RISK OF SOIL AND WATER CONTAMINATION BY INDUSTRIAL TOXIC WASTE IN THE KAZRETI AND ZESTAFONI REGIONS OF GEORGIA

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Abstract

This paper analyses soil and water pollution issues in the Kazreti and Zestafoni regions of Georgia, where industrial activities have led to significant environmental contamination by heavy metals and other toxic compounds. It discusses the causes and scale of chemical contamination of soil and water, and its ecological and social impacts. The paper emphasizes the detrimental impact of soil pollution on ecosystems and human health. It also explores potential solutions to this problem, such as environmental monitoring, the regulation of industrial activities and the implementation of new technologies. The importance of preventive measures and sustainable development strategies for maintaining ecological balance and public health is emphasized.

Keywords: soil contamination, industrial activities, toxic waste, mining activity

I. Introduction

Contamination of soils and water from toxic industrial waste is one of the most significant global environmental challenges, often causing long-term and sometimes irreversible consequences. This issue is severe in Georgia's industrial regions, such as the surrounding areas of Kazreti and Zestafoni towns. Kazreti (in Southeast Georgia) is affected by mining activities related to the extraction of polymetals, while Zestafoni (in West Georgia) faces problems due to its ferroalloy manufacturing plant. In both regions, industrial activities have significantly degraded soil and water quality and disrupted the stability of the ecosystems through interactions between metals and chemical compounds.

There are a lot of publications in the world scientific literature concerning the pollution of the environment, particularly soil, water, air, and plants, both by radionuclides and heavy metals. Relatively recent studies in this area concerning the intake and impact of radionuclides and heavy metals into the environment [1-6], their transfer and behavior factors in soil, monitoring in agroecosystems and restoration [7-9], spatial distribution and ecological risk assessment [10-13], etc. Similar questions have been studied specifically in the soils and waters of Georgia [14-20]. This work paid special attention to industrial soil and water pollution and the comparative analysis of data from these regions.

Toxic wastes generated by industrial activities, including radionuclides (such as Cs-137 and Sr-90) and heavy metals like lead, chromium, and cobalt, are the primary pollutant source of soil, groundwater, and vegetation. Compounding this issue is the persistence of these toxic substances in the soil for a long time, which enables them to maintain their harmful effects over extended periods. Consequently, they impact both the structure of local ecosystems.

This paper explores the issue of soil pollution caused by industrial toxic waste in Georgia, focusing precisely on Kazreti and Zestafoni. It analyzes the forms and impacts of contamination, the associated ecological and health risks, and offers recommendations to improve soil conditions.

Implementing a combination of global and local environmental policies, scientific research, and technological innovations is essential to mitigating this problem and reducing ecological damage (UNEP). However, the current situation in the Kazreti and Zestafoni regions reflects ineffective waste management practices and high environmental risk (GEOSTAT).

The study aims to comprehensively analyze the problem of industrial pollution of soils and water and develop appropriate recommendations for improving the environment's state.

The study regions exemplify the environmental challenges associated with industrial pollution. Although differing in industrial profile, both regions face similarly acute ecological problems. Hence, the scale, causes, and impacts of soil contamination in these two regions are compared.

The Zestafoni Ferroalloy Plant is one of Georgia's largest industrial enterprises, primarily producing silicomanganese and other ferroalloys. The production process generates substantial quantities of dust and waste containing heavy metals, accumulating in the soil and contributing to its degradation. Research indicates that concentrations of manganese, lead, and cadmium in the soils of the Zestafoni region significantly exceed established sanitary norms. The primary contamination sources include emissions from industrial processes and the uncontrolled disposal of industrial waste. These factors alter the soil’s physical and chemical properties, reduce fertility, and hinder essential biological processes.

Kazreti is one of Georgia’s key mining centers that is involved in extracting and processing non-ferrous and precious metals. Extensive mining operations introduce hazardous elements such as arsenic, lead, and mercury into the soil and water, posing long-term ecological and health risks. Of particular concern are the tailings storage facilities, from which toxic substances frequently leak into the surrounding soil and groundwater.

