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HEAVY METAL STATUS OF SOIL AND UNDERGROUND WATER IN URBAN AREA OF PRISHTINA DISTRICT, KOSOVO

Skender Demaku 0000-0001-5582-5323, Donika Sylejmani 0000-0002-9473-3939, Arbnorë Aliu, Blerta Krasniqi 0000-0002-9335-0987, Emirjana Demaj, Kaltrina Jusufi

University of Prishtina "Hasan Prishtina", George Bush Street, 10000. Faculty of Mathematics and Natural Science

ABSTRACT

Aim of the study

This paper focuses on the content of Cu, Fe, Mn, Ni, Pb, Zn, As, Sb, and Cd in both water and soil samples collected from the urban district of Pristhina. The concentrations of these heavy metals were determined using Atomic Absorption Spectroscopy (AAS). The concentration of trace metals in water was (Cu: 0.029 mg/l, Fe: 0.712 mg/l, Mn: 0.033 mg/l, Ni: 0.039 mg/l, Pb: 0.241 mg/l, Zn: 3.564 mg/l, As: 0.028 mg/l, Sb: 0.049 mg/l, and Cd: 0.089 mg/l). In soil samples, the concentration of metals ranges from (Cu: 4.98 mg/kg, Fe: 2.78 mg/kg, Mn: 2.56 mg/kg, Ni: 2.65 mg/kg, Pb: 4.98 mg/kg, Zn: 5.62 mg/kg, As: 0.028 mg/kg, Sb: 0.041 mg/kg, and Cd: 0.098 mg/kg). The sampling procedure was conducted in August 2022.

Material and methods

Instrumentation and statistical analyses. Atomic absorption spectroscopy (AAS) was used to measure the concentrations of heavy metals. For each group of analytical samples, a double-blind analysis was performed.

Results and conclusions

The current study contemplated the examination of soil and water samples collected from four sampling sites close to the wells. To gain a comprehensive understanding, we also studied the presence of heavy metals in the samples.

Keywords: water monitoring; urban area; AAS technique; heavy metals

INTRODUCTION

Pristhina municipality has a varied geography, with mountains in the country's east, north, and south, while the west has flat plains. According to developing plan for Pristhina, it mentions that the environmental management system, which includes the preservation of water, air, and soil as well as waste management and general care for nature, must be improved (Municipal Development Plan for Pristhina, 2012-2022, 2013). Despite being located a few kilometers outside of the capital city, Power Plants of Kosova, namely Kosova A and B are considered to pose the greatest risk for environmental pollution in the Municipality of Pristhina (Detailed Regulatory Plan for the "b" Urban Area of the New Pristhina Neighborhood - East Area in Pristhina, 2017-2025). The data obtained from the Hydro Meteorology In-

✉e-mail: kaltrina.jusufi@uni-pr.edu

stitute in Pristhina, cites that the wind direction is primarily from the northwest to the southeast. Since pollution disperses to a rate of around 90% toward the northeast, the city of Pristhina is thus indirectly impacted by it (City of Pristhina, action plan for a green city, 2021). The high accumulation of heavy metals in the environment can cause significant harm (Mitra et al., 2022). Serious concerns should be taken into consideration when the concentration of these components in water, soil, or air exceeds the acceptable ranges (Jaishankar et al., 2014). Lead, mercury, cadmium, and arsenic are some examples of heavy metals that are frequently found in soil and water (Nuray and Omer, 2021; Wang et al., 2020; Nguyen et al., 2021; Kubier et al., 2019; Ruskeeniemi et al., 2022). According to Iyama et al. (2022) these metals can enter the environment either naturally or because of human activity such as industrial emissions and agricultural practices (Demaku et al., 2020). Thus, it is crucial to keep an eye on soil and water levels from heavy metals to make sure they do not rise to dangerous peaks.

On the other hand, the quantity and quality of available water resources have a significant impact on human societies. Numerous health issues, including cancer, kidney damage, and neurological impairments, can result from high amounts of heavy metals in drinking water (Rehman et al., 2018; Balali-Mood et al., 2021).

This research is a monitoring of an area of the Pristhina district that has a vast population and frequently heavy traffic, which may impact water and soil pollution because of the massive human activity.

