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Assessment of Heavy Metals in the Shkumbini River and Their Risk to Irrigated Agriculture and the Food Chain in Central Albania

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Abstract

Shkumbini River is a typical example of a watershed where natural geological conditions and human activities interact, influencing water quality and its suitability for agricultural use. The river originates in the Pogradec and Librazhd districts and flows westward into the Adriatic Sea. Five sampling sites (Hotolisht, Librazhd, Labinot Fushë, Paper, and Peqin) were selected to evaluate natural and anthropogenic contamination sources affecting irrigation water in central Albania. The aim of this study was to assess heavy metal concentrations in the Shkumbini River, identify their natural and anthropogenic origins, and evaluate their potential risk to irrigated agriculture and the food chain in Central Albania by comparison with international standards. Water samples were collected during 2025-2026. In situ measurements of temperature, pH, conductivity, and dissolved oxygen were performed using a portable multiparameter probe. Heavy metals (Cr, Zn, Ni, and Cu) were analyzed by Atomic Absorption Spectrometry according to ISO 15586 and evaluated using Norwegian Institute for Water Research (NIVA) standards.
Physicochemical parameters were within acceptable ecological limits, indicating suitable conditions for aquatic life. However, heavy metal results showed clear spatial variation. Nickel was the most critical contaminant, with concentrations ranging from 14.97 to 56.63 µg/L, exceeding NIVA guideline values (5–10 µg/L) at all stations. The highest Ni values occurred at Paper (≈56.6 µg/L) and Peqin (≈45.3 µg/L), reflecting strong influence from metallurgical industrial activity in the Elbasan area. Elevated Ni and Cr at Hotolisht and Librazhd are associated with natural ultramafic geological formations, while lower values at Labinot Fushë indicate dilution in non-ultramafic zones. Chromium concentrations ranged from 9.93 to 33.95 µg/L, with maximum values in industrially impacted areas. Zinc remained below toxic thresholds at all stations, whereas copper increased downstream, particularly at Peqin.Overall, both natural geology and anthropogenic activities contribute to heavy metal contamination in the Shkumbini River. The persistent exceedance of Ni and elevated Cr indicate a significant risk for irrigation water quality, with potential transfer into agricultural soils and crops. Considering the extensive use of this river for irrigation in central Albania, there is a risk of heavy metals entering the food chain, requiring continuous monitoring and mitigation strategies.

Keywords: Shkumbini River, heavy metals, irrigation water, ultramafic geology, metallurgical activity, food chain risk

1. Introduction

River systems represent dynamic ecological networks in which natural geochemical processes and human activities interact to regulate water quality, sediment transport, and ecosystem functioning. This interaction is particularly important in regions underlain by ultramafic rocks, where the natural geochemical background can be characterized by elevated concentrations of trace elements such as nickel (Ni), chromium (Cr), cobalt (Co), and iron (Fe). Through weathering, erosion, and sediment transport, these elements may be mobilized from ultramafic rocks and their derived soils and transferred to aquatic systems. This natural geochemical contribution may overlap with

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anthropogenic inputs, making the assessment of metal contamination in rivers draining ultramafic terrains particularly challenging. Albania provides a relevant setting for investigating these processes because ultramafic substrates are widespread throughout the country. Lekaj et al. (2019) reported that ultramafic substrates containing 10–43% MgO occupy approximately 11% of the total area of Albania. These formations constitute an important natural source of Cr, Ni, Co, and other trace elements and influence the geochemical characteristics of soils, sediments, and surface waters in affected catchments. Consequently, rivers crossing ultramafic terrains may receive a substantial geogenic input of metals through natural weathering and erosion, while additional anthropogenic sources can further modify their spatial distribution and environmental concentrations.

The Shkumbini River is one of the major river systems in Albania, with a catchment area of approximately 2440 km² and a length of 181.4 km, flowing from the eastern highlands of Pogradec and Librazhd toward the Adriatic Sea. Its watershed encompasses diverse geomorphological units, including mountainous ultramafic zones, transitional valleys, and lowland plains, generating pronounced spatial heterogeneity in hydrology, sediment dynamics, and chemical composition. The river is also characterized by substantial erosion and sediment transport, which can facilitate the downstream redistribution of naturally occurring metals associated with ultramafic geological formations. Thus, the geochemical setting of the Shkumbini catchment is an important consideration when evaluating the occurrence and distribution of trace metals in the river system. At the same time, the Shkumbini River has experienced long-term anthropogenic pressures and has historically been considered an environmentally impacted river. Of particular importance is the legacy of the Elbasan Metallurgical Combine and associated industrial activities, which have contributed to the contamination of the river and its sediments (Osmani et al.). The influence of these industrial pressures occurs within a catchment that also receives sediments originating from naturally metal-rich ultramafic regions. Consequently, the present-day metal concentrations in the Shkumbini River may reflect the combined influence of natural geochemical processes and historical anthropogenic inputs. Previous studies have highlighted this interaction (Topi et al. 2012; Koto et al. 2013) associated elevated Cr concentrations in sediments with the influence of the Shkumbini River, which flows through ultramafic areas and passes near metallurgical sites in Albania.

