Acta Sci. Pol.
Formatio Circumiectus 25 (2) 2026, 127–145
ENVIRONMENTAL PROCESSES

www.acta.urk.edu.pl ISSN 1644-0765 DOI: http://doi.org/10.15576/ASP.FC/225959

ORIGINAL PAPER Accepted: 14.07.2026

GEOSPATIAL ASSESSMENT OF GROUNDWATER QUALITY AND HEAVY METAL CONTAMINATION IN BAICË VILLAGE, KOSOVO

Kaltrina Jusufi[1] 0000-0002-5502-9893, Krenare Dibrani[1], Skender Demaku[1] 0000-0001-5582-5323, Edon Maliqi[2] 0000-0001-9888-7866

[1] Department of Chemistry, Faculty of Natural Science and Mathematics, University of Pristina, Kosovo
[2] Faculty of Architecture and Spatial Planning, UBT-Higher Education Institution, Pristine, Kosovo

ABSTRACT

Aim of the study

This study addresses the growing concern of water pollution in rural areas, where due to limited monitoring it can affect both human health and ecosystem stability. Contamination of freshwater resources has become an important environmental and public health issue, prompting the need for detailed local assessments. This study specifically assesses **the** pollution status and water quality in Baicë village, Kosovo, a rural area where limited monitoring can affect both human health and ecosystem stability.

Material and methods

Groundwater samples were analyzed for key physicochemical parameters and heavy metals, including Cr, Al, Cu, Fe, Mn, Ni, Pb, Zn, As, and Cd. The results revealed significantly elevated concentrations of lead at all sampling points (M1: 0.27 mg/L, M2: 0.25 mg/L, M3: 0.29 mg/L), exceeding recommended limits and indicating serious contamination. Elevated levels of other parameters, including COD and BOD_5, further suggest anthropogenic impacts on water quality.

Results and conclusions

These findings demonstrate that groundwater in the study area is unsuitable for direct consumption without prior treatment. Spatial analysis identified contamination hotspots, highlighting areas of increased environmental risk and supporting targeted remediation strategies.

Toxic element levels, including Cr, Al, Cu, Fe, Mn, Ni, Pb, Zn, As, and Cd, were analyzed using Inductively Coupled Plasma-Optical Emission Spectrometry (ICP–OES), providing additional insights into contamination. Furthermore, geospatial analysis using GIS and Inverse Distance Weighting (IDW) interpolation generated contamination hotspot maps, revealing spatial variations and helping identify priority areas for targeted remediation efforts. However, due to the limited number of sampling locations and temporal coverage, the results should be considered a preliminary assessment, and further monitoring is recommended to improve the understanding of groundwater contamination patterns in the study area.

Keywords: groundwater quality, heavy metals, geospatial analysis, GIS, water pollution, inductively coupled plasma optical emission spectrometry (ICP-OES)

✉e-mail: skender.demaku@uni-pr.edu

INTRODUCTION

Water pollution is a critical environmental issue that threatens ecosystems, human health, and the accessibility of clean water (Ejiohuo, 2024; Lin et al., 2022). Contaminants originating from industrial activities (Singh et al., 2024; Wang et al., 2024), agricultural and domestic sources (Rana et al., 2024; Yan et al., 2024), as well as untreated sewage (Al-Khuzaie et al., 2023) significantly degrade water quality.

These pollutants contribute to biodiversity loss and pose long-term health risks, including waterborne diseases and heavy metal toxicity (Ali et al., 2025; Endale et al., 2022; Agbasi et al., 2024; Tazri et al., 2025; Maliqi and Jusufi, 2024). Despite extensive global research, site-specific data remain limited in many regions, particularly in developing and transitional countries, where monitoring systems are often insufficient. This gap underscores the importance of localized studies that provide reliable baseline data for environmental assessment and management.

Access to safe drinking water remains a global challenge, requiring effective pollution control and sustainable water management practices (Mueller and Gasteyer, 2021; Majumdar et al., 2024). Increasing population growth and industrial demand further intensify pressure on water resources.

Addressing these challenges requires improved waste management, stricter regulatory enforcement, and increased public awareness (Awewomom et al., 2024). However, effective management strategies depend on accurate identification of contamination sources, quantitative evaluation of pollutants, and comparison with established international standards. In this context, studies integrating chemical analysis with spatial assessment approaches provide enhanced scientific insight and practical applicability.

In Kosovo, water quality management remains a significant challenge due to insufficient monitoring and weak enforcement of environmental regulations (Demaku et al., 2024; Maliqi et al., 2020). Pollution from agriculture, industry, and inadequate wastewater treatment continues to affect water resources, posing risks to both ecosystems and human health. In the Municipality of Lipjan, the impact of local pollution sources on groundwater quality requires particular attention.

The assessment of heavy metal concentrations in water and sediment provides essential information on contamination levels and associated environmental risks. Furthermore, geospatial analysis enables the identification of contamination patterns and potential dispersion pathways, supporting more effective environmental monitoring and decision-making (Maliqi et al., 2020).

The present study aims to evaluate the concentration and spatial distribution of selected heavy metals in water and sediment samples from Baicë village, Kosovo, and to assess their environmental significance through comparison with international guideline values (Khan et al., 2023; Aswal et al., 2024).

Specifically, the study: (1) determines the concentrations of Cr, Al, Cu, Fe, Mn, Ni, Pb, Zn, As, and Cd; (2) analyzes their spatial distribution across sampling locations; and (3) evaluates the measured values against international standards to identify potential environmental and health risks. The findings are expected to support environmental monitoring efforts, contribute to improved water resource management, and provide a scientific basis for future research and remediation strategies in the region.

Previous studies have demonstrated the effectiveness of multivariate statistical approaches, water quality indices, and health risk assessments in evaluating groundwater contamination (Agbasi and Egbueri, 2022; Egbueri and Agbasi, 2022; Singh et al., 2023). Additionally, statistical modeling and water quality indices have been widely applied to better understand contamination patterns and their controlling factors (Agbasi et al., 2022; Egbueri et al., 2023a; Egbueri et al., 2023b). These approaches provide a strong methodological foundation for interpreting groundwater quality and contamination processes.

Study zone

This study evaluates the water quality of resources in Baicë village, located in the municipality of Lipjan, Kosovo. Lipjan is situated approximately 17 km south of Pristine, within the central part of the Kosovo Plain. The Sitnica River flows through this region, supporting intensive agricultural activities and influencing local hydrological conditions. Baicë, located about 18–19 km west of Lipjan, is known for its natural groundwater sources, which are widely used for drinking and domestic purposes by local residents. Due to their environmental and socio-economic importance, these water sources were designated as a "Natural Monument" by the Municipal Assembly of Lipjan in March 2022. Geographically, Lipjan is located at approximately 42.52° N latitude and 21.13° E longitude and covers an area of about 422 km^2. The terrain is predominantly flat to gently undulating, with elevations ranging from 500 to 600 m above sea level. Geologically, the area lies within the Kosovo Basin and is mainly composed of Neogene sedimentary formations and alluvial deposits. These formations contribute to groundwater accumulation and influence the mobility and distribution of dissolved elements, including heavy metals.

The climate of the study area is of moderate continental type, characterized by warm summers (average July temperatures of 20–22°C) and cold winters (around 0°C in January), with annual precipitation ranging from 600 to 700 mm. These climatic and geological conditions play an important role in groundwater recharge processes as well as in the transport and dispersion of potential contaminants within the aquifer system.

MATERIALS AND METHODS

Study design and sampling

Water and sediment samples were collected in 2024 from three sampling stations in Baicë village, Municipality of Lipjan, Kosovo. Three replicates were taken for each sample type to ensure data reliability and reproducibility.

Water samples were collected from groundwater sources located in the study area, including a natural spring, which serves as an important drinking water source for the local population. Samples were collected approximately 20 cm below the surface using precleaned polyethylene bottles. Sediment samples were