Water pollution

Agricultural and industrial activities, sewage discharge, as well as urban and suburban runoff are just a few of the numerous potential causes of water contamination that might occur. (Moss, 2008; Hou et al., 2022; Lin et al., 2022).

Additionally, some pollutants, particularly nitrogen pollution from agricultural runoff, have been found to act as catalysts for eutrophication, a condition marked by an excessive growth of algae that eventually causes oxygen levels to drop and causes aquatic life to suffocate. (Yang et al., 2008).

Plastic pollution is a common problem that raises serious environmental issues, especially when it comes to water. According to Thushari and Senevirathna (2020), the harmful effects of plastic waste go beyond the immediate risk and death of marine life to include complex interactions across the food chain and, ultimately, impact human health. This calls for a thorough understanding of the possible effects on ecological integrity and human welfare.

Sil pollution

The most prominent sources and paths for soil contamination include industrial processes like mining, metallurgy, and different types of industrial waste, as well as agricultural activities using fertilizers and transportation. (Briffa et al 2020). Heavy metals possess adverse effects on living organisms if we consume crops grown in contaminated soils with these elements. Furthermore, these trace elements can leak into groundwater causing massive contamination. Effective remediation procedures for heavy metal soil contamination include removing contaminated soil, adding soil amendments to bind the metals, and using phytoremediation methods, which use plants to draw metals from the soil. However, choosing the most effective method is very challenging and might have an enormous cost.

All things considered, preventing soil contamination is crucial to preserving ecological harmony, human health, maintaining water quality, ensuring sustainable agriculture, economic stability, and securing the well-being of both present and future generations. Therefore, it is advisable to adhere to the guidelines prescribed by the Environmental Protection Agency limits of pollution to prevent any catastrophic event.

Heavy metals

Drinking water may contain traces of **copper,** a metal that is naturally present. Although this metal is essential in low concentrations, according to Taylor (2020) excessive amounts of drinking water can pose potential hazards. This element can come into drinking water due to leaking from corrosion of copper pipes and fittings. The excessive amount of this element in water can cause health problems such as nausea and vomiting or in long-term exposure can harm the liver and kidneys and cause gastrointestinal problems. (Smith, J. et al 2022)

Nickel is an element that can come into the environment naturally, but human activities play a key role in the increased concentration of this element (Chow et al. 2021). The concentration of nickel is greatly increased by anthropogenic activities, notably those related to industrial processes and vehicle emissions, which could have an impact on both human health and environmental quality (Smith, J. M, et al 2023)

Lead, as an element, has the potential to cause neurological developmental delays and behavioral abnormalities with long exposures to this metal. Furthermore, long-term exposure to lead-contaminated water is linked to a higher risk of kidney damage, high blood pressure, and other harmful physiological effects.

Since **zinc** is an important element for living organisms, it is crucial to preserve appropriate concentrations as regulated by the organizations responsible for monitoring the environment with elements present in quantity. However, it is wise to consider its potential hazards when encountered in big quantities. Different forms of this element can be found; dissolved, suspended, and or with other elements in compounds, can be found in water sources. According to different organizations for water quality, American Water Works Association and Water Environment Federation (APHA-AWWA-WEF, 2005), zinc concentrations in water is dependent on the source, having different concentrations from parts per billion to several parts per million.

Water may contain low levels of **arsenic**, an element that may come to the environment in natural form, but anthropogenic activities play a crucial role in the high presence concentration of this element. Drinking water with arsenic pollution can result in several health issues, including skin damage and different cancers. Arsenic can enter the water through human activity like mining, and agriculture, but this element can enter the environment as well as from natural sources like minerals. There are different techniques that are used today to remove arsenic from water such as coagulation, adsorption, reverse osmosis and distillation, and ion exchange (APHA-AWWA-WEF, 2005).

We already mentioned that the industry and agriculture runoff have a profound impact on pollution. Due to this drinking water can contain hazardous heavy metals, in this case **cadmium.** Human activities such as mining and smelting, the use of phosphate fertilizers, the disposal of cadmium-containing waste, and the burning of fossil fuels could be some of the sources that can cause contamination with cadmium elements. Long exposure to this element in high quantities in drinking water can harm the kidneys and increase the probability of developing certain cancers (Suaad, 2021).