II. Methods

Soil samples were collected from selected sites in the Kazreti and Zestafoni regions using a grid sampling method to ensure spatial representativeness. Sampling was performed at 0–30/40 cm depth, corresponding to the biologically active soil layer most affected by anthropogenic activities. Samples were placed in sealed plastic containers and labeled with precise geographic coordinates for traceability. Laboratory analyses were conducted at the Laboratory of the Scientific-Research Institute of Agriculture and Soil Fertility of Georgia. The concentration of heavy metals—specifically lead (Pb), cadmium (Cd), mercury (Hg), arsenic (As), manganese (Mn), nickel (Ni), and zinc (Zn)—was determined using Atomic Absorption Spectroscopy (AAS), a highly sensitive and reliable method for detecting trace metal elements in soil matrices.

Data were compared against both national soil quality standards and international environmental benchmarks, including those set by the World Health Organization (WHO) and the European Union (EU). Results were analyzed to identify spatial variation, assess exceedances of permissible limits, and evaluate potential ecological and health risks. The methodology also included cross-referencing soil contamination patterns with proximity to industrial sites and local hydrographic networks to assess potential leaching and downstream dispersion of contaminants.

The research is based on analyses of soil and water samples collected from the Kazreti and Zestafoni regions. Radionuclide concentrations were determined using high-resolution gamma spectrometry, ensuring precise Cs-137 and Sr-90 levels were measured.

The data used in this study encompass over 150 samples collected between 2022 and 2024 from the Kazreti and Zestafoni regions.

III. Results and Discussion

Environmental radionuclides pose a significant challenge from ecological and public health perspectives. Their distribution and concentration in the environment—especially in soil and water—substantially impact agricultural productivity, the safety of water resources, and human health. In Georgia, radionuclide levels vary across different regions and are influenced by natural and anthropogenic factors.

The Kazreti region, located in a mountainous area, is notable for its intensive mining, metallurgical activities, and abundant naturally occurring radioactive minerals. Research has shown that concentrations of Cs-137 and Sr-90 in Kazreti's soil and water are among the highest in Georgia (Cs-137 in soil: 15.0–25.0 Bq/kg; Sr-90: 7.5–12.0 Bq/kg). These elevated levels are closely linked to mining operations, metallurgical industries, and the natural geochemical composition of the area.

In Zestafoni, radionuclide levels are, on average, lower than in Kazreti; however, they still exceed those recorded in some other regions of Georgia. This is particularly evident in the average activity of Cs-137 in both soil and water.

If in the Kazreti region, high concentrations of radionuclides are geographically closely associated with zones of active mining operations, where elevated radiation levels are observed, in the case of Zestafoni, the distribution of radionuclides is more horizontal and is associated both with anthropogenic activities, particularly the technogenic emissions from the ferroalloy plant, and with natural processes such as surface runoff and wind-driven transport.

The data indicate that Cs-137 and Sr-90 concentrations in Kazreti are significantly higher than those in Zestafoni, particularly in soil samples (**Table 1**). In Kazreti, Cs-137 activity in soil was measured at 21.5 ± 3.8 Bq/kg and Sr-90 at 9.5 ± 1.8 Bq/kg, whereas in Zestafoni the corresponding values were 12.8 ± 2.5 Bq/kg for Cs-137 and 5.4 ± 1.1 Bq/kg for Sr-90. Water samples followed a similar pattern: in Kazreti, Cs-137 activity reached 2.0 ± 0.5 Bq/L and Sr-90 1.0 ± 0.3 Bq/L, while in Zestafoni these levels were 1.1 ± 0.3 Bq/L and 0.5 ± 0.2 Bq/L, respectively.