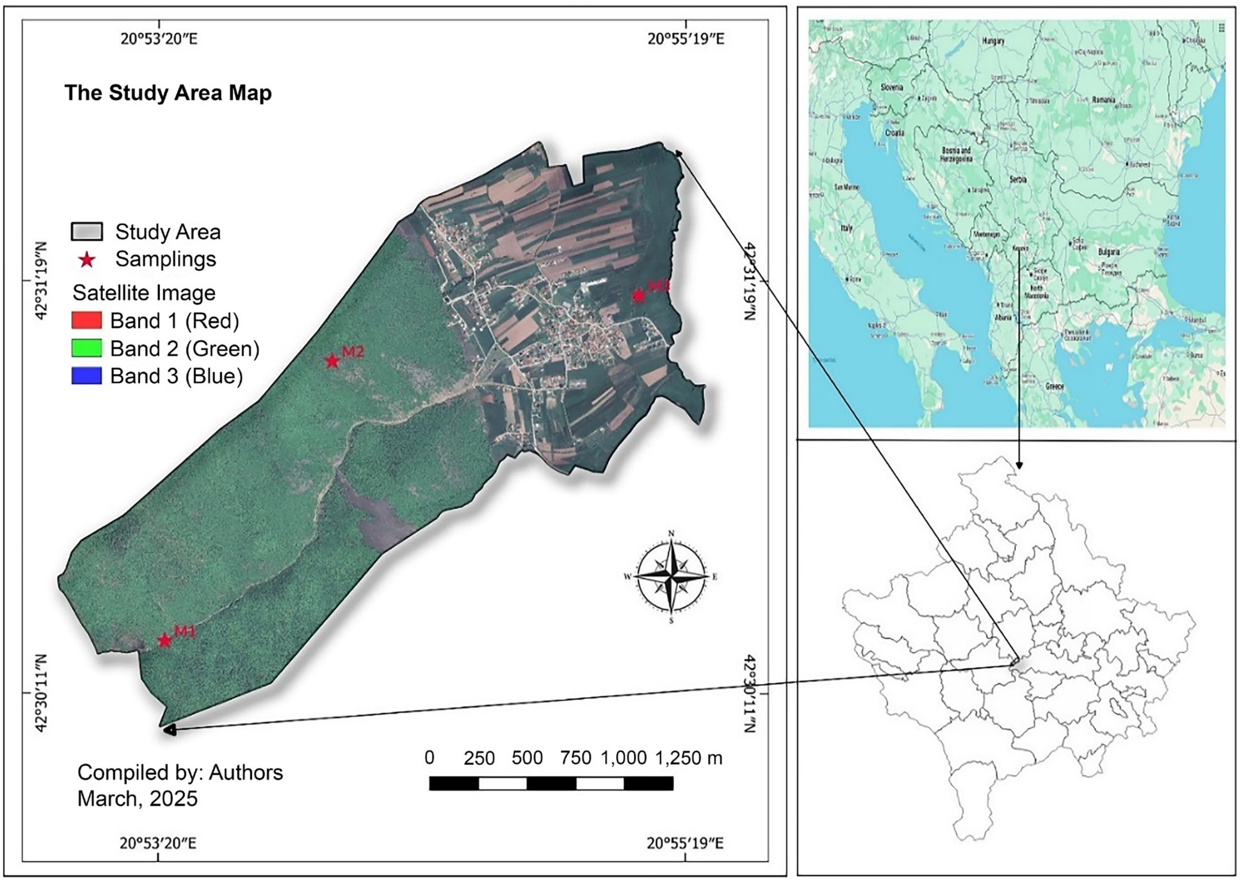

Fig. 1. Study area sampling locations (Map of Kosovo) (Source: Authors' own eleboration)

collected at the same locations as water samples using clean glass containers to ensure consistency between matrices.

All samples were properly labeled, sealed, and transported to the laboratory under cooled conditions (4°C) to preserve their physicochemical integrity until analysis.

Although IDW interpolation was applied to provide a preliminary visualization of groundwater quality patterns, the limited number of sampling locations (n = 3) constitutes an important constraint to spatial modeling.

Therefore, the generated maps should be interpreted as indicative rather than definitive representations of spatial variability. More robust geostatistical approaches such as kriging were not applied due to the insufficient sampling density. Future investigations involving a larger number of monitoring locations are recommended to improve interpolation accuracy and spatial reliability.

Sample preparation and digestion

For heavy metal analysis, water samples were collected in 2-liter glass bottles. The samples were filtered and transferred into Teflon containers. Prior to analysis, samples were acidified with 1 mL of HCl and 5 mL of HNO_3 and subjected to microwave digestion.

Sediment samples (2 g) were digested using 69% nitric acid (HNO_3) and heated at 130°C for 5 hours. After digestion, the samples were filtered, washed with 0.1 M HNO_3, and diluted with deionized water in accordance with U.S. EPA guidelines (U.S. EPA, 2017).

Instrumentation and analytical methods

Physicochemical parameters were measured using a Photo Lab® 7600 UV-VIS spectrophotometer. Heavy metal concentrations in water and sediment samples were determined using an ICP-OES instrument (PerkinElmer Optima 2100 DV).

High-purity standard solutions (99.98%) obtained from Merck, Germany, were used for instrument calibration and quality assurance.

Quality assurance and quality control (QA/QC) procedures were implemented throughout the analytical process. Instrument calibration was performed using multi-element standard solutions developed from certified reference materials. Calibration verification was performed periodically during the analytical sequence to ensure measurement stability. However, detailed instrumental performance parameters such as calibration coefficients (R^2), limits of detection (LOD), and limits of quantification (LOQ) were not available for inclusion in this study.

The analytical precision was maintained within acceptable limits, and all laboratory procedures followed standard ICP-OES quality control protocols.

Procedural blanks were analyzed together with samples to verify the absence of contamination during sample preparation and analysis. All measurements were performed in triplicate, whereas the reported values represent average concentrations. The analytical precision was maintained within acceptable limits, with relative standard deviations below 5%.

Quality control and data analysis

All analyses were performed in triplicate, and results are expressed as mean ± standard deviation. Descriptive statistical analysis, including mean and standard deviation, was conducted using Microsoft Excel.

Measured concentrations of heavy metals were expressed in mg/L for water samples and mg/kg for sediment samples. The obtained values were compared with permissible limits established by U.S. EPA standards to assess contamination levels.

Spatial data collection

Geographic coordinates of the sampling locations were recorded using GNSS technology through the KOPOS (Kosova Positioning System). The coordinates were used for spatial analysis and map generation. Inverse Distance Weighting (IDW) interpolation was applied in QGIS to provide a preliminary visualization of groundwater quality patterns. Due to the limited number of sampling locations (n = 3), the resulting interpolation maps should be interpreted as indicative representations of spatial variability rather than accurate spatial predictions. No advanced geostatistical methods, such as kriging, were applied due to the available sampling density being insufficient.

RESULTS AND DISCUSSION

Physicochemical properties of water

The physical and chemical properties of water provide important information for understanding pollution levels, water safety, and ecological conditions (Zou et al., 2024). Parameters such as temperature, dissolved oxygen, pH, and nutrient concentrations can serve as indicators of both natural processes and anthropogenic impacts.

Table 1 presents the physicochemical characteristics of water samples from Baicë village, Lipjan Municipality, including minimum, maximum, and average values across the three sampling points (M1, M2, and M3).

The results show that water temperature ranged from 24.6°C to 25.7°C, which is typical for freshwater systems during warm seasonal conditions. Electrical conductivity (EC) was highest at M2 (630 µS/cm), indi-

Table 1. Physical and chemical properties of water samples from Baicë village, Lipjan Municipality, including minimum, maximum, and average concentrations, as well as WHO/EU guideline values

Parameter	M1	M2	M3	Min	Max	Average	WHO/EU
Temp water (°C)	24.9	25.7	24.6	24.6	25.7	25.1	–
DO (mg/L)	1.16	1.14	1.13	1.13	1.16	1.14	–
O_2 (%)	11.5	16.5	8.64	8.64	16.5	12.2	–
EC (µS/cm)	576	630	544	544	630	583	2500
pH	6.44	6.81	6.87	6.44	6.87	6.71	6.5–9.5
TDS (mg/L)	150	128	170	128	170	149	1000
Cl^- (mg/L)	0.25	0.23	0.21	0.21	0.25	0.23	250
COD (mg/L)	18.3	15.6	19.1	15.6	19.1	17.7	–
BOD_5 (mg/L)	11.2	14.9	16.1	11.2	16.1	14.1	–
P total (mg/L)	0.165	0.154	0.169	0.154	0.169	0.16	–
NO_3^- (mg/L)	0.6	0.7	0.6	0.6	0.7	0.63	50
N total (mg/L)	0.21	0.31	0.29	0.21	0.31	0.27	–
NH_4^+ (mg/L)	0.06	0.05	0.08	0.05	0.08	0.06	0.5
NO_2^- (mg/L)	0.6	0.7	0.6	0.6	0.7	0.63	0.5
N inorganic (mg/L)	0.17	0.23	0.22	0.17	0.23	0.21	–
$SO4_2^-$ (mg/L)	11.1	11.3	12.1	11.1	12.1	11.5	250
$PO4_3^-$ (mg/L)	0.03	0.033	0.036	0.03	0.036	0.03	–
TOC (mg/L)	6.3	7.8	8.3	6.3	8.3	7.47	–
Color	without	transparent	transparent	–	–	–	acceptable
TMS (mg/L)	21	19.9	55.3	19.9	55.3	32.1	–
F^- (mg/L)	0.1	0.2	0.3	0.1	0.3	0.2	1.5
Total hardness (°dH)	16.36	17.21	18.65	16.36	18.65	17.4	–
Ca hardness (°dH)	5.6	4.79	5.35	4.79	5.6	5.25	–
Mg hardness (°dH)	10.7	12.4	13.3	10.7	13.3	12.1	–
Ca (mg/L)	18.8	19.4	21.3	18.8	21.3	19.8	–
Mg (mg/L)	19.9	21.6	19.8	19.8	21.6	20.4	–
MA (mg/L)	12.13	11.31	12.41	11.31	12.41	12	–
HCO_3^- (mg/L)	121.22	154.36	149.51	121.22	154.36	142	–
Turbidity (NTU)	3.1	3.3	3.5	3.1	3.5	3.3	5
$KMnO_4$ (mg/L)	2.36	3.65	5.43	2.36	5.43	3.81	–
SUR (mg/L)	<0.2	<0.2	<0.2	–	–	–	0.5
Temp air (°C)	29.6	29.7	30.1	29.6	30.1	29.8	–

Note: Guideline values are based on the World Health Organization (WHO) and EU Drinking Water Directive. Parameters without specified limits (—) are not regulated or do not have health-based guideline values. All concentrations are expressed in mg/L, except where otherwise indicated. Sampling points M1–M3 represent three monitoring locations.

cating increased ionic content. Dissolved oxygen (DO) varied between 1.13 and 1.16 mg/L, suggesting relatively low oxygenation conditions, particularly at M3.

Total dissolved solids (TDS) were highest at M3 (170 mg/L), indicating a higher presence of dissolved substances and potential localized contamination. The pH values ranged from 6.44 to 6.87, indicating slightly acidic to near-neutral conditions, which are generally acceptable for natural waters.

Chemical Oxygen Demand (COD) and Biological Oxygen Demand (BOD_5) showed elevated values, particularly at M3 (COD: 19.1 mg/L; BOD_5: 16.1 mg/L), indicating increased organic pollution. Similarly, elevated phosphate (PO_4^{3-}) concentrations and turbidity suggest potential nutrient enrichment and possible eutrophication risks.