Study area

Kosovo's capital and largest city is Prishtina. The Sharr Mountains surround Prishtina on its south and western sides. The capital city has an area of around 523 km2. Lepenci River flows to the city and it splits Prishtina in half. Due to its continental climate, the city has cold winters and warm summers (Maliqi et al., 2020). Since it's the largest city in Kosovo, it also has the highest population. The main sources of air pollution in the city are industrial activities and traffic. As a result, it has significant air pollution (Ukhaxhaj et al., 2013). Four samples of soil and water were collected from various locations. The areas selected for sampling included the University of Prishtina campus, the city square, the vicinity of the Newborn monument in the city center, and the Adem Jashari barracks at the entrance of the city. These locations were chosen due to their high vulnerability to pollution.

The figure below (Figure 1) shows the map of Kosovo with the area of Prishtina, pointing out the sampling spots in Prishtina district.

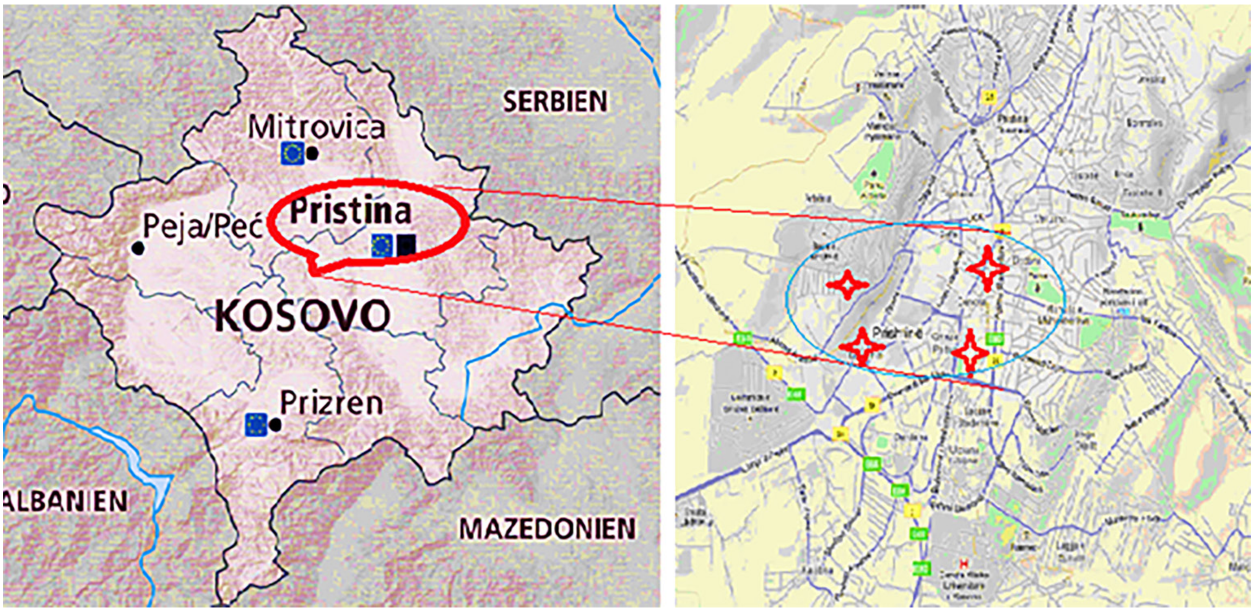

Fig. 1. Map of Kosovo and study area of Prishtina district (source: own elaboration)

MATERIALS AND METHODS

Soil sampling and treatment. There are various methods for taking the samples for the soil, each with advantages and disadvantages. Using a spiral auger with a 2.5 cm diameter, four soil samples were taken from two different depths (0–15 cm and 15–30 cm). The selected soil samples were gathered, bulked up to create a composite sample, and delivered to the lab. Samples were crushed, air-dried, put through a 2 mm mesh sieve, and then put in plastic jars for storage.