Table 1: *Average Concentrations of Cs-137 and Sr-90 in Soil and Water Samples from Kazreti and Zestafoni, 2022*

Region	Sample Type	Cs-137 (Bq/kg or Bq/L)	Sr-90 (Bq/kg or Bq/L)
Kazreti	Soil	21.5 ± 3.8	9.5 ± 1.8
	Water	2.0 ± 0.5	1.0 ± 0.3
Zestafoni	Soil	12.8 ± 2.5	5.4 ± 1.1
	Water	1.1 ± 0.3	0.5 ± 0.2

These results support the hypothesis that elevated radionuclide levels in Kazreti are associated with intensive mining and metallurgical activities. In contrast, Zestafoni, although less pollution, still exhibits radionuclide levels above baseline values observed in other regions of Georgia. The results confirm that the Kazreti region remains a radionuclide contamination hotspot in Georgia, with the primary risk factors associated with mining and metallurgical processes. The newly obtained data indicate that the current situation partially aligns with international findings in similar industrial regions.

Statistical average generalized data for 2022, 2023, and 2024 show that the average activity of Cs-137 in soil samples from Kazreti is approximately 2.8 times higher than in Zestafoni, while Sr-90 levels are about three times greater (**Figure 1**). Similar trends are observed in water samples, where radionuclide concentrations are consistently higher in Kazreti than Zestafoni. These differences highlight the elevated environmental burden of artificial radionuclides in the Kazreti region, further supporting the hypothesis that mining and metallurgical activities significantly contribute to local contamination. Figures below show the average concentrations of radionuclides (Cs-137 and Sr-90) in soils and water in the areas of Zestafoni and Kazreti in 2022 (Fig. 2) and 2023-2024 (Fig. 3).

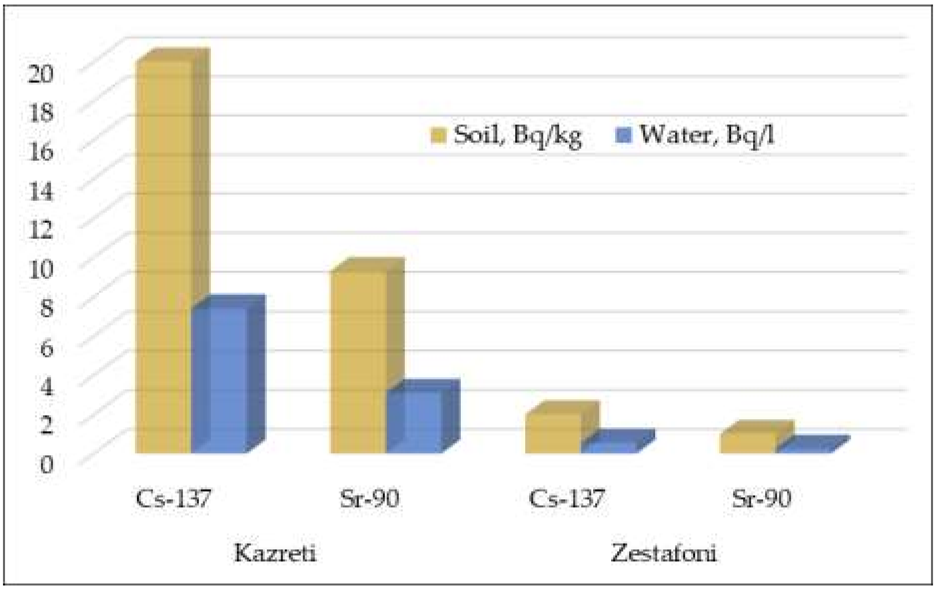

Figure 1: *Average Activity of Cs-137 and Sr-90 in Soils and Water in Kazreti and Zestafoni (2022-2024)*