In contrast, chloride, sulfate, fluoride, and hardness parameters remained relatively stable across all sampling points, indicating consistent background geochemical conditions. No significant surfactants were detected, suggesting limited detergent or industrial contamination.

Overall, the results indicate that M3 exhibits comparatively higher levels of pollution, likely influenced by anthropogenic activities. These findings are consistent with previous studies in similar hydro geological settings (Lu et al., 2024; Chen et al., 2024), highlighting the need for continuous monitoring and targeted environmental management.

Heavy metals in water

The concentrations of heavy metals in water samples are presented in Table 2. The results indicate that most elements (Cr, Al, Cu, Fe, Ni, Zn, As, and Cd) were present at low and relatively stable concentrations across all sampling locations, with minor spatial variability observed among sampling points.

The concentrations of Cr ranged from 0.048 to 0.049 mg/L, while Al remained constant at 0.10 mg/L. Cu concentrations varied between 0.25 and 0.29 mg/L, and Fe ranged from 0.04 to 0.05 mg/L. Overall, these elements remained within WHO guideline values, suggesting no immediate exceedance-related health risk.

The concentrations of Mn ranged from 0.40 to 0.50 mg/L, with the highest value reaching the WHO guideline limit of 0.50 mg/L, suggesting the need for continued monitoring of manganese levels in groundwater.

The most concerning finding was related to Pb concentrations, which ranged from 0.25 to 0.29 mg/L.

Table 2. The presence of heavy metals in water samples (mg/L)

Elements (mg/L)	M1	M2	M3	StDev	Min	Max	WHO maximum allowable limits	Compliance with WHO/ EU standards
Cr	0.048	0.049	0.049	0.0006	0.048	0.049	0.05	complies (below limit)
Al	0.1	0.1	0.1	0.0000	0.1	0.1	0.2	complies
Cu	0.28	0.25	0.29	0.0208	0.25	0.29	2	complies
Fe	0.05	0.04	0.05	0.0058	0.04	0.05	0.2	complies
Mn	0.4	0.4	0.5	0.0577	0.40	0.5	0.5	complies (M3 at the limit)
Ni	0.02	0.02	0.02	0.0000	0.02	0.02	0.02	complies (at the limit)
Pb	0.27	0.25	0.29	0.0200	0.25	0.29	0.01	exceeds WHO/EU limit
Zn	0.05	0.05	0.05	0.0000	0.05	0.05	3	complies
As	0.006	0.005	0.007	0.0010	0.005	0.007	0.01	complies
Cd	0.001	0.002	0.002	0.0006	0.001	0.002	0.005	complies

Note: Heavy metal concentrations (mg/L) were determined at three sampling points (M1–M3). Standard deviation (StDev), minimum (Min), and maximum (Max) values are presented. The measured concentrations were evaluated against the World Health Organization (WHO) drinking water guidelines and the European Union Drinking Water Directive (EU, 2021). The compliance assessment indicates whether the measured concentrations meet the WHO/EU maximum allowable limits.

All sampling locations exceeded the WHO guideline value of 0.01 mg/L by more than twenty-fold, indicating significant contamination and a potential risk to human health.

Such elevated Pb levels may be associated with anthropogenic sources including agricultural inputs, traffic-related atmospheric deposition, corrosion of plumbing infrastructure, and improper waste management practices.

Overall, while most analyzed heavy metals remained within acceptable limits, the elevated Pb concentrations indicate localized groundwater contamination and highlight the need for targeted mitigation measures, continued monitoring, and further source identification studies.

Heavy metals in sediment

Table 3 presents the concentrations of heavy metals in sediment samples and their comparison with EPA sediment quality guidelines.

The results show that Cr (0.79–0.99 mg/kg), Al (0.69–0.97 mg/kg), Fe (0.95–0.99 mg/kg), and Zn (1.78–1.98 mg/kg) exhibited relatively stable and low concentrations across all sampling points, indicating generally low spatial variability and no evidence of elevated contamination levels.

The concentrations of Cu, Mn, and Ni exhibited moderate variability among the sampling locations; however, all measured values remained substantially below the corresponding EPA sediment quality guideline limits, indicating a low level of sediment contamination by these elements.

Pb concentrations ranged from 2.26 to 4.23 mg/kg, remaining well below the EPA sediment quality guideline value of 35.8 mg/kg. Although these concentrations do not indicate an immediate ecological risk, the elevated value observed at M3 sampling location may reflect localized anthropogenic influences and warrants continued environmental monitoring.

Similarly, As and Cd were detected at relatively low concentrations, ranging from 0.008 to 0.011 mg/kg and 0.006 to 0.021 mg/kg, respectively. All measured values were considerably lower than internationally accepted sediment quality thresholds, suggesting minimal anthropogenic enrichment and low ecological risk under current conditions.

Overall, the sediment quality assessment indicates that heavy metal contamination in the investigated

Table 3. The presence of heavy metals in sediment samples measured (mg/kg)

Elements (mg/kg)	M1	M2	M3	StDev	Min	Max	EPA maximum allowable limits	Compliance with EPA standards
Cr	0.79	0.95	0.99	0.1058	0.79	0.99	52	complies
Al	0.69	0.88	0.97	0.1429	0.69	0.97	–	not regulated by EPA
Cu	0.93	0.96	1.21	0.1537	0.93	1.21	48	complies
Fe	0.99	0.95	0.99	0.0231	0.95	0.99	–	not regulated by EPA
Mn	0.21	0.29	0.44	0.1168	0.21	0.44	–	not regulated by EPA
Ni	0.29	0.27	0.48	0.1168	0.27	0.48	48	complies
Pb	2.26	2.68	4.23	1.0380	2.26	4.23	35.8	complies
Zn	1.78	1.89	1.98	0.1002	1.78	1.98	121.1	complies
As	0.008	0.009	0.011	0.0015	0.008	0.011	9	complies
Cd	0.006	0.008	0.021	0.0081	0.006	0.021	1.2	complies

Note: Heavy metal concentrations (mg/kg) were determined at three sampling points (M1–M3). Standard deviation (StDev), minimum (Min), and maximum (Max) values are presented. The measured concentrations were evaluated against the U.S. Environmental Protection Agency (EPA, 2003), sediment quality guidelines. The compliance assessment indicates whether the measured concentrations meet the EPA maximum allowable limits.

sediments is generally low, with all analyzed elements remaining below the established regulatory guideline values.

These findings suggest limited anthropogenic impact on sediment quality during the monitoring period, although localized variability (particularly at M3) should be considered in future monitoring campaigns.

Multivariate and spatial analysis

Multivariate statistical analysis, including correlation analysis and Principal Component Analysis (PCA), was used to evaluate relationships among heavy metals.

The PCA results (Fig. 2 and 3) indicate that the first few principal components explain the majority of the variance, suggesting that certain elements may share common geochemical behavior or potential common sources.

However, given the limited number of sampling locations (n = 3), these patterns should be interpreted cautiously.

Principal Component Analysis (PCA) and Hierarchical Cluster Analysis (HCA) were applied primarily as exploratory statistical tools to identify potential relationships among the analyzed variables.

Due to the very small dataset and limited spatial coverage, the results are not intended to provide statistically robust source apportionment. Instead, they serve to highlight possible tendencies and preliminary associations among variables.

Therefore, the findings should be considered indicative and hypothesis-generating rather than confirmatory.

Geospatial analysis of groundwater quality

It should be emphasized that the spatial distribution maps generated in this study are intended to provide preliminary visualization of contamination patterns rather than precise spatial predictions.

Because the interpolation was based on only three sampling locations (n = 3), the resulting surfaces should be interpreted with caution as indicative representations of spatial trends rather than accurate spatial estimations. Nevertheless, the generated maps remain useful for identifying potential hotspots and guiding future monitoring efforts.

Geospatial analysis of groundwater quality was conducted using QGIS and Inverse Distance Weighting (IDW) interpolation to examine the spatial dis-

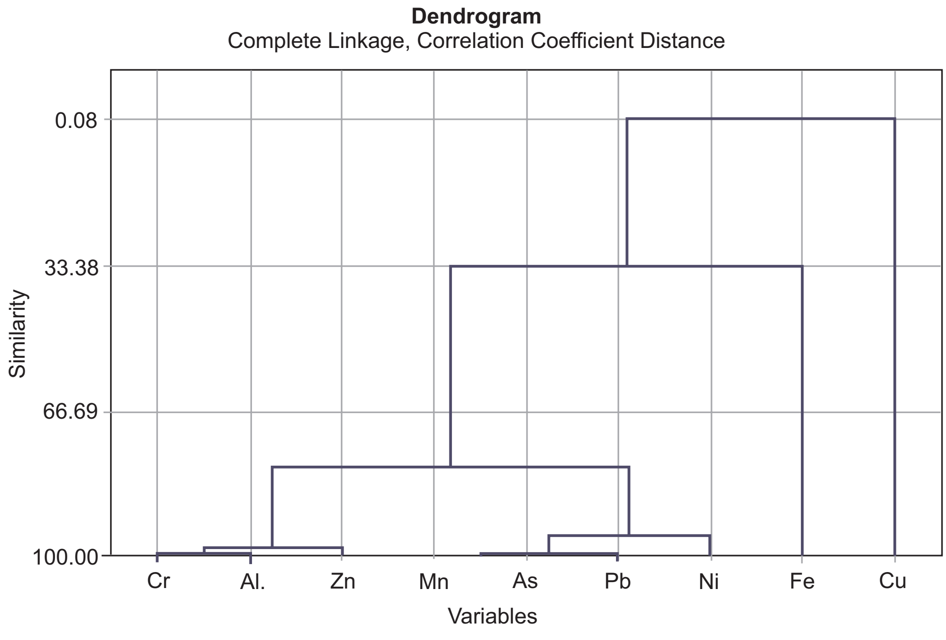

Fig. 2. Dendrogram of heavy metal distribution in water resources of Baicë village, Lipjan Municipality, Kosovo (Source: Authors' own eleboration)