Beyond its environmental significance, the Shkumbini River plays an important role in regional socio-ecological systems, supporting irrigation, fisheries, and local livelihoods. River water is also used for agricultural production in central Albania, creating potential pathways for the transfer of metals from aquatic systems to agricultural soils and, ultimately, to crops and the food chain (Bushi et al 2026). Heavy metals can enter river systems through both natural pedo-geological and anthropogenic pathways and may subsequently be distributed among water, sediments, and biota (Topi et al. 2012; Koto et al. 2013).

While elements such as Ni, Cu, and Zn are essential at low concentrations, elevated concentrations may adversely affect aquatic organisms, accumulate in biota, and contribute to their transfer through food webs. Their mobility and bioavailability are controlled by environmental conditions including pH, redox potential, organic matter, and interactions with mineral surfaces. These processes make rivers important indicators of changes in both natural geochemical conditions and anthropogenic environmental pressures.

Understanding the relative contribution of geogenic and anthropogenic processes is therefore particularly important for the Shkumbini River, where extensive ultramafic formations and the legacy of metallurgical activities coexist within the same drainage system. Given the importance of the river for irrigation and ecosystem services, characterizing the spatial distribution of trace metals is also relevant for evaluating potential pathways of metal transfer from the river system to agricultural soils and the food chain.

The aim of this study was to evaluate heavy metal concentrations in the Shkumbini River, investigate their spatial distribution in relation to the geochemical setting and anthropogenic pressures, and assess their potential implications for metal transfer within the river–agroecosystem continuum and associated risks to irrigated agriculture and the food chain in Central Albania, in comparison with relevant international guideline values.

2. Materials and Methods

2.1 Sampling design and study sites

Water sampling was conducted at five stations along the Shkumbini River representing different environmental conditions and potential contamination sources (Figure1): Hotolisht, Librazhd, Labinot Fushë, Paper, and Peqin. These sites were selected to capture spatial variability associated with upstream ultramafic geological formations, transitional zones, and downstream areas influenced by urban and industrial activities, particularly in the Elbasan region.

Sampling campaigns were carried out during 2025–2026. At each station, surface water samples were collected at approximately 20 cm below the water surface using 1.5 L polyethylene bottles. Samples were labeled according to site and immediately stored under cooled conditions (4 °C) and transported to the laboratory within 24 hours. All laboratory analyses were carried out at the Laboratory of Department of Environment and Natural Resources at Agricultural University of Tirana, Albania.

2.2 Physico-chemical measurements

In situ measurements of key physico-chemical parameters were performed at each sampling site using a portable multiparameter probe. The parameters measured included water temperature, pH, electrical conductivity, and dissolved oxygen. These variables were selected to characterize the ecological status of the aquatic system and to assess environmental conditions influencing metal mobility and availability.

2.3 Heavy metal analysis in water

For trace metal analysis, water samples were acidified to pH < 2 using analytical-grade nitric acid (HNO_3) to preserve dissolved metals and prevent microbial alteration. Concentrations of nickel (Ni), chromium (Cr), zinc (Zn), and copper (Cu) were determined by Atomic Absorption Spectrometry (AAS) following ISO 15586 standard procedures.

All analyses were conducted using appropriate calibration standards, and results were expressed in $\mu g\ L^{-1}$. The obtained concentrations were evaluated against guideline values provided by the Norwegian Institute for Water Research (NIVA) to assess ecological quality and potential risks for irrigation use.

Statistical analysis was performed using independent sample t-tests to evaluate differences in mean concentrations of heavy metals among the sampling stations and between industrial an dultramafic areas of the Shkumbin River

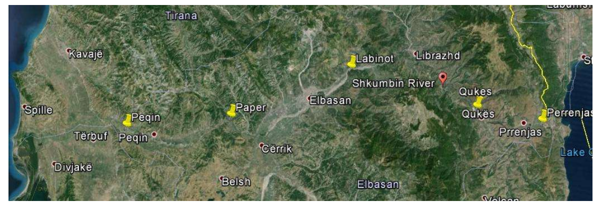

Figure. 1 Sampling Study site, Shkumbini river, Albania

3. Results and Discussion

3.1 Physico-chemical characteristics of river water

The physico-chemical parameters of the Shkumbini River showed moderate spatial and seasonal variability across the five sampling stations (Table 1). Water temperature (17.7–27.5°C) reflected seasonal differences between summer and early autumn and longitudinal variation along the river continuum, which is consistent with observed river thermal dynamics under changing climatic and hydrological conditions in temperate river systems (Webb et al., 2020; Science of the Total Environment). The pH remained neutral to slightly alkaline (6.05–7.20), indicating stable buffering conditions typical of well-buffered river systems. Small decreases (e.g., Labinot Fushë, 6.05) may be linked to increased organic matter decomposition and microbial respiration, which influence carbonate equilibrium in running waters (Ferreira et al., 2020).