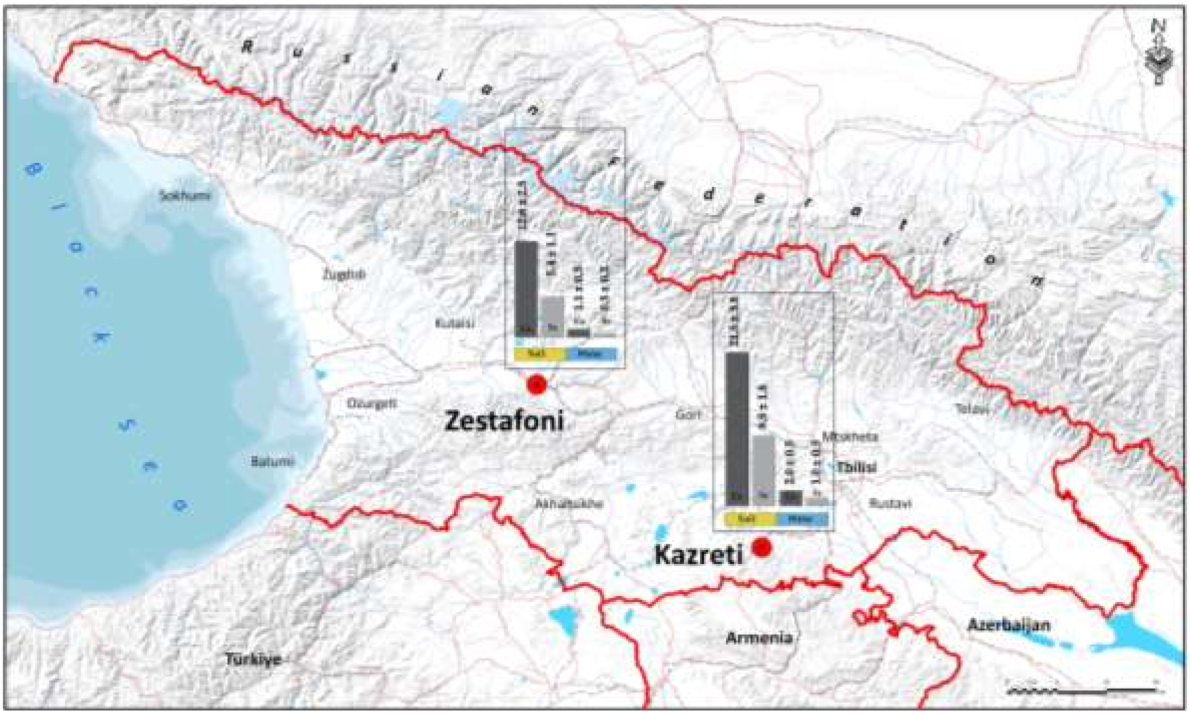

Figure 2: *Average concentrations of radionuclides in soils and water in the Zestafoni and Kazreti regions, 2023-2024*

The study highlights the necessity of regular monitoring and control of radionuclide levels in the Kazreti and Zestafoni regions to accurately assess the extent of environmental contamination and to develop appropriate safety standards.

The heavy metals were also assessed in the soil and water of the research sites, focusing primarily on elements such as Manganese (Mn), Mercury (Hg), Cadmium (Cd), Zinc (Zn), Arsenic (As), Nickel (Ni), and Lead (Pb). The graphs below illustrate the concentrations of mercury, zinc, arsenic, nickel, and lead over three years in Kazreti (Fig. 4) and two years in Zestafoni (Fig. 5).