Before beginning their processing and digestion, the samples were dried at laboratory air temperature for a couple of days. After they were dried, samples were put in the oven at a temperature of 105 °C. The 3.5 grams of a sample were treated with 10 cm^3 of aqua regia, until dissolved, filtered, and leveled up to 50 ml. (US-EPA. 1996). We used the atomic absorption spectrophotometer (AAS) technique to measure the presence of heavy metals in our samples.

Water sampling and treatment. Water samples were initially filtered using Whatman 1442-185 Ashless Quantitative Filter Paper before being divided into 50cm^3 and placed in Teflon containers. The samples were then digested and treated with 1 cm^3 of HCl and 5 cm^3 of HNO_3 (Canbay and Doantürk, 2017).

RESULTS AND DISCUSSION

Results of water testing and analysis

The present study was carried out with four sampling sites of water, and four soil samples in the vicinity of the wells. The results of water quality were compared to the WHO-drinking water (WHO, 2011).

Table 1 below contains the results of the physical and chemical quality of water samples that were taken in the Pristhina district.

Based on the results obtained from four sampling locations in the wells, the physical and chemical parameters values varied as follows: The temperature in our samples ranged from 11 °C to 16 °C. The presence of suspended particles represents turbidity. High turbidity might be an indication of pollutants in the water. In our samples, the turbidity value falls in the range of 2–5 NTU. Dissolved oxygen is a crucial additional indicator of the growth of life in water (US-EPA, 1996). The values in our samples are 6.8–8.5 mg/L.

The pH may impact aquatic species' ability to survive and reproduce, also it shows solubility and

Table 1. Physical and chemical parameters of water samples (source: own elaboration)

Parameters	M.1	M.2	M.3	M.4
Time	$10{:}00^{h}$	$12{:}00^{h}$	$14{:}15^{h}$	$15{:}45^{h}$
Weather	Clear weather	Clear weather	Clear weather	Clear weather
Temperature	12 °C	15 °C	11 °C	16 °C
Turbidity	2 NTU	2.5 NTU	3 NTU	5 NTU
DO mg/l	8.5	7.2	6.8	7.4
O_2%	99	94	78	86
EC	235.6 μS/cm^{-1} /19 °C	224.7 μS/cm^{-1} / 19 °C	239.4 μS/cm^{-1} / 19 °C	247.7 μS/cm^{-1} / 19 °C
pH	8.4	8.2	8.3	8.1
TDS mg/l	64	52	74	89
COD mg/l	11.1	13.5	14.3	12.5
BOD mg/l	5.4	3.5	3.8	2.6
TOC mg/l	4.8	5.4	2.9	3.9
NO_3^- mg/l	4.2	5.5	9.8	17.5
NH_4^+ mg/l	0.44	0.48	0.52	0.64
NO_2^- mg/l	0.03	0.02	0.03	0.5
PO_4^{3-} mg/l	0.045	0.063	0.075	0.098
SO_4^{2-} mg/l	8.21	8.48	9.91	15.43
Cl^- mg/l	11.65	14.2	13.2	18.29
Na^+ mg/l	3.37	4.15	5.35	11.15
FP d^0H	6.62	7.45	6.39	7.78
Ca^{2+} mg/l	31.94	35.18	33.3	38.96
Mg^{2+} mg/l	6.45	7.68	5.87	8.64
HCO_3^- mg/l	138.9	148.7	152.4	168.9

toxicity of specific compounds. In our water samples, the pH value started from 8.1 and went up to 8.4. Another critical parameter that shows the water's complete inorganic and organic component is "total dissolved solids" (TDS). In our samples, this parameter varies from 52 to 89 mg/L. COD values ranged from 11.1 mg/L–14.3 mg/L. We found a similarity in approximate values between BOD and TOC, namely 2–6 mg/L-5.4 for BOD and 2.9–5.4 mg/L for TOC. Conductivity is the ability of water to carry electrical current. This parameter also shows the number of ions that are dissolved in water. Our samples range from 224.7 $\mu S/cm^{-1}$ to 247.7 $\mu S/cm^{-1}$. The electrical conductivity of the water indicates high dissolved ion content, which is typical of drinking water.

