Journal of the Georgian Geophysical Society, e-ISSN: 2667-9973, p-ISSN: 1512-1127
Physics of Solid Earth, Atmosphere, Ocean and Space Plasma, v. 28(2), 2025, pp. 76-85

Comparative Radioecological Assessment of Soil Contamination in Mining Areas of Chiatura, Kazreti, and Zestaponi, Georgia

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ABSTRACT

Abandoned mining areas, especially those areas where heavy metals and radioactive elements were previously mined, represent one of the most important ecological problems. Chiatura, as the main center of manganese mining in Georgia, turned out to be a region where heavy metals and radioactive substances caused significant contamination of soil and water resources. The aim of the study is to analyze, assess and study the radioecological risks of soil contamination from abandoned mines in Chiatura. The study discusses the concentration of heavy metals in the soil, including manganese, lead, cadmium and others, as well as the impact of their potential radioactive contaminants on ecosystems. Modern ecological monitoring methods were used, including measuring the content of radioactive elements, analyzing soil samples and testing water. The results showed that the concentration of heavy metals in the territory of the abandoned mines of Chiatura exceeds safety standards, which directly affects both the ecological state of the soil and the flora and fauna. The article emphasizes the need to study radioecological risks and effectively respond to them. The study also includes an analysis of the subsidence of the soils of Kazreti, Zestaponi and Chiatura. These results indicate an increased risk of radioactive and non-radioactive substances, which requires the implementation of appropriate ecological remediation measures.

***Key words**: radioactive elements, radionuclides, soil, radioecological, Georgia*

Introduction

The mining industry plays a critical role in soil contamination with lead, zinc, manganese, iron, and copper ions. Mining activities, product processing, waste management, and atmospheric deposition are major sources of contamination. These pollutants have a wide range of impacts on soil, water, plants, wildlife, and human health [1-5].

Chiatura — one of the most important industrial centers of Georgia — has been a major site for the extraction and processing of manganese for decades. As a result of intensive mining and quarrying activities, numerous open-pit and underground mines have been created in the region, many of which are currently abandoned and in a neglected state. Abandoning mines without proper ecological rehabilitation creates environmental and, in particular, radioecological hazards.Although manganese itself is not a radioactive element, its deposits often contain natural radionuclides such as uranium, thorium, and potassium-40 [6-8]. The spread of these compounds in the environment can have a significant impact on soil, water resources, and living organisms.Special attention needs to be paid to studying the content of radionuclides in soil, as it is both an indicator of environmental pollution and a source of risk transmission for humans and ecosystems.The aim of this study is to assess the radioecological state of the soil in the areas near the abandoned mines of Chiatura and analyze the potential risks associated with it. [9-12].

Our study includes a comparative analysis of pollution in the mining and industrial areas of three large regions: Chiatura, Kazreti, and Zestaponi. Kazreti, Chiatura and Zestaponi are three important technogenically loaded regions of Georgia, which are polluted by various types of industrial activities. Kazreti is characterized by intensive open-pit mining of copper-polymetallic ores; Chiatura - by long-term underground mining of manganese; and Zestaponi - by metallurgical production of ferro-alloys (ferromanganese). These differences significantly determine the nature and intensity of soil pollution.

Fig. 1. Long-term underground mining of manganese

Fig. 2. Long-term underground mining of manganese

Kazreti and Zestaponi represent two important industrial-technogenic zones of Georgia, however, the nature, intensity, and chemical profile of soil contamination are different, which is determined by the type of production and technological processes. Differences in pollution sources. [14,15].

Fig. 3.

Fig. 4.

Kazret: open-pit mining (copper-polymetallic ores)

Kazret:
• Main sources: open-pit mining (copper-polymetallic ores);
• Tailings;
• Ore enrichment processes.

Zestafoni
• Main source: Metallurgical production of ferroalloys (ferromanganese);
• Atmospheric emissions;
• Technogenic dust deposition. Kazreti

Elevated concentrations of Cu, Zn, Pb, Cd and As are recorded in the soils of the Kazreti mining district, especially in the vicinity of quarries, waste heaps and ore enrichment facilities. The dominant contaminant is copper, the content of which often significantly exceeds background values. The presence of cadmium and arsenic indicates a high level of technogenic impact and increases the ecological risk [16,17].

Fig. 5. Metallurgical production of ferroalloys (ferromanganese) in Zestafoni

Chiatura

The contamination of Chiatura soils is mainly associated with high concentrations of manganese (Mn), which is due to the long-term extraction of manganese ores. Additionally, increased contents of lead (Pb), zinc (Zn) and iron (Fe) are noted [16,17]. The contamination is spatially heterogeneous and is especially high in the areas adjacent to mines, waste heaps and transport routes.