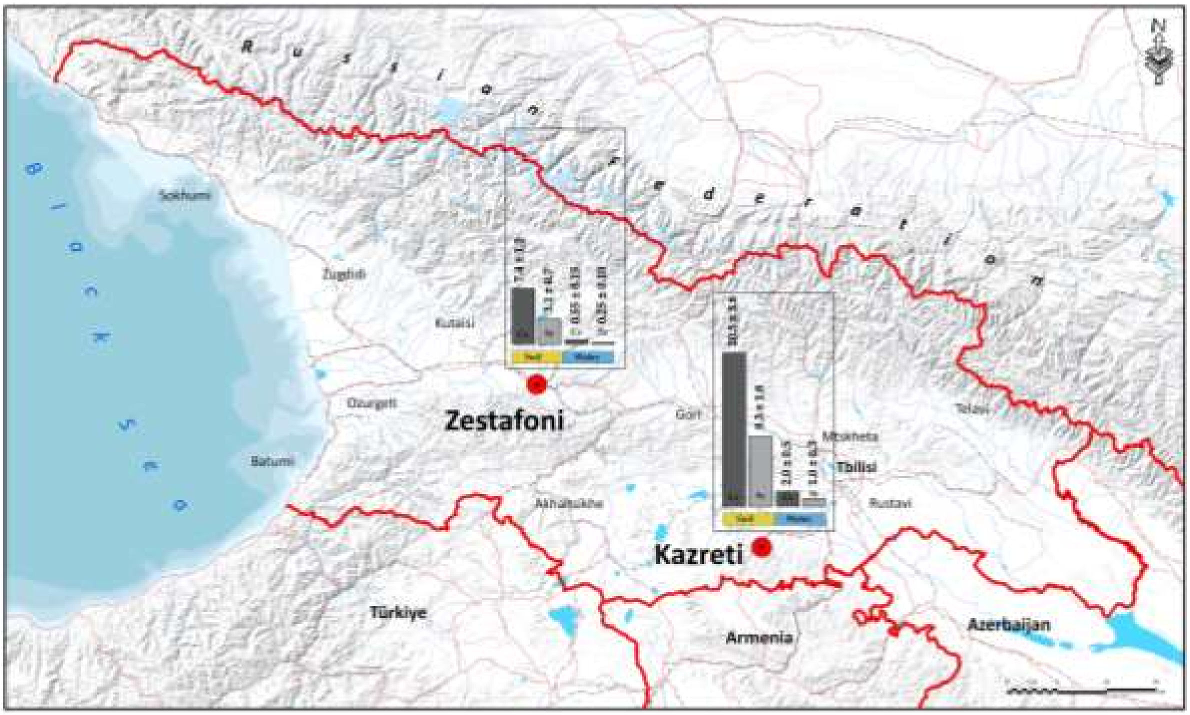

Figure 3: *Average concentrations of radionuclides in soils and water in the Zestafoni and Kazreti regions, 2022*

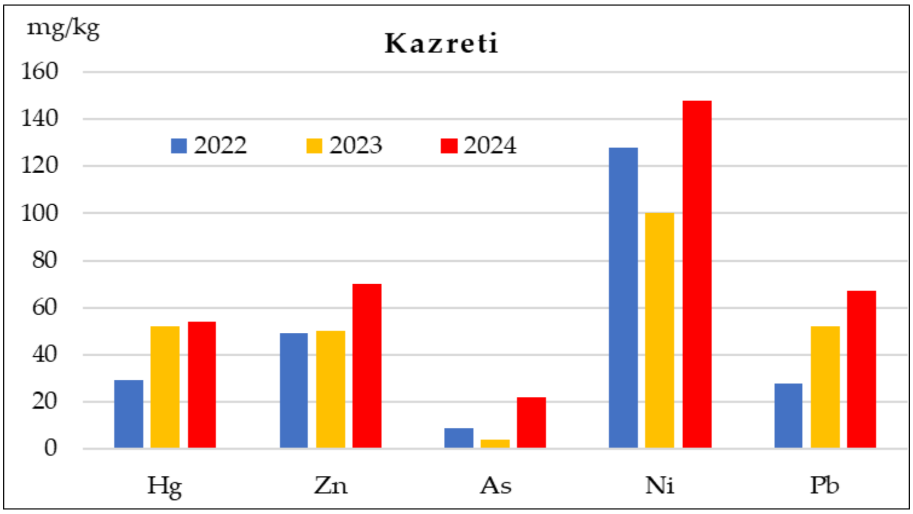

Figure 4: *Concentrations of Hg, Zn, As, Ni, Pb in soils of Kazreti (2022, 2023, 2024)*

It is worth noting that if, in the case of radionuclides, the territory of Kazreti is characterized by a markedly increased content of Cesium and Strontium, then the opposite picture is observed concerning heavy metals. Most of the studied chemical elements are clearly distinguished by a higher concentration in the soils of the Zestafoni territory, especially nickel, where, according to data for 2023, it exceeded 750 mg/kg (Fig. 5). It is evident that the concentration of manganese in the Zestafoni area, which is the region of extraction and processing of this raw material, prevails (in 2024 it reached 16’500 mg/kg) and significantly exceeds the Kazreti indicator (Fig. 6). Its concentration in both areas exceeds the maximum permissible concentration (500 mg/kg) several times. The cadmium and lead content in both places is within the normal range (the maximum allowable concentration is 0.5-2 mg/kg for Cd and 300 mg/kg for Zn), with a minimum content in Kazreti (Fig. 7).