The excessive presence of phosphate and nitrate ions in the water causes the process of eutrophication. Drinking water must not contain more than 15 mg/L of nitrate as nitrogen. In surface waters, these are present in small quantities (WHO, 2011) whereas in groundwater they are found in larger amounts. Nitrates are the final product of the biological oxidation of organic pollution (APHA-AWWA-WEF, 2005). Nitrites are toxic and their maximum acceptable amount in drinking water is 0.005 mg/L of nitrite (APHA-AWWA-WEF, 2005). In our groundwater samples, the concentration of NO_2^- ranges from 0.02 to 0.5 mg/l, NO_3^- ranges from 4.2 to 17.5 mg/l, NH_4^+ from 0.44 to 0.64 mg/L and PO_4^{3-} from 0.045 to 0.098 mg/L. Sulfates in water can come from different rocks and minerals. Their concentration can vary. The EPA recommends not exceeding 250 mg/L of water in cases where the water is used for drinking. In our samples, this parameter is between 8.21 and 15.43 mg/L. Ca and Mg ions can also similarly enter the water. In their case, it is more difficult to determine the maximum amount that can be safely present in drinking water (EPA, 1996). Their concentration in our samples is 31.94–38.96 mg/L for Ca, and 5.87–8.64 mg/L for Mg. The maximum amount for Cl^- and Na^+ in drinking water is 250 mg/L and 20 mg/L, respectively, for sodium, according to EPA. However, our samples have lower concentrations than expected as maximum values, for Cl^- from 11.65–18.29 mg/L and Na^+ from 3.37–11.15 mg/L.

The table below (Table 2) summarizes the heavy metals measured in our water samples: Cu, Fe, Mn, Ni, Pb, Zn, As, Sb, and Cd. The results for water samples are summarized in the form of mean, standard deviation, minimum, maximum, median, and maximum values per mg/L.

Most heavy metals are presented in concentrations far below the permitted levels in water if we compare the results according to the WHO (WHO, 2011).

Copper in drinking water has a maximum contamination level set by the Environmental Protection

Table 2. Statistical variables in water samples in mgL^{-1} (source: own elaboration)

Variable	Mean	StDev	Minimum	Maximum	Range	Median	Limit mg/L
Cu	0.02475	0.0035	0.021	0.029	0.008	0.0245	1.3
Fe	0.594	0.1148	0.441	0.712	0.271	0.6115	0.3
Mn	0.02525	0.00645	0.019	0.033	0.014	0.0245	0.3
Ni	0.02625	0.01269	0.011	0.039	0.028	0.0275	0.1
Pb	0.1232	0.1191	0.01	0.241	0.231	0.121	0.015
Zn	2.595	0.773	1.854	3.564	1.71	2.482	5
As	0.011	0.0114	0.004	0.028	0.024	0.006	0.01
Sb	0.0165	0.022	0.003	0.049	0.046	0.007	0.006
Cd	0.0415	0.0441	0.002	0.089	0.087	0.0375	0.005

Agency (EPA, 1996) at 1.3 milligrams per liter (mg/L). In our samples remains below the maximum allowed limit (1.3 mg/L), where the recorded concentration is from 0.021–0.029 ml/L. According to EPA, the maximum nickel value in water samples should be lower than 0.1 mg/L. In our samples, this metal has a higher concentration, it ranges from 0.011 to 0.039 mg/L. The maximum concentration was noted in the third and fourth sampling locations, which are closer to urban areas with heavier traffic also. (Balali-Mood et al., 2021).

The concentration of lead in our analyzed samples ranges from 0.01 mg/L to 0.241 mg/L. In terms of the maximum concentration in water, according to EPA, the content of this element should be zero, and at the very most, it should not exceed the value of 0.015 mg/L in drinking water. However, our samples have a higher concentration of this element, more than 16 times greater than the permitted value (Mitra et al., 2022).

Zinc ranges in our water samples from 1.854 to 3.564 mg/L. We note that we are dealing with a concentration that is lower than 5 mg/L, which is anticipated as the maximum amount value according to EPA (1996). This value is set to protect public health and is based on the best available scientific information (Directive 2000/60/EC, 2000).

