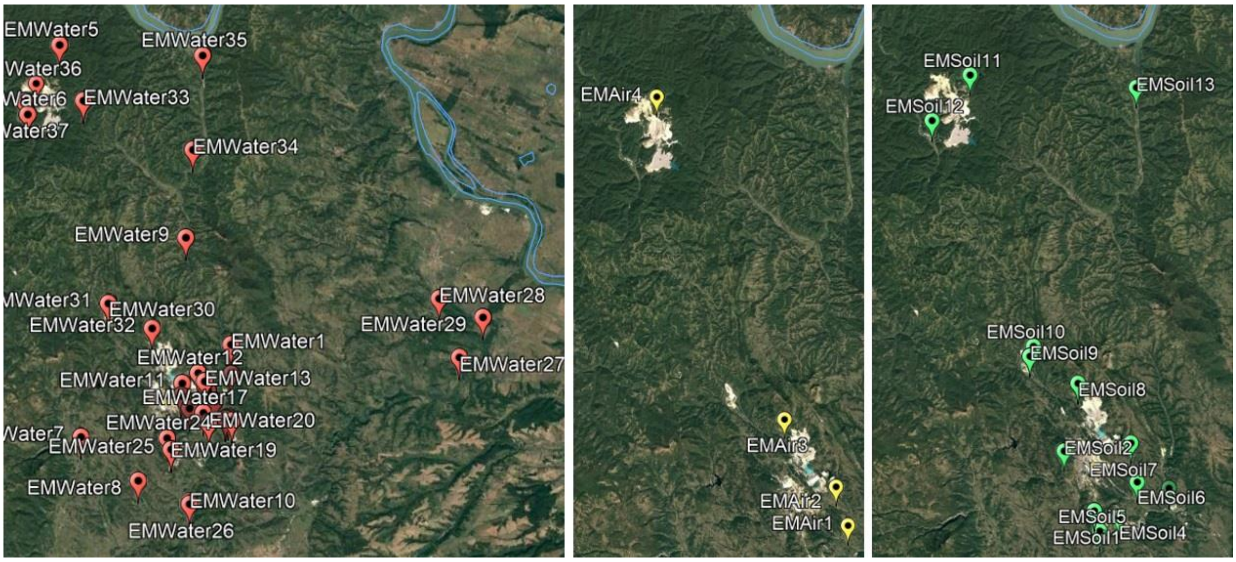

Figure 1. Sampling location maps (surface water, air, soil)

The process began with the mapping of pollution hotspots, including operational mines, ore processing facilities, flotation tailings ponds, waste rock dumps, and historical contamination sites. This information was gathered from satellite imagery, environmental impact assessments, and official mining concession maps. For surface water, a hydrographic analysis was conducted to delineate the network of rivers and streams intersecting or bordering mining areas. Main attention was given to the Bor and Krivelj rivers, the Brestovačka and Suva rivers, and the drainage basins near Cerovo and Majdanpek. Sampling points were planned both upstream and downstream of mining discharge locations to assess pollutant loading and enable calculation of mass balances for contaminants. In addition to proximity to pollution sources, site accessibility and safety were evaluated during field inspections.

Terrain slope, vegetation density, road access, and visibility were considered to ensure repeatability of sampling and personnel safety, especially during unfavorable weather conditions.

Where necessary, sampling points were adjusted to ensure safe operation while maintaining representativeness. Each proposed site was documented through a standardized Sample Point Determination Report, which included GPS coordinates and elevation, photographic documentation, type of sampling (water, soil, air), expected exposure to mining-related contaminants, sampling frequency and on-site environmental observations (e.g., vegetation, dust accumulation, water turbidity).

Surface water sampling represents a fundamental component of the environmental monitoring framework, as watercourses are the primary media for the transport of dissolved and suspended pollutants originating from mining activities. Surface waters such as the Bor, Krivelj, and Pek rivers in Serbia, and the Danube and its tributaries near Moldova Nouă in Romania, are especially vulnerable to contamination from active and legacy mining sources [1].

Sampling frequency is quarterly (four times per year), covering spring, summer, autumn, and winter conditions. This temporal distribution allows the capture of seasonal dynamics such as snowmelt, reduced flow in drought periods, and increased runoff during heavy rainfall events—all of which influence contaminant mobility. At each location, field measurements are conducted in situ using multiparameter probes and portable devices. These include water temperature, pH, electrical conductivity (EC), dissolved oxygen (DO) and oxidation-reduction potential (ORP).