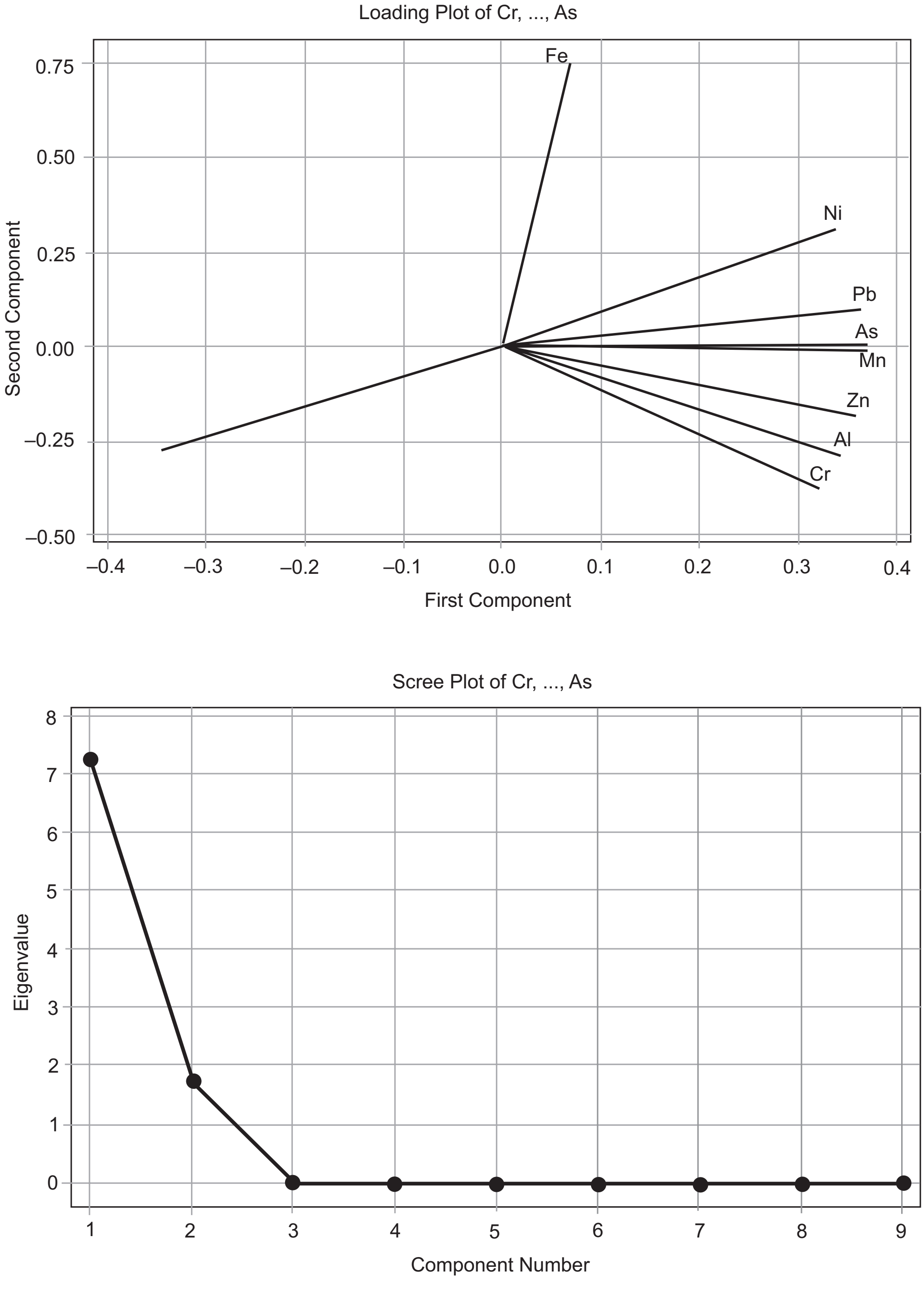

Fig. 3. Principal Component Analysis (PCA) and Scree Plot of heavy metals in water samples (Cr–As): a. Principal component analyses; Cr… As; b. Scree Plot of Cr… As (Source: Authors' own eleboration)

tribution of key water quality parameters across the study area.

The generated thematic maps, with a spatial resolution of 10 m, illustrate apparent spatial variability, which may be influenced by both natural hydrogeochemical processes and localized anthropogenic impacts.

The application of QGIS in environmental studies has been widely recognized as an effective approach for generating spatial representations of environmental data (Zhang et al., 2023; Ahmed et al., 2016; Aktar et al., 2017).

The IDW interpolation method was employed to transform discrete sampling data into continuous spatial surfaces. This method assigns greater weight to nearby data points, allowing estimation of parameter values in unsampled locations.

In groundwater studies, IDW is particularly useful in areas with limited sampling density, as it provides a preliminary approximation of spatial variability, although it does not replace robust geostatistical methods when sufficient data are available.

The spatial analysis focused on key parameters, including Total Suspended Solids (TSS), Chemical Oxygen Demand (COD), Biological Oxygen Demand (BOD_5), Lead (Pb), Manganese (Mn), Total Organic Carbon (TOC), and Total Phosphorus (TP). These parameters serve as indicators of both organic and inorganic pollution and reflect potential influences from anthropogenic activities such as agriculture, urban runoff, and localized emission sources.

The IDW-generated maps suggest the presence of potential spatial hotspots, with elevated concentrations of selected parameters observed in specific areas of the study site. However, due to the limited dataset, these patterns should be interpreted as indicative rather than definitive. These findings highlight the value of spatial visualization in supporting preliminary environmental assessment and guiding future, more detailed monitoring designs.

The distribution maps (Fig. 4–10) illustrate the spatial variability of TSS, COD, BOD_5, Pb, Mn, TOC, and TP, providing a visual overview of groundwater quality patterns across the study area and supporting the identification of areas requiring further investigation.

Chemical Oxygen Demand (COD) is a key indicator of organic pollution and oxygen demand in aquatic systems (WHO, 2021). COD values vary depending on water type: in drinking water, concentrations are typically below 5 mg/L, while surface waters generally range from 10 to 50 mg/L. Values exceeding 50 mg/L indicate pollution, whereas levels above 100 mg/L are associated with heavily contaminated conditions.

In wastewater systems, COD values commonly range between 100 and 500 mg/L; however, effective treatment is required to reduce COD to below 100 mg/L prior to environmental discharge. Elevated COD levels reflect a high presence of oxidizable organic matter, which can significantly degrade water quality and negatively impact aquatic ecosystems and human health (Che et al., 2024).

The COD values obtained in this study (16.3–18.4 mg/L) fall within the range typical for slightly to moderately impacted surface waters. Although these values are well below wastewater-related thresholds, they indicate the presence of organic matter inputs.

Therefore, while the water does not exhibit severe organic pollution, it may not be considered suitable for direct consumption without appropriate treatment, in accordance with drinking water safety guidelines.

Biochemical Oxygen Demand (BOD_5) is a key parameter used to assess organic pollution in water, as it measures the amount of dissolved oxygen required by microorganisms to decompose biodegradable organic matter. Elevated BOD_5 values are commonly associated with increased organic loading, often originating from anthropogenic activities such as wastewater discharge, agricultural runoff, and the presence of degradable organic compounds, which can adversely affect aquatic ecosystems by reducing dissolved oxygen availability (Lv et al., 2024).

The BOD_5 thresholds vary depending on water type and intended use. For surface waters, values between 1 and 5 mg/L are generally considered indicative of clean water conditions, whereas values exceeding 5 mg/L suggest organic pollution, and levels above 10 mg/L indicate severe contamination. In contrast, untreated wastewater typically exhibits substantially higher BOD_5 values, often exceeding 100 mg/L, and therefore requires treatment prior to environmental discharge.

The BOD_5 values obtained in this study indicate the presence of organic pollution in the analyzed water samples. Elevated BOD_5 levels suggest a considerable

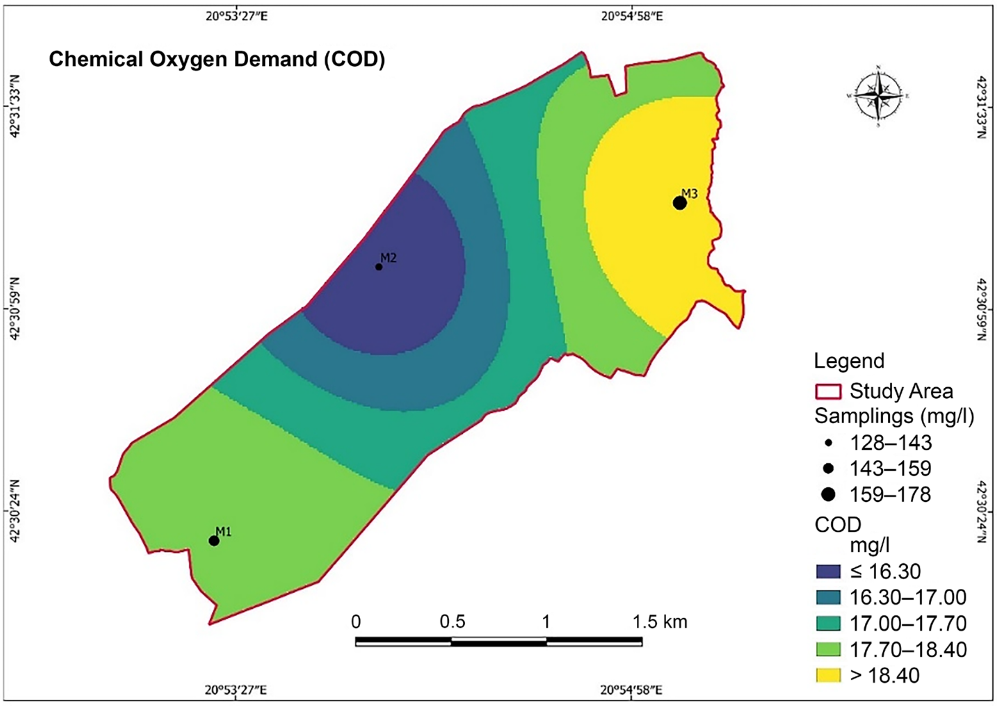

Fig. 4. Spatial distribution of COD concentrations generated using IDW interpolation in Baicë village, Lipjan Municipality, Kosovo (Source: Authors' own eleboration)