The maximum observed content of arsenic in our groundwater samples ranged from 0.004 to 0.028 mg/L. We have a higher concentration of this element than the EPA recommends for protecting human health. If we compare our maximum concentration sample, we have 2.5 times more arsenic in water samples than the norm allows –according to the recommendations, where it states that it should be less than 0.01 mg/L (Balali-Mood et al., 2021).

Cadmium's maximum contamination limit in drinking water has been set by the Environmental Protection Agency (EPA, 1996) at five parts per billion (ppb).

Cadmium in our samples ranges from 0.002 to 0.089 mg/L (Balali-Mood et al., 2021). This element is found in a higher concentration than the EPA standard allows- lower than 0.005 mg/L. In our samples, this element is almost 18 times higher than the permissible value (Directive 2000/60/EC, 2000).

The figure below (Figure 2) shows the concentration of these elements in water samples and their individual distribution.

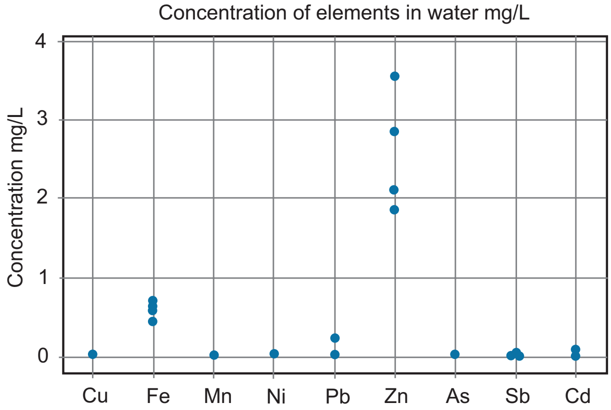

Fig. 2. Individual distribution diagram of heavy metals measured in water samples (source: own elaboriation)

The figure above (figure 2) shows the distribution diagram of these elements in the measured water samples (mg/L). According to the distribution of the concentration of the studied elements, we see that we are dealing with a normal distribution of elements in the measured samples. The level of heavy metals is relatively consistent and not heavily skewed towards high or low concentrations.

Results of soil testing and analysis

It is a well-known fact already that soil may store a variety of environmental contaminants. Soil quality needs to be continually monitored (Wang et al., 2020). We measured the physical and chemical properties of the soil and the presence of heavy metals. In our samples, the pH of the soil ranges from 7.5 to 8.9. The humus percentage starts from 0.32 to 2.21%. Humidity ranges from 3.3% to 7.06%.

To compare our findings, we used the Dutch soil and sludge standard, which is the most widely used set of standard values for soil quality, (Dutch Target and Intervention Values, 2000). We note that our samples fall below the maximum permissible levels for soils according to the Dutch standard. (Table 3)

The figure below (Figure 3) shows a general box plot of heavy metals in soil analysis in mg/kg. According to Everitt et al. (1992), this approach is often employed in environmental investigations.

The table below, table 3, summarizes the values of heavy metals in soils measured in our samples: Cu, Fe, Mn, Ni, Pb, Zn, As, Sb, and Cd. All the results from soil samples are summarized in the form of mean, standard deviation, minimum, maximum, median, and maximum limited values according to Dutch list in mg/kg (Dutch Target and Intervention Values, 2000).

Table 4 shows the physical and chemical properties of soils in terms of humus, pH, moisture, and conductivity. The pH range for neutral to mild bare soil is between 7.0 and 8.5. Most plants can thrive in this range, which is considered somewhat alkaline. However, certain plants could need a more particular pH range to grow. To keep the soil healthy and fertile, humus is essential. It aids in enhancing the soil's structure, which enables improved aeration and water retention. Humus also serves as a natural fertilizer, providing plants with vital nutrients (Maliqi et al., 2020).