Electrical conductivity (262–475 µS/cm) increased downstream, particularly at Librazhd and Peqin, indicating increasing dissolved ion loads. This pattern is widely recognized as a combined effect of natural lithological weathering and anthropogenic pressures such as agriculture and urban runoff, which elevate ionic content in river systems (Li et al., 2024; Nature Climate Change). Dissolved oxygen remained high (7.0–8.8 mg/L) across all stations, indicating well-oxygenated conditions suitable for aquatic life. DO variability is strongly controlled by temperature, hydrological regime, and river–catchment interactions, as confirmed in recent global river oxygen synthesis studies (Krause et al., 2026, Earth System / preprint review).

Overall, the physico-chemical profile indicates generally good ecological status of the Shkumbini River. However, spatial gradients in conductivity and pH suggest combined influence of natural geological background (Bani et al 2018) and anthropogenic pressures. These parameters are critical regulators of metal mobility, speciation, and bioavailability in river systems, directly linking water chemistry to ecosystem and agricultural exposure pathways (Li et al., 2024; Krause et al., 2026

Parameter	**Peqin**	**Paper**	**Labinot Fushë**	**Hotolisht**	**Librazhd**
	July / Sept	July / Sept	July / Sept	July / Sept	July / Sept
Temperature (°C)	25.9 / 17.7	25.4 / 19.5	27.5 / 20.2	26.3 / 21.0	19.0 / 17.9
pH	6.95 / 6.79	6.85 / 7.20	7.10 / 6.05	7.00 / 7.20	6.90 / 7.10
Conductivity (µS/cm)	414 / 423	398 / 395	270 / 262	340 / 330	475 / 450
Dissolved Oxygen (mg/L)	7.1 / 8.0	7.0 / 8.1	7.6 / 8.5	7.9 / 8.8	7.9 / 8.8

Table 1. In situ measurement of physico-chemical water parameters in the Shkumbini River using a portable multiparameter probe

3.2 Heavy metal concentrations in Shkumbini River water

Heavy metal concentrations in Shkumbini River water (Table 2) showed clear spatial variation across the five sampling stations, reflecting the interaction between natural ultramafic geochemical background and anthropogenic inputs.

Nickel (Ni) was the dominant contaminant, ranging from 14.97 ± 0.74 µg/L at Labinot Fushë **to** 46.63 ± 3.54 µg/L at Paper**.** Elevated concentrations were also recorded at Peqin (45.33 ± 3.17µg/L)**,** Librazhd (28.62 ± 1.89 µg/L)**,** andHotolisht **(**≈13.83–18.70 µg/L range depending on replicate variability). All Ni values exceeded the Norwegian Institute for Water Research (NIVA) guideline range for freshwater and irrigation waters (5–10 µg/L), indicating persistent exceedance along the entire river system (Bratli, 2000).

Zinc (Zn) concentrations ranged from 6.80 ± 2.80 µg/L to 12.80 ± 9.44 µg/L**,** remaining well below NIVA threshold values (~50 µg/L), indicating low ecological risk across all stations.

Copper (Cu) ranged from 1.50 ± 1.36 µg/L at Labinot Fushë **to** 4.97 ± 1.29 µg/L at Peqin, remaining within NIVA guideline limits (3–6 µg/L), with higher values downstream reflecting combined agricultural and industrial influence.

Chromium concentrations in the Shkumbini River water ranged from 9.93 ± 0.82 µg/L at Hotolisht to 33.95 ± 0.47 µg/L at Paper. Although all measured concentrations remained below the NIVA guideline value of 50 µg/L, the increasing concentrations observed at downstream and industrially influenced stations, particularly at Paper and Peqin, indicate a clear spatial enrichment of Cr. This pattern is consistent with the geochemical characteristics of the Shkumbini River basin, which crosses extensive ultramafic formations. Ultramafic rocks and their derived soils are naturally enriched in Cr, and weathering and erosion of these materials can contribute to the transport of Cr into river systems. Thus, the presence of Cr in the Shkumbini River should not be attributed solely to anthropogenic inputs, but should also be considered in relation to the natural geochemical background of the catchment.