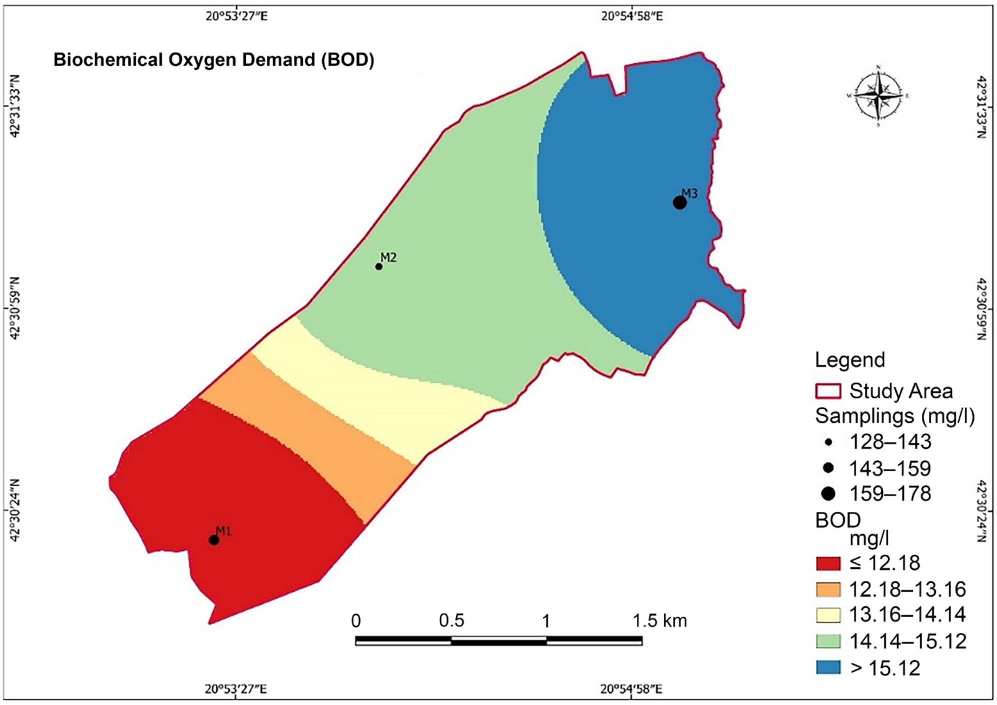

Fig. 5. Spatial distribution of BOD_5 concentrations generated using IDW interpolation in Baicë village, Lipjan Municipality, Kosovo (Source: Authors' own eleboration)

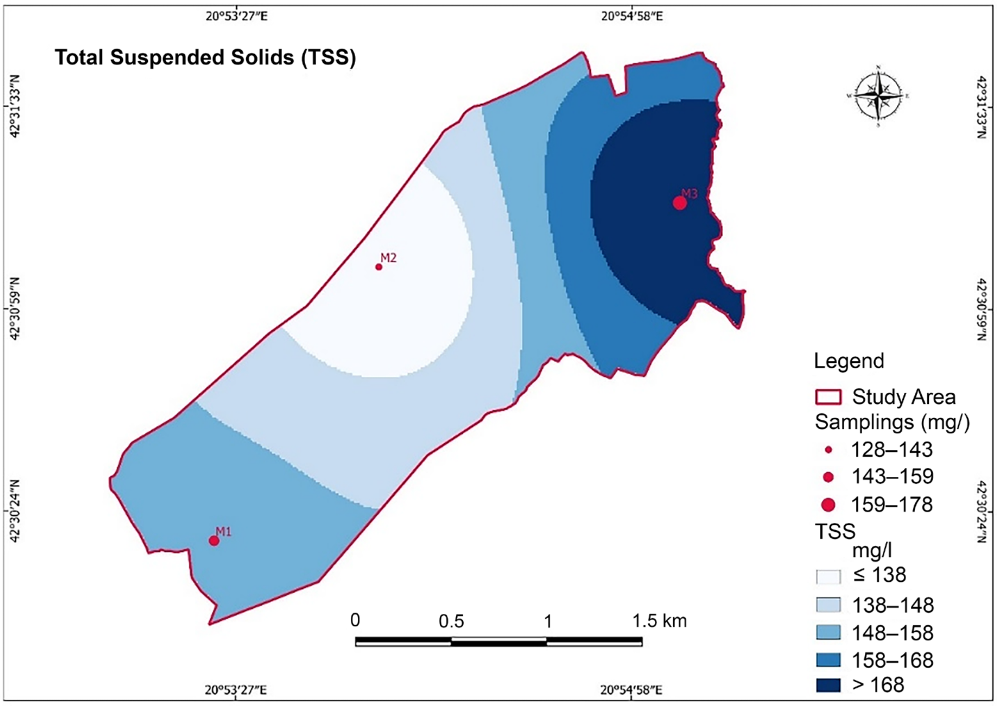

Fig. 6. Spatial distribution of TSS concentrations generated using IDW interpolation in Baicë village, Lipjan Municipality, Kosovo (Source: Authors' own eleboration)

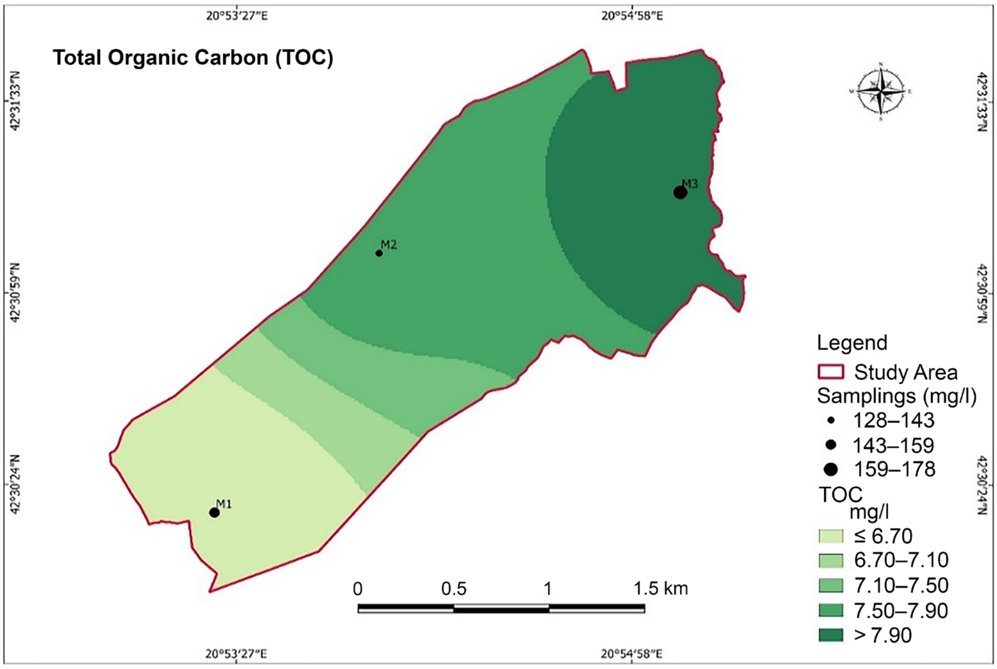

Fig. 7. Spatial distribution of TOC concentrations generated using IDW interpolation in Baicë village, Lipjan Municipality, Kosovo (Source: Authors' own eleboration)

amount of biodegradable organic matter, which may contribute to oxygen depletion and negatively affect aquatic life. These findings are consistent with anthropogenic influence in the study area and indicate that the water requires treatment prior to direct human consumption.

Total Suspended Solids (TSS) represents an important indicator of water quality, reflecting the concentration of particulate matter suspended in water bodies. TSS levels vary depending on hydrogeological conditions and anthropogenic influences (Aktar et al., 2017).

Guideline values for TSS differ depending on water use; in general, lower concentrations are associated with better water clarity and reduced particulate pollution, while elevated levels indicate increased turbidity and potential environmental stress in aquatic systems.

Elevated TSS concentrations can reduce light penetration, increase turbidity, and negatively affect photosynthetic activity, thereby altering aquatic ecosystem functioning. Values exceeding approximately 30 mg/L are commonly associated with degraded surface water quality conditions.

The results obtained in this study indicate elevated TSS concentrations in the analyzed samples**,** suggesting the presence of suspended particulate matter in the groundwater system. These particles may originate from natural processes such as soil erosion, as well as anthropogenic activities including agricultural runoff and inadequate land management practices.

Overall, the observed TSS levels indicate reduced water clarity in parts of the study area and highlight the influence of surface-derived inputs on groundwater quality.

Total Organic Carbon (TOC) is a comprehensive indicator used to quantify the total amount of organic carbon present in the water, including both dissolved and particulate organic matter. It provides a reliable estimate of the overall organic pollution load in aquatic systems by measuring the carbon content of organic compounds (Adjovu et al., 2023; A.P.H. Association (2005).

Although the World Health Organization (WHO) does not establish a specific guideline value for TOC in drinking water, concentrations below 1 mg/L are generally considered acceptable to avoid issues related to taste and odor.