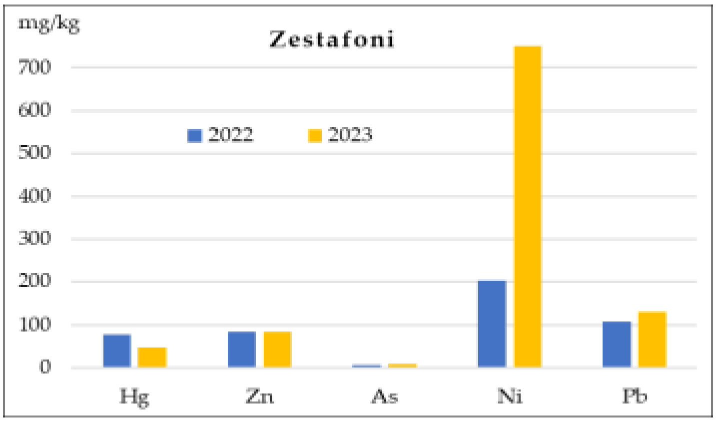

Figure 5: *Concentrations of Hg, Zn, As, Ni, Pb in soils of Zestafoni (2022, 2023)*

Figure 6: *Concentrations of Mn in Soils (2022-2024)*

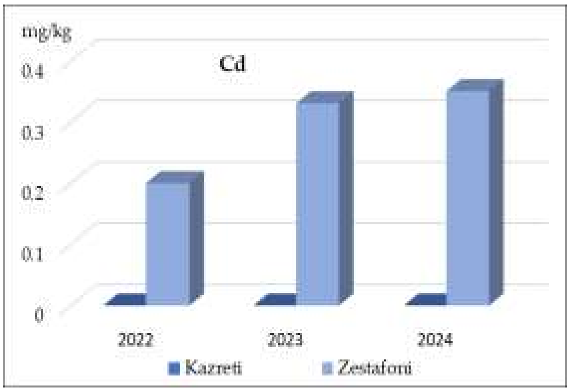

Figure 7: *Concentrations of Cd in Soils (2022-2024)*

Based on the evaluation data presented, there is an apparent disparity in the degree of environmental impact between Kazreti and Zestafoni. According to four key ecological criteria, Kazreti consistently qualifies as a high-risk zone, while Zestafoni can be categorized as a moderately impacted area, where contamination remains more localized (Table 2, Fig. 8).

Table 2: *Rating Scale of Statistical Data on Environmental Impact*

Criterion	Kazreti	Zestafoni	Rating scale (1-5)
Heavy metal concentration	Very high (Pb, As, Cd, Hg)	Medium-high (Mn, Ni, Zn)	Kazreti-5 Zestafoni-3
Soil contamination level	Large-scale, acute	Local, partial	Kazreti-5 Zestafoni-3
Pollution of water resources	Heavy metal pollution of rivers and reservoirs	Minor impact only on nearby waters	Kazreti-4 Zestafoni-2
Environmental risk	Extremely high	Moderate	Kazreti-5 Zestafoni-3

1. Heavy Metal Concentration. Kazreti shows a very high concentration of heavy metals (Pb, As, Cd, Hg), indicating widespread and chronic pollution of soil and environment as a result of intensive mining activities. In contrast, Zestafoni presents medium to high levels of metals (Mn, Ni, Zn), largely due to metallurgical industry operations. Kazreti scores the maximum – 5 on the rating scale, and Zestafoni – 3.