The figure below (Figure 4) shows the concentration of these elements in soil samples and their individual distribution in mg · kg$^{-1.}$

Table 3. Statistical summary of variables in soil samples mg/kg (source: own elaboriation)

Variable	Mean	StDev	Minimum	Median	Maximum	Dutch list mg/kg
Cu	4.373	0.582	3.78	4.365	4.98	36
Fe	2.307	0.439	1.89	2.28	2.78	
Mn	1.75	0.702	1.1	1.67	2.56	
Ni	1.813	0.784	1.1	1.75	2.65	35
Pb	3.62	1.462	2.11	3.695	4.98	85
Zn	3.59	1.489	2.13	3.305	5.62	140
As	0.01225	0.01072	0.005	0.008	0.028	29
Sb	0.01375	0.01843	0.002	0.006	0.041	3
Cd	0.0465	0.0491	0.004	0.042	0.098	0.8

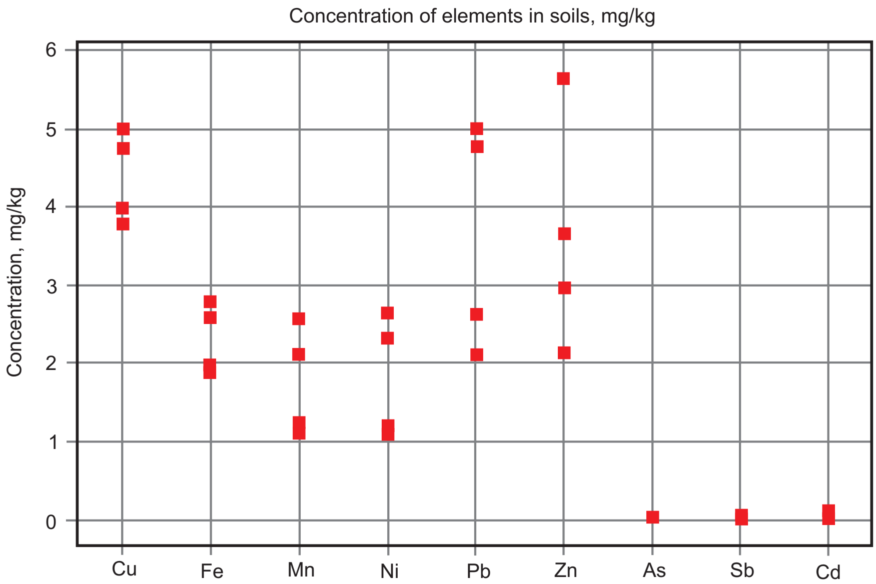

Fig. 3. Concentration of Cu, Fe, Mn, Ni, Pb, Zn, As, Sb and Cd in soil samples (mg/kg) (source: own elaboration)

Table 4. Experimental values of conductivity, pH, humus, and soil moisture (source: own elaboration)

Conductivity µS/cm^3	pH	Humus %	Moisture %
286	7.57	0.324	7.06
135	7.55	1.03	5.485
265	7.5	0.55	5.5
137	8.92	2.21	3.3

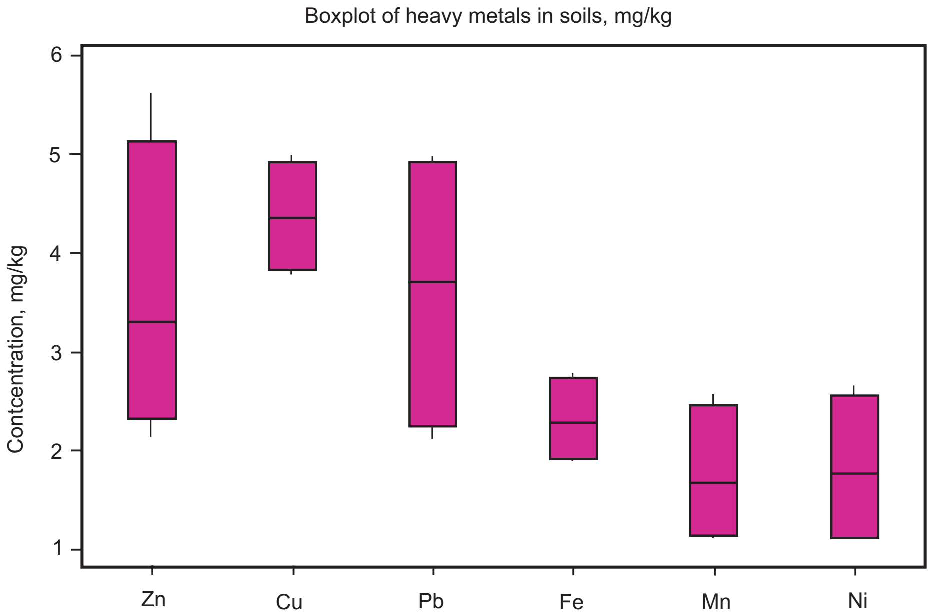

Fig. 4. Concentration of Cu, Fe, Mn, Ni, Pb, Zn, As, Sb and Cd in soil samples (mg/kg) (source: own elaboration)