The Environmental Protection Agency (EPA) recommends that TOC levels in surface water remain below 10 mg/L to maintain ecological balance. For treated wastewater, TOC concentrations should be reduced to below 50 mg/L prior to discharge into the environment.

The TOC results obtained in this study indicate moderately elevated levels of organic carbon in the analyzed samples. Such values suggest the presence of organic matter inputs, which may originate from anthropogenic sources such as agricultural runoff, domestic waste, or localized human activities.

Overall, the observed TOC concentrations indicate minor to moderate organic enrichment in parts of the study area, suggesting that while severe contamination is not evident, the water quality is influenced by external organic inputs and may require treatment prior to direct consumption.

Excessive phosphorus concentrations in aquatic systems are a major driver of eutrophication, a process that can lead to algal blooms, oxygen depletion, and significant harm to aquatic ecosystems. The Environmental Protection Agency (EPA) recommends that phosphorus levels in freshwater should remain below 0.1 mg/L to protect ecological integrity.

Although the World Health Organization (WHO) does not specify a guideline value for phosphorus in drinking water, maintaining low concentrations is considered essential for preserving overall water quality.

The results obtained in this study indicate that phosphorus concentrations in several sampling locations exceed the recommended threshold of 0.1 mg/L.

Such elevated levels suggest a potential risk of eutrophication, likely associated with anthropogenic inputs such as agricultural runoff, domestic wastewater, and other nutrient sources.

These findings highlight the potential environmental impact of nutrient enrichment and emphasize the need for proper water quality management in the region (Aguilar-Torrejón et al., 2023; Zhang et al., 2021).

Sources of lead contamination include agricultural activities involving the use of fertilizers and pesticides, atmospheric deposition from traffic-related emissions, corrosion of aging plumbing systems, improper waste disposal practices, and natural geochemical weathering processes.

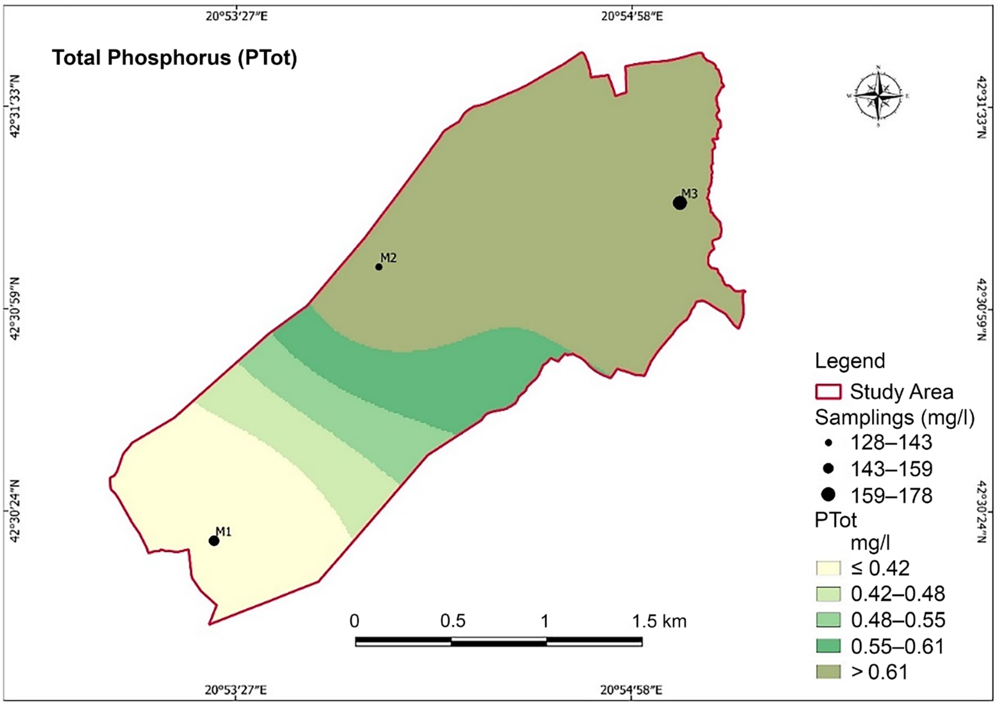

Fig. 8. Spatial distribution of P (tot) concentrations generated using IDW interpolation in Baicë village, Lipjan Municipality, Kosovo (Source: Authors' own eleboration)

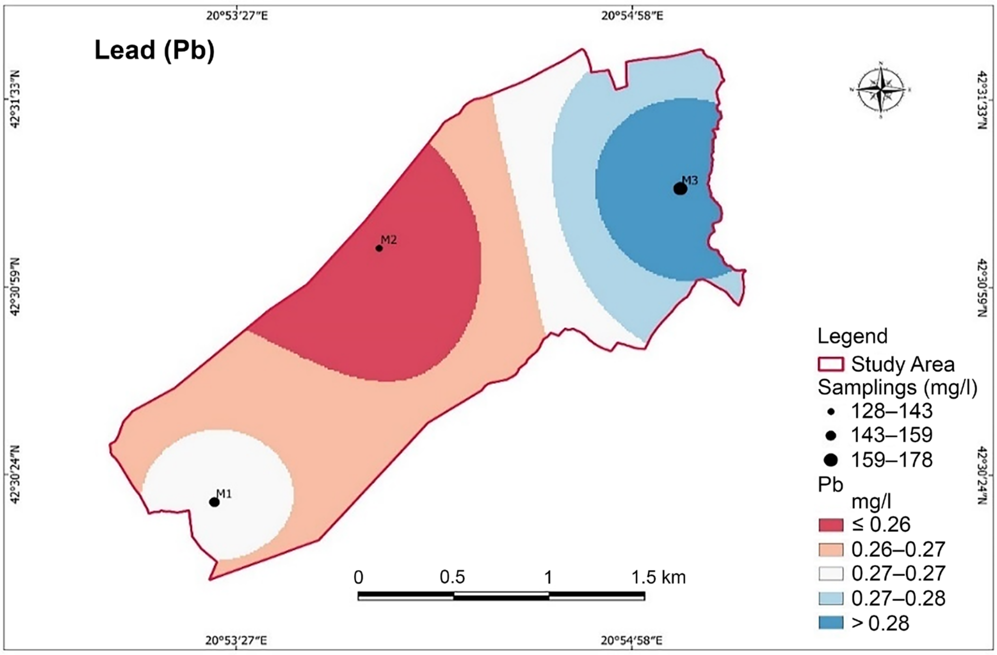

Fig. 9. Spatial distribution of Pb concentrations generated using IDW interpolation based on groundwater samples collected at three monitoring locations in Baicë village, Lipjan Municipality, Kosovo (Source: Authors' own eleboration)

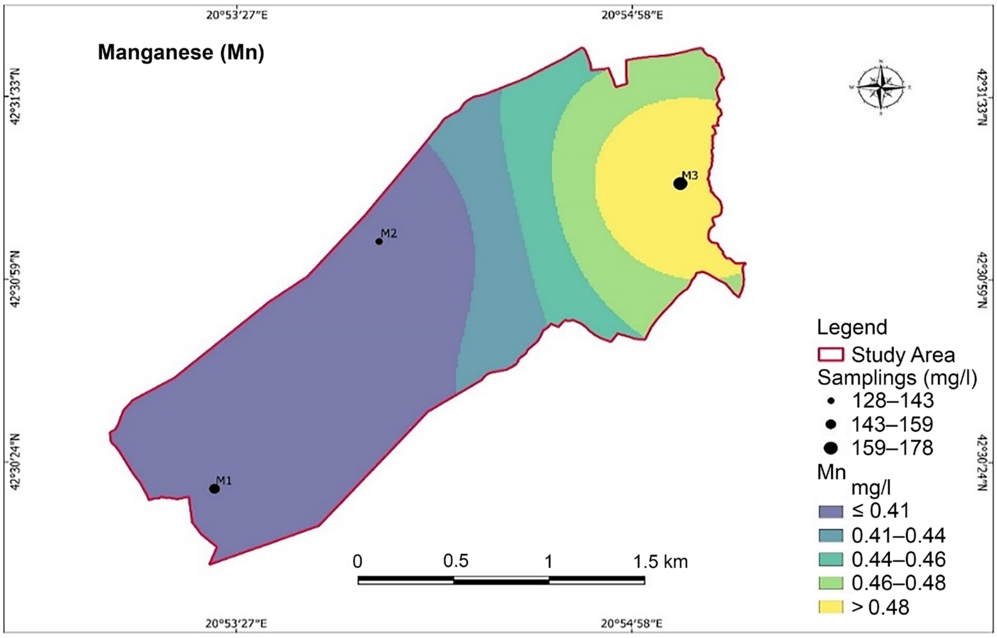

Fig. 10. Spatial distribution of Mn concentrations generated using IDW interpolation in Baicë village, Lipjan Municipality, Kosovo (Source: Authors' own eleboration)

Among the analyzed elements, Pb concentrations exceeded the WHO guideline value (0.01 mg/L) at all sampling locations, indicating significant groundwater contamination and a potential risk to public health.

These elevated levels warrant attention and highlight the need for further investigation and monitoring.

Therefore, additional monitoring campaigns and analytical verification are recommended to confirm the persistence of contamination and to identify its primary sources. The findings highlight the need for appropriate management and mitigation measures aimed at reducing lead contamination and protecting groundwater resources in the study area.

Manganese (Mn) is a naturally occurring metal that can enter water systems through both natural geochemical processes and anthropogenic activities such as industrial discharges.

At elevated concentrations, manganese can negatively affect water quality, cause aesthetic issues such as staining of plumbing fixtures, and pose potential health risks, particularly with long-term exposure.