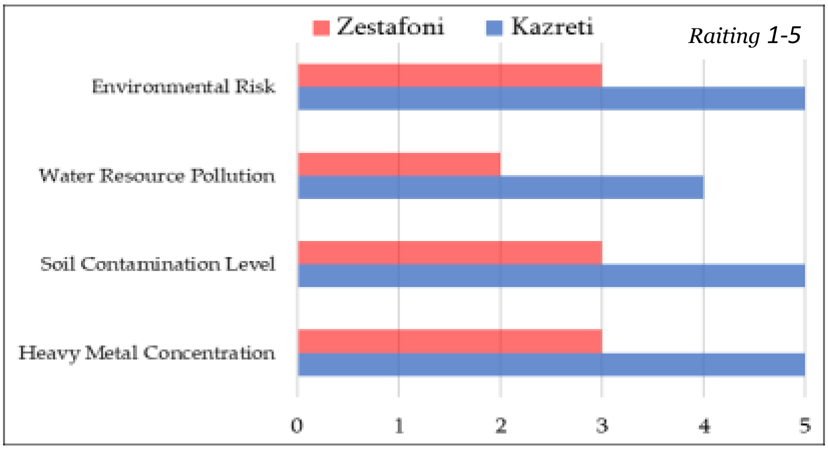

Figure 8: *Environmental Impact Comparison: Kazreti vs Zestafoni*

2. Soil Contamination Level. Soil pollution in Kazreti is large-scale and acute, suggesting that contaminants penetrate deeper soil layers and severely hinder natural recovery. In Zestafoni, the contamination is localized and partial. Kazreti once again scores 5, while Zestafoni scores 3.

3. Water Resource Pollution. Kazreti suffers from significant heavy metal pollution in rivers and reservoirs, which poses a serious threat to aquatic ecosystems. In Zestafoni, the impact is minor and limited to nearby waters. Therefore, the ratings are Kazretiasd – 4, Zestafoni – 2.

4. Environmental Risk. Kazreti is considered an area of extremely high environmental risk, with pollution affecting soil, water, and potentially biota. Zestafoni, meanwhile, poses a moderate risk, mainly due to localized industrial activity. Rating scores: Kazreti – 5, Zestafoni – 3.

IV. Conclusions

The cases of Zestafoni and Kazreti show that inadequate environmental safety measures lead to severe contamination and ecosystem degradation, and the type of industrial activity determines the nature and scale of soil contamination. Despite differences in industrial processes, both regions share the common issue of excessive heavy metal and radionuclide accumulation, which results in significant ecological and public health consequences.

The study of both regions faces a common notable environmental challenge — the ongoing soil degradation and water pollution. Addressing this issue requires a systemic approach: strengthening environmental monitoring, developing remediation programs, tightening environmental regulations, and raising public awareness.

To address these challenges, it is essential to implement the following measures:

- Regular environmental monitoring;
- Introduction of soil remediation programs;
- Effective management of industrial waste;
- Enforcement of environmental legislation.

A comprehensive and systematic approach can improve soil quality and protect the health of local populations.

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CONFLICT OF INTEREST.
Authors declare that they do not have any conflict of interest.

References

[1] Atwood D.A. (Editor). Radionuclides in the Environment. John Wiley & Sons; 2013, 19.

[2] Walther C., Gupta DK. Radionuclides in the Environment. Springer International. Springer International Publishing, Switzerland, 2015, 10, 978-983.

[3] Bundt M., Albrecht A., Froidevaux P., Blaser P., Flühler H. Impact of Preferential Flow on Radionuclide Distribution in Soil. // Environmental Science & Technology. 2000, 34(18), 385-389.

[4] Koch-Steindl H., Pröhl G. Considerations on the Behaviour of Long-Lived Radionuclides in the Soil. // Radiation and Environmental Biophysics. 2001, 40(2), 93-104.

[5] Kou M., Wang Z., Wang M., Benedetti M.F., Avena M.J., Fang L., Tan W. Cadmium and lead ions interaction: A model for assessing combined heavy metal contamination in soils for food safety risk evaluation. // Ecotoxicology and Environmental Safety, 2025, 298:118324

[6] Mohamoud A.M., Halder B., Shakir H.S., Yaseen Z.M. Soil Heavy Metal Contamination Analysis: A Representative Case Study in New Zealand. // Journal of Environmental Chemical Engineering, 2025, 116808.