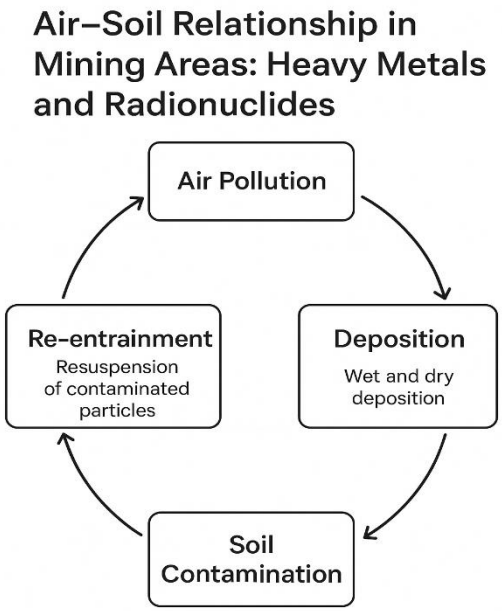

Fig. 6. Air-Soil Relationship in Mining Areas:Heavy Metals and Radionuclides

Zestafoni

The dominant element in Zestafoni soils is manganese (Mn), accompanied by Pb, Zn, Cr, and Ni. Unlike Kazreti and Chiatura, pollution here is mainly caused by the deposition of atmospheric dust generated by metallurgical production, due to which heavy metals are relatively evenly distributed over a wide area. Soil Chemical and Physical Changes

Kazret soils are often characterized by increased acidity, decreased organic matter content, and structural degradation, which is associated with acid mining drainage.

In Chiatura soils, structural damage is relatively moderate, although the accumulation of heavy metals occurs mainly in the upper horizons.

In Zestafoni soils, a tendency to alkalization is observed in some areas, which is due to industrial emissions, while the physical structure is relatively better preserved.

Overall, Kazreti is characterized by the highest level of pollution in terms of heavy metal concentration and toxicity (especially Cu and Cd). Chiatura is a region mainly polluted by manganese, with additional impacts of Pb and Zn. Zestafoni is under relatively less concentrated, but constant and widespread technogenic impact.

Research methodology

The study aims to assess the radioecological state of the soil in the area surrounding the abandoned mines in Chiatura. For this purpose, a scientific procedure was carried out in several stages:

1. Fieldwork and sampling

• Soil samples were taken in the immediate vicinity of the abandoned mines and, for comparison, in control areas located away from them.
• Samples were taken from different depths: surface layer (0–10 cm), middle layer (10–30 cm) and deep layer (30–50 cm).
• At least three parallel samples were taken at each site to ensure representativeness.
Laboratory Analysis
• Soil samples were dried, ground, and calcined according to standard procedures.
• Gamma-spectrometry with a high-precision detector was used to determine the concentration of radioactive elements (including ^238U, ^232Th, ^40K).
• In parallel, soil pH, moisture, organic matter content, and granular composition were determined — to enable an in-depth analysis of the conditions for the spread of contamination.
• The obtained radioactive data were compared with international norms (e.g., UNSCEAR or IAEA limits).

Results and discussion

Analysis of the data obtained as a result of the study showed that in the areas surrounding the abandoned mines of Chiatura, an increased concentration of natural radionuclides was found in the soil, especially in the form of ^238U (uranium), ^232Th (thorium) and ^40K (potassium-40). Their average activity levels in some samples significantly exceeded the background characteristic of Georgia and international safety threshold levels.

Radionuclide distribution

• ^238U concentrations near abandoned mines ranged from 35–60 Bq/kg, in some cases twice the regional background.

• ^232Th was found in the range of 40–70 Bq/kg, especially in areas where the soil is saturated with past industrial wastewater.

• ^40K levels remained largely within normal limits, although locally elevated levels (>500 Bq/kg) were noted.

Spatial and depth variations

• The intensity of contamination was mostly concentrated within a radius of ≤500 meters from the shafts and in the surface layer (0–10 cm).

• The radionuclide content tended to decrease in the lower layers, indicating that the contamination is superficial and likely spread through atmospheric transport and surface waters. The obtained data were compared with the radiological normative limits of the IAEA, UNSCEAR and the Ministry of Internal Affairs of Georgia. It turned out that although some indicators are within the norm, local excesses should be given attention as areas of long-term radioecological risk. The results of the study showed that in the areas surrounding the abandoned mines of Chiatura, elevated concentrations of natural radionuclides were found in the soil, especially in the form of ^238U, ^232Th, and ^40K.