Regulatory guidelines have been established to control manganese levels in drinking water. The Environmental Protection Agency (EPA) recommends a maximum concentration of 0.05 mg/L, while the World Health Organization (WHO) sets a higher guideline value of 0.4 mg/L to minimize potential health and aesthetic concerns.

The manganese concentrations measured in this study ranged from 0.41 mg/L to 0.48 mg/L, exceeding the WHO guideline value at all sampling locations and the EPA limit in all cases, indicating elevated manganese levels in the groundwater system (Egbueri et al., 2022; Panneerselvam and Priya, 2021).

These elevated levels indicate potential implications for water quality and usability, particularly for drinking and domestic purposes.

While not necessarily indicative of acute toxicity, such concentrations suggest that the water may require treatment prior to consumption and that continued monitoring is necessary to assess temporal stability and source contributions.

CONCLUSIONS

This study evaluated groundwater quality in Baicë village, Lipjan Municipality, Kosovo, during the summer and autumn of 2024 through the analysis of key physicochemical parameters and potentially toxic elements (PTEs). Most physicochemical parameters, including pH, electrical conductivity, salinity, total dissolved solids (TDS), and major ions, remained within the permissible limits established by the World Health Organization (WHO), indicating generally acceptable groundwater quality conditions.

Nevertheless, notable spatial variations were observed among the sampling locations. The upstream stations (M1 and M2) exhibited relatively stable water quality characteristics, whereas the downstream station (M3) showed signs of deterioration, most likely associated with anthropogenic influences such as agricultural runoff and potential inputs from domestic or localized wastewater discharges.

Among the analyzed potentially toxic elements, Pb and Mn were identified as the most environmentally relevant contaminants due to their elevated concentrations and potential implications for groundwater quality.

In particular, Pb concentrations exceeded the WHO guideline value (0.01 mg/L) at all sampling locations, indicating significant contamination and a potential risk to public health, while Mn levels also exceeded recommended guideline values.

The geospatial analysis performed using GIS and IDW interpolation provided a preliminary visualization of the spatial distribution of contaminants and assisted in identifying areas of increased environmental concern. In addition, multivariate statistical analyses, including Principal Component Analysis (PCA) and Hierarchical Cluster Analysis (HCA), were applied as exploratory tools to evaluate relationships among water quality variables and potential contamination patterns.

Several limitations should be acknowledged. First, the study was based on only three groundwater sampling locations, which restricts the spatial representativeness of the results and limits the reliability of spatial interpolation. Second, sampling was conducted during only two seasonal periods, preventing a comprehensive assessment of long-term temporal variability.

Therefore, the findings should be interpreted as a preliminary assessment of groundwater quality conditions in Baicë village and they need to be confirmed through broader spatial and temporal investigations.

Future studies should include a larger number of monitoring locations, extended seasonal coverage, as well as long-term monitoring programs to improve the understanding of groundwater contamination dynamics and to strengthen the reliability of spatial and statistical analyses.

Overall, the results highlight the importance of continuous groundwater quality monitoring and the implementation of appropriate management and mitigation measures to reduce contamination risks, protect water resources, and safeguard public health in the study area.

An additional limitation of the study is that detailed analytical validation parameters, including calibration coefficients (R^2), limits of detection (LOD), and limits of quantification (LOQ), were not available for reporting. Although standard QA/QC procedures were implemented during ICP-OES analysis, the absence of these validation parameters should be considered when interpreting the analytical results.

ACKNOWLEDGMENTS

This research was supported by the University of Prishtina and the Ministry of Education, Science, Technology and Innovation of the Republic of Kosovo.

REFERENCES

Abba, S.I., Egbueri, J.C., Benaafi, M., Usman, J., Usman, A.G., Aljundi I.H. (2023). Fluoride and nitrate enrichment in coastal aquifers of the Eastern Province, Saudi Arabia: The influencing factors, toxicity, and human health risks. Chemosphere, 336, 139083.

Adjovu, G.E., Stephen, H., James, D., Ahmad, S. (2023). Measurement of Total Dissolved Solids and Total Suspended Solids in Water Systems: A Review of the Issues, Conventional, and Remote Sensing Techniques. Remote Sens., 15, 3534.

Agbasi, J.C., Ezugwu, A.L., Omeka, M.E., Ucheana, I.A., Aralu, C.C., Abugu, H.O., Egbueri, J.C. (2024). More about making profits or providing safe drinking water? A state-of-the-art review on sachet water contamination in Nigeria. J. Environ. Sci. Health Part C, 42(4), 255–297.

Ahmed, K., Rahman, A., Sarkar, M., Islam, J., Jahan, I., Moniruzzaman, M., Bhoumik, N. (2016). Assessment on the level of contamination of Turag River at Tongi area in Dhaka Bangladesh. J. Sci. Ind. Res., 51(3), 193–202.

Aktar, P., Moonajilin, M.S., Sabrina, M. (2017). Assessment of water quality status of Turag River due to industrial effluent. Int. J. Eng. Inform. Syst., 1(6), 105–118.

Al-Khuzaie, M.M., Abdul Maulud, K.N., Wan Mohtar, W.H.M., Yaseen, Z.M. (2023). Assessment of untreated wastewater pollution and heavy metal contamination in the Euphrates river. Environ. Pollut. Bioavail., 36(1).

Ali, N.M., Khan, M.K., Mazhar, B., Madiha, M. (2025). Impact of water pollution on waterborne infections: Emphasizing microbial contamination and associated health hazards in humans. Discov. Water, 5, 19.

A.P.H. Association (2005). Standard methods for the examination of water and wastewater. American Public Health Association (APHA), Washington.

Aguilar-Torrejón, J.A., Balderas-Hernández, P., Roa-Morales, G., Barrera-Díaz, C.E., Rodríguez-Torres, I., Torres-Blancas, T. (2023). Relationship, importance, and development of analytical techniques: COD, BOD, and TOC in water. An overview through time. SN Appl. Sci., 5, 118.

Aswal, R.S., Prasad, M., Singh, J., Singh, H., Shrivastava, U., Wadhwa, M., Pandey, O.P., Egbueri, J.C. (2024). Spatial analysis and soft computational modeling for hazard assessment of potential toxic elements in potable groundwater. Scientific Reports, 14, 25473. https://doi.org/10.1038/s41598-024-76147-w

Awewomom, J., Dzeble, F., Takyi, Y.D., Ashie, W.B., Osei Ettey, E.N.Y., Afua, P.E., Sackey, L.N.A., Opoku, F., Akoto, O. (2024). Addressing global environmental pollution using environmental control techniques: a focus on environmental policy and preventive environmental management. Discov. Environ., 2, 8.

Ayejoto, D.A., Agbasi, J.C., Egbueri, J.C. (2022). Assessment of heavy metal contamination and associated human health risks in groundwater sources of southeastern Nigeria. Environmental Science and Pollution Research.

Ayejoto, D.A., Agbasi, J.C., Egbueri, J.C. (2023). Health risk assessment and water quality evaluation in rural groundwater sources, southeastern Nigeria. Environmental Monitoring and Assessment.

Ayejoto, D.A., Agbasi, J.C., Egbueri, J.C. (2024). Assessment of oral and dermal health risk exposures associated with contaminated water resources: An update in Ojoto area, southeast Nigeria. Environmental Geochemistry and Health.

Barroso, G.R., Pinto, C.C., Gomes, L.N.L., Oliveira, S.C. (2024). Assessment of water quality based on statistical analysis of physical-chemical, biomonitoring, and land use data: Manso River supply reservoir. Sci. Total Environ., 912, 169554.

Che, X., Tian, Z., Fu, D., Bi, Z., Wang, L., Zhu, D. (2024). Research on COD parameter in water based on the combination of UV absorption photometry and laser spectroscopy. Environ. Technol. Innov., 35, 103730.

Chen, D., Zeng, Q., Hu, P., Yang, Z., Yang, Q., Liu, H., Yan, L., Wang, W.Y., Wang, A.H. (2024). Biogenic elements--informed assessment of the impact of human activities on river ecosystems. J. Environ. Manag., 353, 120276.

Demaku, S., Jusufi, K., Maliqi, E., Shabani, E. (2024). Integrated geospatial assessment and geovisualization of water and sediment quality in an artificial lake. Insights from Sferk, Klina, Kosovo. J. Environ. Prot. Eng., 50(3).

Doré, E., Lytle, D.A., Wasserstrom, L., Swertfeger, J., Triantafyllidou, S. (2020). Field analyzers for lead quantification in drinking water samples. Crit. Rev. Environ. Sci. Technol., 51(20), 2357–2388.

Egbueri, J.C., Agbasi, J.C. (2022). Combining data intelligent algorithms for the assessment and predictive modeling of groundwater resources quality in parts of southeastern Nigeria. Environmental Science and Pollution Research.

Egbueri, J.C., Agbasi, J.C. (2023). Extent of anthropogenic influence on groundwater quality and human health related risks: An integrated assessment based on selected physicochemical characteristics. Int. J. Environ. Anal. Chem.

Egbueri, J.C., Ayejoto, D.A., Agbasi, J.C. (2022). Pollution assessment and estimation of the percentages of toxic elements to be removed to make polluted drinking water safe: a case from Nigeria. Toxin Rev., 42(1), 146–160.

Egbueri, J.C., Unigwe, C.O., Agbasi, J.C., Nwazelibe, V.E. (2021). Indexical and artificial neural network modeling of the quality, corrosiveness and encrustation potential of groundwater resources in industrialized areas of southeastern Nigeria. Environment, Development and Sustainability.

Egbueri, J.C., Unigwe, C.O., Agbasi, J.C., Nwazelibe, V.E. (2023). Indexical and artificial neural network modeling of the quality, corrosiveness and encrustation potential of groundwater resources in industrialized areas of southeastern Nigeria. Environment, Development and Sustainability, 25, 14753–14783. https://doi.org/10.1007/s10668-022-02687-8

Ejiohuo, O. (2024). Ensuring water purity: Mitigating environmental risks and safeguarding human health. Water Biol. Secur., 100341.