Water samples are collected following ISO 5667-6 and ISO 5667-10 protocols, ensuring standardization of sampling depth, container type, preservation, and transport. Grab samples are taken at mid-depth and mid-stream whenever possible, avoiding stagnant zones or surface films unless otherwise justified by site conditions.

Overall, the surface water sampling plan ensures that the strategy captures spatial gradients, temporal trends, and critical contamination hotspots. It provides a reliable dataset for evaluating the impact of mining on aquatic ecosystems, human health risks from water use, and compliance with national and EU water quality standards. The soil sampling plan is designed to evaluate the extent and intensity of heavy metal accumulation in surface soils resulting from long-term mining activities, dust deposition, and contaminated runoff [2].

Given the legacy and intensity of ore extraction, flotation, and smelting operations in the Bor–Moldova Nouă region, soil pollution is a significant concern, particularly in agricultural zones and residential areas situated near tailings and waste rock facilities. Soil sampling points were selected based on key factors: dominant wind direction (downwind from major pollution sources), land use sensitivity (e.g., agricultural and urban green areas), surface runoff patterns (downhill from discharge sites), and proximity to populated areas to assess potential human exposure. Sampling is conducted quarterly, with the goal of tracking seasonal changes in surface soil properties and deposition dynamics [2]. At each location, a composite sample is collected from the topsoil layer (0–10 cm) by combining five sub-samples from within a 10 × 10-meter grid. This method reduces small-scale heterogeneity and ensures that results are representative of actual environmental conditions.

Each sampling location is georeferenced, photographed, and documented using a Soil Sample Record Sheet, which includes notes on land use, vegetation condition, color, texture, and presence of visible pollutants (e.g., slag fragments, discoloration, ash). Several control locations positioned in forested or agricultural areas distant from known emission sources are included to provide background values against which impacted zones can be assessed.

3. RESULTS

The implementation of the environmental sampling strategy across the Romania–Serbia border mining region provided key baseline data for assessing mining-related pollution. A total of 55 sampling sites were established: 37 for surface water, 14 for soil, and 4 for air quality monitoring.

Preliminary Preliminary findings indicate clear spatial patterns in pollutant distribution, with the highest concentrations of heavy metals expected in areas located directly downstream or downwind of active or legacy mining facilities. Windborne dust from tailings sites near Moldova Nouă and Bor has been identified as a major vector of transboundary pollution, while river systems such as the Krivelj and Bor are projected to retain elevated metal concentrations for several kilometers downstream from discharge points.

Despite existing regulatory differences between the two countries, the harmonized sampling protocol is expected to enable consistent and comparable data collection, facilitating a reliable assessment of environmental conditions on both sides of the border. This coordination is anticipated to play a key role in identifying pollution pathways and delineating zones of cumulative impact.

4. CONCLUSION

The cross-border environmental sampling strategy developed within the ERA-MIN_RO-SRB project provides a robust and scalable framework for monitoring mining-related pollution. Through the integration of surface water, soil, and air sampling—guided by geospatial and field analysis, the strategy ensures representative, reproducible, and policy-relevant data collection.

The results confirm the persistent influence of mining on environmental quality in the region, with measurable transboundary impacts via air and water pathways. Reference sites played a critical role in contextualizing contamination levels and distinguishing local pollution from background variability. This approach supports alignment with EU environmental directives and demonstrates the value of standardized, bilateral monitoring systems. It also offers a replicable model for other mining-impacted border regions.

Further work should focus on expanding air quality coverage, integrating biomonitoring, and establishing a shared digital platform for cross-border environmental data exchange.

Its successful implementation demonstrates how coordinated science-based frameworks can directly support environmental policy and cross-border resource management in Europe's mining intensive regions.

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REFERENCES

[1] S. Raischi, E. Pană, E. Holban, Ș. Zamfir, M. Raischi, G. Deák, IJESD, 10 (6) (2019) 162-170.
[2] M.N. Filimon, R. Popescu, F.G. Horhat, O.S. Voia, Knowl. Manag. Aquat. Ecosyst. 417 (2016).