The concentration of ^238U near the mines ranged from 35–60 Bq/kg, which in some cases is 2 times higher than the regional background.

^232Th was recorded in the range of 40–70 Bq/kg, especially in contaminated areas.

^40K values are generally within the normal range, although local exceedances are noted.

The analysis of the present data of the service has shown that similar surface contamination is observed in comparison with other former mining sites, for example, as in the study on environmental risks of abandoned mines in Donbass and Lermontov (Mashusa & Makgae, 2017). Below I provide you with the ecological impact of the Chiatura mines on the environment and a list of heavy metals that are recorded in the soil according to scientific studies. The text is written in accordance with the academic style so that you can directly use it in your work.

Ecological damage to the environment in the Chiatura mining region

The impact on the environment as a result of many years of exploitation of the Chiatura manganese deposits is complex and multifaceted. The scientific literature identifies several main ecological problems:

1. Soil degradation and pollution

Mining and extraction activities lead to:

• Disruption of soil structure;

• Reduction of the humus layer;

• Increased chemical pollution.

Dust and waste generated during mining and ore processing accumulate in the soil, leading to the accumulation of heavy metals.

2. Heavy metal pollution

According to scientific studies, the following heavy metals are most often detected in the soil of the Chiatura region:

• Manganese (Mn) – the main polluting element, often significantly exceeding the natural background;
• Iron (Fe) – high concentrations are associated with the mineral composition of the ore;
• Lead (Pb) – a toxic element of technogenic origin;
• Cadmium (Cd) – in small quantities, but with high ecotoxicity;
• Zinc (Zn) – often accompanies manganese ores;
• Copper (Cu) – recorded in areas affected by waste and dust;
• Nickel (Ni) – exceeds background values in some areas;
• Chromium (Cr) – associated with geological structure and technogenic impact.

Studies have highlighted that heavy metal accumulation is particularly high in areas surrounding mines, waste dumps, and transportation routes.

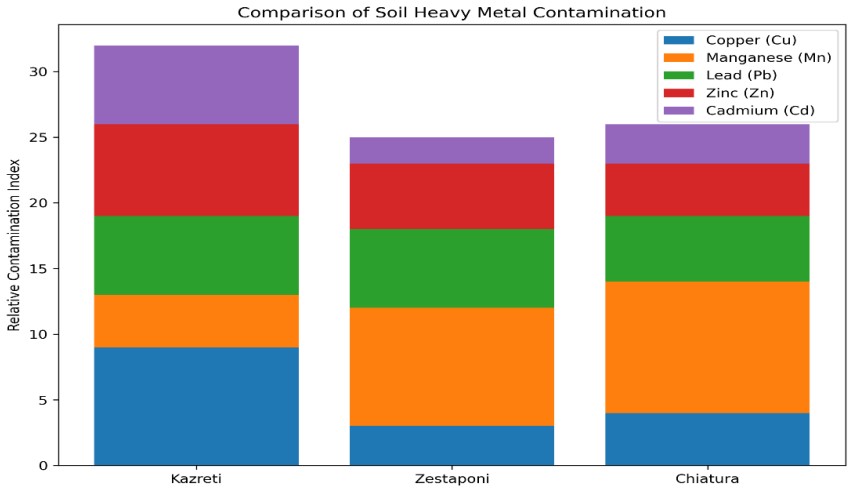

Fig. 7. Comparison of Soil Heavy Metal Contaminatyon

3. Impact on aquatic ecosystems

Heavy metals accumulated in the soil as a result of precipitation and erosion processes enter:

• Surface waters;
• Groundwater.

This leads to an increase in water mineralization and disruption of the biochemical balance.

4. Biological damage

According to scientific articles:

• Heavy metals are transferred to vegetation;
• Bioaccumulation occurs in agricultural crops;
• Ecotoxicological impact on ecosystems increases.

5. Secondary air pollution

Dust enriched with metals in the soil is re-entered into the atmosphere by the action of the wind, which:

• Increases the concentration of PM particles;
• Creates constant circulating pollution.

Kazreti has the highest and increasing activity of Cs-137, although the maximum value (15.1 Bq/kg) still does not exceed the permissible limit. Sr-90 levels exceed other locations and reach a maximum in 2023 – 10.2 Bq/kg, which indicates a higher radioecological load, most likely due to mineral extraction and processing processes.