Endale, Y.T., Ambelu, A., Sahilu, G. (2022). Tracking sources and contributing factors of Pb contamination in drinking water supply system of Addis Ababa, Ethiopia. Int. J. Environ. Anal. Chem., 104(14), 3263–3279.

Khan, M.Y.A., ElKashouty, M., Khan, N., Subyani, A.M., Tian, F. (2023). Spatio-temporal evaluation of trace element contamination using multivariate statistical techniques and health risk assessment in groundwater, Khulais, Saudi Arabia. Applied Water Science, 13, 123. https://doi.org/10.1007/s13201-023-01928-z

Kumar, P., Singh, L., Sharma, R. (2022). Assessment of heavy metal contamination in river water and sediment: A case study of the Ganga River, India. Environmental Monitoring and Assessment, 194(12), 789.

Lin, L., Yang, H., Xu, X. (2022). Effects of water pollution on human health and disease heterogeneity: A review. Front. Environ. Sci., 10, 880246.

Lu, L., Wang Z., Wang, Z., Deng, L., Zou, S., Fan, L., Yang Y. (2024). Chemical characteristics and water quality assessment of groundwater in the Dongjiang-Hanjiang River Basin, China. J. Environ. Chem. Eng., 12(6), 114721.

Lv, Z., Ran, X., Liu, J., Feng, Y., Zhong, X., Jiao, N. (2024). Effectiveness of chemical oxygen demand as an indicator of organic pollution in aquatic environments. Ocean-Land-Atmosphere Res., 3, Article ID: 0050.

Majumdar, M.K., Upadhyay, K., Giri, B., Yadav, P., Moulick, D., Sarkar, S., Thakur, B.K., Sahu, K., Srivastava, A.K., Buck, M., Tibbett, M., Jaiswal, M.K., Roychowdhury, T. (2024). Sustainable water management in rice cultivation reduces arsenic contamination, increases productivity, microbial molecular response, and profitability. J. Hazard. Mater., 466, 133610.

Maliqi, E., Jusufi, K. (2024). Quantitative monitoring of pollution in Mitrovica Lake using empirical model and geographic information science and systems. Int. J. Environ. Anal. Chem., 1–17.

Maliqi, E., Jusufi, K., Singh S.K., (2020). Assessment and spatial mapping of groundwater quality parameters using metal pollution indices, graphical methods and geoinformatics. Anal. Chem. Lett., 10(2), 152–180.

Menberu, Z., Mogesse, B., Reddythota, D. (2021). Evaluation of water quality and eutrophication status of Hawassa Lake based on different water quality indices. Appl. Water Sci., 11, 61.

Mueller, J.T., Gasteyer, S. (2021). The widespread and unjust drinking water and clean water crisis in the United States. Nat. Commun., 12, 3544.

Pande, C.B.A.D. Tolche, J.C., Egbueri, L., Mohd Sidek, R., Singh, A.P., Mishra, J.C., Agbasi, S.S., Refadah, Alshehri, F.M., Khan, Y.A., Scholz, M., Sammen, S.S. (2025). Implications of seasonal variations of hydrogeochemical analysis using GIS, WQI, and statistical analysis method for the semi-arid region. Appl. Water Sci., 15(4), Article 80.

Panneerselvam, B., Priya, K.S. (2021). Phytoremediation potential of water hyacinth in heavy metal removal in chromium and lead contaminated water. Int. J. Environ. Anal. Chem., 103(13), 3081–3096.

Rahman, I., Jahanara, Y., Jolly, N. (2021). Assessment of physicochemical properties of water and their seasonal variation in an urban river in Bangladesh. Water Sci. Eng., 14(2), 139–148.

Rajaka, S.K., Chelak, P., Tapadia, K. (2025). Geospatial analysis of industrial and agricultural pollution impact on pond water quality in Raipur district, central India. Adv. Environ. Technol., 11(2), 164–181.

Rana, Q., Latif, S., Perveen, S., Haq, A., Ali, S., Irfan, M., Gauttam, R., Shah, T.A., Dawoud, T.M., Wondmie, G.F., Bourhia, M., Badshah, M. (2024). Utilization of microalgae for agricultural runoff remediation and sustainable biofuel production through an integrated biorefinery approach. Bioresour. Bioprocess., 11, 8.

Singh, P.K., Kumar, U., Kumar, I., Dwivedi, A., Singh, P., Mishra, S., Seth C.S., Sharma, R.K. (2024). Critical review on toxic contaminants in surface water ecosystem: sources, monitoring, and its impact on human health. Environ. Sci. Pollut. Res., 31, 56428–56462.

Tazri, Z., Sakib, S., Das, R., Faruque, M.H., Hossain, A., Hosen, M.M., Habibullah-Al-Mamun, M. (2025). Heavy metal contamination in a transboundary river: Ecological and human health risk assessment. Int. J. Environ. Anal. Chem., 1–25.

U.S. Environmental Protection Agency (EPA) (2003). Draft sediment quality guidelines for the protection of aquatic life. U.S. Environmental Protection Agency.

U.S. EPA (2017). Method 3051A (SW-846). Microwave Assisted Acid Digestion of Sediments, Sludges, and Oils. Revision 1. Washington, DC.

Wang, Q., Sun, X., Xiong, H., Wang, Q., Zhang, B. (2024). Environmental taxes, environmental outsourcing, and pollution abatement: Evidence from Chinese industrial sewage discharge enterprises. Energy Econ., 133, 107480.

WHO (2021). Guidelines for drinking-water quality. 4th ed. World Health Organization, Geneva.

Yan, X., Xia, Y., Ti, C., Shan, J., Wu, Y., Yan, X. (2024). Thirty years of experience in water pollution control in Taihu Lake: A review. Sci. Total Environ., 914, 169821.

Zhang, X., Li, J., Wang, L. (2023). Spatial distribution and health risk assessment of heavy metals in groundwater: A case study of the industrial region in northern China. Chemosphere, 319, 139083.

Zhang, Y., Li, M., Dong, J., Yang, H., Van Zwieten, L., Lu, H., Alshameri, A., Zhan, Z., Chen, X., Jiang, X., Xu, W., Bao, Y., Wang, H. (2021). A Critical Review of Methods for Analyzing Freshwater Eutrophication. Water, 13, 225.

Zou, Y., Lou, S., Zhang, Z., Liu, S., Zhou, X., Zhou, F., Radnaeva, L.D., Nikitina, E., Fedorova I.V. (2024). Predictions of heavy metal concentrations by physiochemical water quality parameters in coastal areas of Yangtze River estuary. Mar. Pollut. Bull., 199, 115951.

GEOPRZESTRZENNA OCENA JAKOŚCI WÓD GRUNTOWYCH ORAZ ZANIECZYSZCZENIA METALAMI CIĘŻKIMI W MIEJSCOWOŚCI BAICË, KOSOWO

ABSTRACT

Cel badania

Niniejsze badanie odnosi się do narastającego problemu zanieczyszczenia wód na obszarach wiejskich, gdzie ograniczony monitoring może wpływać zarówno na zdrowie ludzi, jak i stabilność ekosystemów. Zanieczyszczenie zasobów wód słodkich stało się istotnym problemem środowiskowym i zdrowia publicznego, co podkreśla potrzebę szczegółowych ocen lokalnych. Badanie to ocenia stopień zanieczyszczenia oraz jakość wody w miejscowości Baicë w Kosowie, będącej obszarem wiejskim, gdzie ograniczony monitoring może oddziaływać zarówno na zdrowie ludzi, jak i stabilność ekosystemów.

Materiały i metody

Próbki wód gruntowych analizowano pod kątem kluczowych parametrów fizykochemicznych oraz zawartości metali ciężkich, w tym Cr, Al, Cu, Fe, Mn, Ni, Pb, Zn, As i Cd. Wyniki wykazały istotnie podwyższone stężenia ołowiu we wszystkich punktach poboru próbek (M1: 0,29 mg/L, M2: 0,25 mg/L, M3: 0,26 mg/L), przekraczające dopuszczalne normy i wskazujące na poważne zanieczyszczenie. Podwyższone wartości innych parametrów, w tym ChZT (COD) oraz BZT (BOD_5), dodatkowo sugerują antropogeniczny wpływ na jakość wody.

Wyniki i wnioski

Uzyskane wyniki wskazują, że wody gruntowe na badanym obszarze nie nadają się do bezpośredniego spożycia bez wcześniejszego uzdatniania. Analiza przestrzenna pozwoliła zidentyfikować obszary o najwyższym poziomie zanieczyszczenia, wskazując na strefy podwyższonego ryzyka środowiskowego oraz wspierając opracowanie ukierunkowanych strategii remediacji. Poziomy pierwiastków toksycznych, w tym Cr, Al, Cu, Fe, Mn, Ni, Pb, Zn, As i Cd, analizowano metodą spektrometrii emisyjnej ze wzbudzeniem w plazmie sprzężonej indukcyjnie (ICP-OES), co dostarczyło dodatkowych informacji na temat zanieczyszczenia. Ponadto analiza geoprzestrzenna z wykorzystaniem systemów GIS oraz interpolacji metodą odwrotnej odległości (IDW) umożliwiła opracowanie map stref zanieczyszczeń, ukazując zróżnicowanie przestrzenne oraz pomagając w identyfikacji obszarów priorytetowych dla działań naprawczych.

Słowa kluczowe: jakość wód gruntowych, metale ciężkie, analiza geoprzestrzenna, GIS, zanieczyszczenie wód, spektrometria emisyjna ze wzbudzeniem w plazmie sprzężonej indukcyjnie (ICP-OES)