Previous studies have similarly highlighted the importance of both geological and anthropogenic sources of Cr in the Shkumbini River system. (Koto et al. 2013) reported high Cr levels in sediments of Karavasta Lagoon and explained this enrichment by the influence of the Shkumbini River flowing through ultramafic areas and passing near metallurgical sites in Albania. The relatively higher Cr concentrations recorded at Paper and Peqin in the present study may therefore reflect the combined influence of natural Cr inputs from ultramafic rocks and soils and additional contributions associated with historically industrially influenced areas. The lower concentration measured at Hotolisht, located upstream, further supports the occurrence of spatial variation along the river, although the contribution of individual sources cannot be distinguished solely from dissolved Cr concentrations.

The concentrations measured in the present study nevertheless indicate that, despite the natural Cr enrichment characteristic of ultramafic catchments, dissolved Cr in the investigated river water remained below the referenced guideline value. Continued monitoring is therefore important, particularly at downstream stations influenced by both ultramafic geology and historical industrial activities, where natural and anthropogenic sources may act simultaneously.

Overall, Ni represents the primary limiting factor for irrigation water quality in the Shkumbini River, with consistent exceedance at all stations (Bratli, 2000). Cr and Cu show localized enrichment, while Zn remains within safe ecological limits. These results confirm that both natural ultramafic lithology (Echevarria 2015, Bani et al 2018) and anthropogenic pressures control river water chemistry, particularly in downstream agricultural zones. This pattern is consistent with previous ecological assessments of the Shkumbini River reporting elevated Ni and Cr linked to serpentine geology and industrial activity (Sallaku et al 1999; Bani et al., 2020; Osmani et al. 2017).

Sampling station	**Cr (µg/L)**	**Zn (µg/L)**	**Ni (µg/L)**	**Cu (µg/L)**
Hotolisht	9.93 ± 0.82a	12.80 ± 9.44a	15.98 ± 2.34a	1.63 ± 1.25a
Librazhd	15.28 ± 1.49b	12.41 ± 3.17a	28.62 ± 1.89b	1.50 ± 1.36a
Labinot Fushë	10.93 ± 0.75a	6.80 ± 2.80a	15.00 ± 0.74a	2.10 ± 0.60b
Paper	33.95 ± 0.47c	13.86 ± 11.26a	46.63 ± 3.54b	2.69 ± 0.73b
Peqin	18.54 ± 1.85b	10.53 ± 3.70a	45.33 ± 3.17b	4.97 ± 1.29b
NIVA guideline values	**50**	**50–100**	**5–10**	**3–6**

Table 2. Heavy metal concentrations (µg/L) in Shkumbini River water (mean ± SD, n = 3) and NIVA guideline values

The t-tests for mean values showed significant variation for Ni and Cr concentrations in stations of Librazhd, Paper and Peqin station ($P < 0.05$). The Cr and Nickel concentrations in water were higher in the industrial area than in the part of river that crosses an ultramafic area. In Paper and Peqin stations the level of nickel in Shkumbin water is higher than in three other stations explained by the fact that it is affected by pollution of the metallurgical activity that generates ferro-nickel waste. t-Tests showed that in general there was significant statistical difference between industrial and ultramafic area for the concentration of Cr and Ni in water of Shkumbini River ($P < 0.05$).

4. Conclusions

The Shkumbini River exhibits generally stable physico-chemical conditions, with neutral to slightly alkaline pH, well-oxygenated waters, and conductivity values reflecting a combined influence of natural lithological weathering and anthropogenic inputs. Seasonal and spatial variability in temperature and conductivity confirms the dynamic hydrological character of the basin and the role of catchment processes in shaping basic water chemistry.

Heavy metal analysis reveals a clear geochemical and anthropogenic imprint on river water quality. Nickel is the dominant contaminant and consistently exceeds NIVA guideline values at all sampling stations, indicating a basin-wide geochemical pressure strongly influenced by ultramafic (serpentine) bedrock, particularly in upstream and transitional zones, as well as by industrial activity in downstream areas. Chromium shows moderate enrichment, especially in industrially impacted sections, while copper remains generally within guideline limits but increases in downstream agricultural–urban interfaces. Zinc concentrations remain low and environmentally safe throughout the system.

The combined results demonstrate that the Shkumbini River functions as a mixed geochemical system where natural ultramafic background levels are amplified by localized anthropogenic inputs. Among all measured elements, nickel represents the primary constraint for irrigation water quality and the main potential risk for agricultural exposure pathways. Persistent exceedance of Ni, together with localized Cr enrichment, suggests a potential transfer risk from water to soils and crops in irrigated areas of central Albania.

Overall, while the river maintains acceptable general physico-chemical conditions for aquatic life, its chemical load—particularly Ni—highlights the need for continued monitoring and integrated watershed management. These findings confirm the importance of distinguishing between natural geogenic contamination and human-induced pollution when assessing river suitability for agricultural use and ecosystem protection.

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