[7] Alharbi A., El-Taher A. A study on Transfer Factors of Radionuclides from Soil to Plant. // Life Science Journal. 2013. 10(2), 532-539.

[8] Panov A.V., Trapeznikov A.V., Kuznetsov V.K. Radioecological Monitoring of Agroecosystems in the Vicinity of Beloyarsk NPP. Tomsk Polytechnic University // Geo Assets Engineering, 2021, 156.

[9] Nawaz I., Afshan A., Bukhari S.M., Niaz M., Kamran S., Durrani F., Chohan A.A., Sikandri Z., Yasmin R. Remediation of Cadmium-Contaminated Soil Using Biochar and its Impact on Wheat Germination and Growth. // Journal of Medical & Health Science Review, 2025, 2(2).

[10] Dai Dk., Zhou J. Spatial distribution and risk assessment of heavy metal contamination in soil-crop systems near gold mining areas. // Environ Geochem Health, 2025, Vol. 47, 19147, 191.

[11] Afifudin A.F.M., Pramesti H.N., Irawanto R., Sari A., Soegianto A., Affandi M., Payus C.M. Spatial Distribution and Risk Assessment of Heavy Metal Contamination in Western Madura Strait Sediments. // Results in Engineering, Vol. 26, 2025, 105157.

[12] Ullah I., Adnan M., Nawab J., Safi I., Khan S. Occurrence, Distribution and Ecological Health Risk Assessment of Heavy Metals Through Consumption of Drinking Water in Urban, Industrial, and Mining Areas of Semi-Arid to Humid Subtropical Areas. // Journal of Geochemical Exploration, Vol. 275, 2025, 107786.

[13] Xiang M., Lou Z., Sheng M., Ren Z., Xiao R., Fei X., Lv X. Exploring the Spatio-Temporal Dynamics and Driving Mechanisms of Toxic Metal Pollution in Soil Using a Hybrid Machine Learning-based Model. // Journal of Environmental Chemical Engineering, Vol. 13, Issue 3, 2025, 116644.

[14] Matchavariani L., Kalandadze B., Lagidze L., Gokhelishvili N., Sulkhanishvili N., Paichadze N., Dvalashvili G. Soil Quality Changes in Response to Their Pollution of Heavy Metals in Georgia. // Journal of Environmental Biology, SI "Ecology, Geography & Environment in the Mediterranean", 2015, 36(1), 85-91

[15] Khatisashvili G., Matchavariani L., Gakhokidze R. Improving Phytoremediation of Soil Polluted with Oil Hydrocarbons in Georgia. Chapter 19 in the book "Soil Remediation and Plants: Prospects and Challenges". Elsevier, 2015, pp.547-569

[16] Avkopashvili G., Avkopashvili M., Gongadze A., Gakhokidze R. Eco-monitoring of Georgia's Contaminated Soil and Water with Heavy Metals. Carpathian // J. Earth & Env. Sci., 2017, 12(2), 595-604.

[17] Avkopashvili M., Gongadze A., Avkopashvili G., Matchavariani L., Asanidze L., Lagidze L. Metals distribution in soil contaminated by gold and copper mining in Georgia. // Journal of Environmental Biology, SI "Environment, Biodiversity, Geography", 2020, Vol.41(2), 310-317.

[18] Avkopashvili M., Avkopashvili G., Avkopashvili I., Asanidze L., Matchavariani L., Gongadze A., Gakhokidze R. Mining-Related Metal Pollution and Ecological Risk Factors in South-Eastern Georgia. // Sustainability, 2022, vol.14, issue 9, 5621.

[19] Matiashvili S., Chankseliani Z., Mepharidze, E. Comparison of radionuclides and heavy metals distribution in Georgian soils. // Journal of the Georgian Geophysical Society, 2022, 25(1), 95-102.

[20] Gventsadze G., Ghambashidze G., Chankseliani Z., Sarjveladze I., Blum W.E.H. Impacts of crop-specific agricultural practices on the accumulation of heavy metals in soil in Kvemo Kartli region (Georgia): A preliminary assessment. // Sustainability, 2024, 16(10), 4244.