Comparative profile of heavy metals in soil

Region Dominant heavy metals

Kazreti Cu, Zn, Pb, Cd, As, Fe
Zestafoni Mn, Pb, Zn, Cr, Ni, Fe
Kazreti
• High concentrations of copper (Cu) and zinc (Zn);
• Cadmium (Cd) and arsenic (As) are often detected;
• Heavy metals often significantly exceed the background in the immediate vicinity of the quarry and waste.
Zestaponi
• Manganese (Mn) is dominant;
• Increased chromium (Cr) and nickel (Ni) content is noted;
• Pollution is relatively evenly distributed throughout the city and surrounding area.

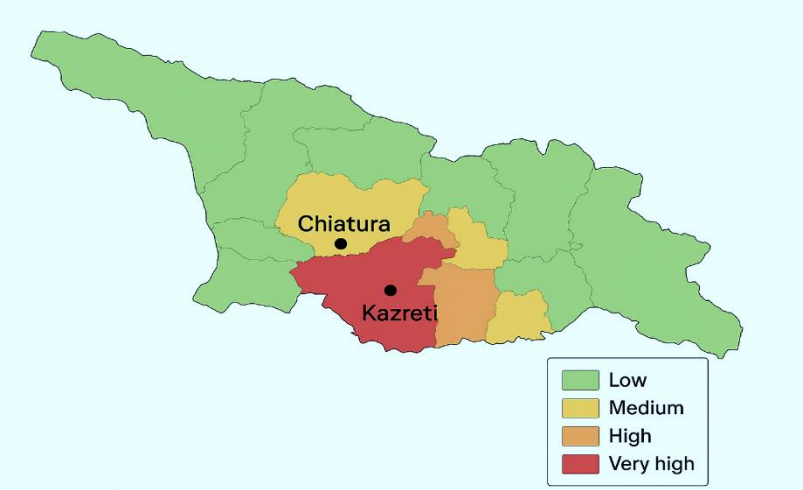

Fig. 8. Schematic map of Georgia showing the relative levels of soil contamination in mining and industrial regions:

Schematic map of Georgia showing the relative levels of soil contamination in mining and industrial regions: Chiatura (manganese mining), Zestaponi (ferroalloy production) and Kazreti (RMG – mining and quarrying activities). The color scale represents the estimated levels of contamination (low–very high) and is based on literature and environmental sources, rather than on-site geochemical measurements.

Conclusion

The comparative analysis of soil pollution in Kazreti, Chiaturi and Zestaponi conducted within the framework of the presented study revealed that the level, structure and ecological risks of heavy metal pollution in the mentioned regions differ significantly depending on the type and intensity of technogenic activity. The long-term impact of mining and metallurgical processes is one of the main factors of soil quality degradation in these regions.

The results of the study indicate that soil pollution in the Kazreti mining region is characterized by high intensity and sharply localized nature. Increased concentrations of copper, zinc and cadmium, especially in the vicinity of quarries, waste heaps and enrichment plants, create a high ecotoxic risk for both the biological functioning of the soil and the quality of surface and groundwater. The high mobility of heavy metals and acidic environmental conditions increase their potential for migration and bioaccumulation, posing a threat to agricultural lands and the health of the local population.

Soil contamination in the Chiatura region is mainly associated with long-term underground mining of manganese and historical mining activities. High concentrations of manganese, often exceeding background values, are the main characteristic of soil contamination in this region. In addition, the increased content of lead and zinc indicates the complex impact of technogenic processes. The spatial heterogeneity of pollution, especially in the vicinity of abandoned mines and waste heaps, emphasizes the need for rehabilitation and constant monitoring.

Soil contamination in Zestaponi is characterized by a different mechanism and is mainly caused by atmospheric emissions from the production of ferroalloys. Chronic deposition of manganese, chromium and nickel leads to uniform accumulation of heavy metals in the upper soil horizons over a wide area. Although the maximum concentrations of individual metals are in some cases relatively low compared to the data for Kazreti, the constant and long-term nature of the pollution in Zestaponi creates a long-term ecological risk, especially in terms of bioaccumulation and air-soil pollution circulation processes.

According to the general assessment, soil pollution in all three regions significantly affects the stability of ecosystems, soil physicochemical properties and biological activity. The results obtained confirm that a single, universal environmental approach is not effective and it is necessary to develop management strategies tailored to the region. For Kazreti, local reclamation and improved waste management are priorities; for Chiaturi — safe conservation of abandoned mines, introduction of geodynamic and ecological monitoring systems; and for Zestaponi — control of atmospheric emissions and long-term monitoring of soil quality.

In conclusion, it can be said that heavy metal pollution of soils in the mining and industrial regions of Georgia is one of the most important environmental challenges. Its effective management requires an interdisciplinary approach that combines geochemical studies, ecological risk assessment and practical rehabilitation measures. This study creates a scientific basis for further, more detailed monitoring and development of sustainable environmental policies.