CONCLUSIONS

Recent decades have seen the worst of ecological and environmental issues, creating a serious threat of environmental destruction not just in the Pristhina region but also over the entirety of Kosovo. The potential harm of heavy metals in the environment, especially considering their bioaccumulation throughout the food chain and their existence in nature, is one of the specific worries.

Urbanization is a component that contributes to the water contamination that has been found in certain metropolitan areas. To address these worries, the current study was carried out to evaluate the level of heavy metals in the soil and groundwater in the urban district of Pristhina, Kosovo. The findings showed that several heavy metals, including Fe (0.712 mg/l), Pb (0.241 mg/l), As (0.028 mg/l), Sb (0.049 mg/l), and Cd (0.089 mg/l), had increased levels in the groundwater, in some cases higher than the safety criteria recommended by the Environmental Protection Agency (EPA) for water quality.

Nevertheless, heavy metals in the soil samples were found to be within acceptable limits. But the fact that heavy metals can easily end up from water to soil raises concerns and needs to be frequently analyzed.

The findings of this study are essential in giving an idea of environmental quality in the examined region. It provides a crucial call to action for the protection of Kosovo's natural environment. To protect the area's water and soil quality from the negative effects of anthropogenic contamination, appropriate measures must be taken with vigilant monitoring. Environmental sustainability in Kosovo may be attained by collaborative efforts that are motivated by the methods used by more developed countries.

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ZAWARTOŚĆ METALI CIĘŻKICH W GLEBIE I WODACH PODZIEMNYCH NA OBSZARZE MIEJSKIM PRISZTINA W KOSOWIE

ABSTRAKT

Cel badania

W ramach badań oznaczono zawartość następujących pierwiastków: Cu (w wodzie: 0,029 mg/l; w glebie: 4,98 mg/kg), Fe (w wodzie: 0,712 mg/l, w glebie: 2,78 mg/kg), Mn (w wodzie: 0,033 mg/l, w glebie: 2,56 mg/kg), Ni (w wodzie: 0,039 mg/l, w glebie: 2,65 mg/kg), Pb (w wodzie: 0,241 mg/l, w glebie: 4,98 mg kg), Zn (w wodzie: 3,564 mg/l, w glebie: 5,62 mg/kg), As (w wodzie: 0,028 mg/l, w glebie: 0,028 mg/kg), Sb (w wodzie: 0,049 mg/l, w glebie: 0,041 mg/kg) oraz Cd (w wodzie: 0,089 mg/l, w glebie 0,098 mg/kg). Próbki pobrano z gleby i wód gruntowych w rejonie miasta Prisztina w sierpniu 2022 r. Procedurę eksperymentalną przeprowadzono za pomocą atomowej spektroskopii absorpcyjnej (spektrofotometr AA – seria S2 – system AA – Thermo Electron Corporation).

Materiał i metody

Pomiary wykonano za pomocą odpowiednich instrumentów pomiarowych, następnie przeprowadzono analizy statystyczne. Do pomiaru stężeń metali ciężkich zastosowano absorpcyjną spektroskopię atomową (AAS). Do przetworzenia każdej z grup próbek analitycznych zastosowano metodę podwójnej ślepej próby.

Wyniki i wnioski

Próbki pobrano w czterech punktach poboru wody oraz próbki z gleby w czterech lokalizacjach w pobliżu studni. Chociaż właściwości fizyczne i chemiczne zapewniają pewien wgląd w jakość wody, to nie dają pełnego obrazu zanieczyszczenia wód.

Słowa kluczowe: monitoring jakości wody, obszar miejski, technika AAS, metale ciężkie