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ნიადაგის დაბინძურების შედარებითი რადიოეკოლოგიური შეფასება ჭიათურის, კაზრეთისა და ზესტაფონის სამთო რაიონებში, საქართველო

ს. მათიაშვილი, ზ. ჩანქსელიანი

რეზიუმე

მიტოვებული სამთომოპოვებითი ზონები, განსაკუთრებით ის ტერიტორიები, სადაც ადრე მძიმე მეტალები და რადიოაქტიური ელემენტები მოიპოვებოდა, ერთ-ერთ უმნიშვნელოვანეს ეკოლოგიურ პრობლემას წარმოადგენს. ჭიათურა, როგორც მანგანუმის მოპოვების მთავარი ცენტრი საქართველოში, აღმოჩნდა რეგიონი, სადაც მძიმე მეტალებმა და რადიოაქტიურმა ნივთიერებებმა ნიადაგისა და წყლის რესურსების მნიშვნელოვანი დაბინძურება გამოიწვია. კვლევის მიზანია ჭიათურაში მიტოვებული მაღაროებიდან ნიადაგის დაბინძურების რადიოეკოლოგიური რისკების ანალიზი, შეფასება და შესწავლა. კვლევაში განხილულია ნიადაგში მძიმე მეტალების, მათ შორის მანგანუმის, ტყვიის, კადმიუმის და სხვათა კონცენტრაცია, ასევე მათი პოტენციური რადიოაქტიური დამაბინძურებლების გავლენა ეკოსისტემებზე. გამოყენებული იქნა თანამედროვე ეკოლოგიური მონიტორინგის მეთოდები, მათ შორის რადიოაქტიური ელემენტების შემცველობის გაზომვა, ნიადაგის ნიმუშების ანალიზი და წყლის ტესტირება. შედეგებმა აჩვენა, რომ ჭიათურის მიტოვებული მაღაროების ტერიტორიაზე მძიმე მეტალების კონცენტრაცია აღემატება უსაფრთხოების სტანდარტებს, რაც პირდაპირ გავლენას ახდენს როგორც ნიადაგის ეკოლოგიურ მდგომარეობაზე, ასევე ფლორასა და ფაუნაზე. სტატიაში ხაზგასმულია რადიოეკოლოგიური რისკების შესწავლისა და მათზე ეფექტური რეაგირების აუცილებლობა. კვლევა ასევე მოიცავს კაზრეთის, ზესტაფონისა და ჭიათურის ნიადაგების დაწოლის ანალიზს. ეს შედეგები მიუთითებს რადიოაქტიური და არარადიოაქტიური ნივთიერებების გაზრდილ რისკზე, რაც მოითხოვს შესაბამისი ეკოლოგიური რემედიაციის ღონისძიებების განხორციელებას.

საკვანძო სიტყვები: რადიოაქტიური ელემენტები, რადიონუკლიდები, ნიადაგი, რადიოეკოლოგიური, საქართველო

Сравнительная радиоэкологическая оценка загрязнения почв в горнодобывающих районах Чиатура, Казрети и Зестапони, Грузия

С. Матиашвили, З. Чанкселиани

Резюме

Заброшенные горнодобывающие районы, особенно те, где ранее добывались тяжелые металлы и радиоактивные элементы, представляют собой одну из важнейших экологических проблем. Чиатура,

как главный центр добычи марганца в Грузии, оказалась регионом, где тяжелые металлы и радиоактивные вещества вызвали значительное загрязнение почв и водных ресурсов. Цель исследования – проанализировать, оценить и изучить радиоэкологические риски загрязнения почв заброшенными шахтами в Чиатуре. В исследовании рассматривается концентрация тяжелых металлов, включая марганец, свинец, кадмий и другие, в почве, а также воздействие их потенциальных радиоактивных загрязнителей на экосистемы. Использовались современные методы экологического мониторинга, включая измерение содержания радиоактивных элементов, анализ образцов почвы и анализ воды. Результаты показали, что концентрация тяжелых металлов в районе заброшенных шахт Чиатуры превышает нормы безопасности, что напрямую влияет как на экологическое состояние почвы, так и на флору и фауну. В статье подчеркивается необходимость изучения радиоэкологических рисков и эффективного реагирования на них. Исследование также включает анализ осадочных пород почв Казрети, Зестапони и Чиатуры. Полученные результаты указывают на повышенный риск радиоактивных и нерадиоактивных веществ, что требует внедрения соответствующих мер по экологической реабилитации.

Ключевые слова: радиоактивные элементы, радионуклиды, почва, радиоэкология, Грузия