ORIGINAL ARTICLE

Annals of Agricultural and Environmental Medicine 2024, Vol 31, No 2, 205–211
www.aaem.pl

Concentration and risk assessment of metals in snow cover monitoring in urban and rural areas

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Kujawska J, Wojtaś E, Zaburko J, Kamińska I, Czerpak J, Jamka K, Babko R, Łagód G. Concentration and risk assessment of metals in snow cover monitoring in urban and rural areas. Ann Agric Environ Med. 2024; 31(2): 205–211. doi: 10.26444/aaem/190317

Abstract

Introduction and Ojective. Snow cover serves as a unique indicator of environmental pollution in both urban and rural areas. As a seasonal cover, it accumulates various pollutants emitted into the atmosphere, thus providing insight into air pollution types and the relative contributions of different pollution sources. The aim of the study is to analyze the distribution of trace elements in snow cover to assess the anthropogenic influence on pollution levels, and better understand ecological threats.

Materials and Method. The study was conducted in rural areas around the village of Wólka in the Lublin Province of eastern Poland, and in urban districts of the city of Lublin, capital of the Province. Samples were analyzed using Inductively Coupled Plasma-Mass Spectrometry, the Enrichment Factor (EF), and ecological risk indices (RI), were calculated to evaluate the contamination and potential ecological risks posed by the metals.

Results. The findings indicate higher concentrations of metals like sodium and iron in urban areas, likely due to road salt use and industrial activity, respectively. Enrichment factors showed significant anthropogenic contributions, particularly for metals like sodium, zinc, and cadmium, which had EF values substantially above natural levels. The potential ecological risk assessment highlighted a considerable ecological threat in urban areas compared to rural settings, primarily due to higher concentrations of metals.

Conclusions The variation in metal concentrations between urban and rural snow covers reflects the impact of human activities on local environments. Urban areas showed higher pollution levels, suggesting the need for targeted pollution control policies to mitigate the adverse ecological impacts. This study underscores the importance of continuous monitoring and comprehensive risk assessments to effectively manage environmental pollution.

Key words

heavy metals, snow cover, risk assessment.

INTRODUCTION AND OBJECTIVE

The presence of snow provides a distinctive source of data regarding the condition of environmental pollution, both in urban and rural areas. As a seasonal phenomenon, snow accumulates a diverse range of pollutants that are subsequently emitted into the atmosphere. For these reasons, snow cover is commonly used as a reliable indicator to assess the type of air pollution and to track the relative contribution of different sources of atmospheric pollution [1]. Analysis of the content and distribution of trace elements in snow cover can provide information about the behaviour and sources of atmospheric pollution. Consequently, research is being conducted worldwide on the chemical composition of snow [2, 3, 4].

The chemical composition of snow is influenced by a number of factors, including local air pollutants, which can introduce substances such as heavy metals or sulphur into the atmosphere. Furthermore, snow can also contain pollutants that have been transported from distant regions by atmospheric air currents. This phenomenon is exemplified by the occurrence of Saharan dust reaching Europe. Meteorological conditions, including temperature and humidity, influence the substances that are captured from the atmosphere. Furthermore, the proximity of large urban, industrial or intensive agricultural areas increases the level of pollution in the snow. These factors are of crucial importance for the monitoring of the impact of human activities on the environment and the assessment of ecological change, as well as the impact on human health [5].

Numerous factors impact the presence of pollutants in the atmosphere, which vary depending on the specific characteristics of each region. The concentration of metals in snow is influenced by meteorological conditions, leading to an accumulation of heavy metal content in snow layers over time. This occurrence may stem from a variety of factors, some of which are not directly linked to the overall rise of metals in the atmosphere. The concentrations of metals in the atmosphere are tied to diverse mechanisms, posing a challenge in identifying a singular source of heavy metal contamination [6].

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Received: 23.05.2024; accepted: 20.06.2024; first published: 26.06.2024

During the process of melting caused by elevated temperatures, various pollutants are present in the snowpack or carried by run-off from precipitation are discharged into groundwater and diverse aquatic and terrestrial ecosystems, such as rivers or lakes, potentially causing adverse effects on the environment [7], while potassium (K), copper (Cu), and zinc (Zn) are emitted during the incineration of waste materials. Manganese (Mn), iron (Fe), and lead (Pb) are recognized as pollutants originating from the burning of oil in the environment. Lead (Pb), iron (Fe), and zinc (Zn) may also come from the exhaust emissions of vehicles, while calcium (Ca) and zinc (Zn) are commonly found in motor oil components. Potassium (K) is typically released during the combustion of wood, and copper (Cu) emissions are notably linked to the use of car brakes [8].

Pb released from vehicles gathers in road dust, contributing to its presence in snow. zinc (Zn) was also identified in the snow samples, potentially originating from the vicinity of a cement factory and the re-suspension of road dust. The levels of cadmium (Cd), copper (Cu), and nickel (Ni) reported were relatively modest, with these metals primarily emanating from oil combustion, residential coal burning, and vehicle discharges. Metals have the capacity to adhere to dust particle surfaces, with the average duration of these fine particles (diameter 0.1–0.2 μm) in the atmosphere ranging from 3 – 7 days. During this period, particles could travel considerable distances, possibly extending to several thousand kilometers, settling in regions far from their original source [9].

Metal ions play a crucial role in the biological functions within living organisms. However, when present in elevated levels, these ions can manifest toxic or potentially carcinogenic properties. The toxicity of metal ions towards mammalian systems stems from their interactions with proteins, enzymes, and the membrane structure. Metal compounds also possess the ability to induce carcinogenicity in both humans and animals. Research has demonstrated that certain metals, e.g. chromium (Cr) and nickel (Ni), can lead to the development of cancer in populations with prolonged exposure, or result in chronic poisoning in laboratory animals and humans. Exposure to cadmium (Cd) has been linked to complications in the kidney and respiratory systems, potentially causing conditions such as proteinuria, glycosuria, or emphysema. Lead (Pb) tends to accumulate in the nervous system, haematopoietic system, and kidneys, giving rise to such conditions as peripheral neuropathy, central nervous system disorders, and anemia. The escalation of environmental pollution by metals has emerged as a significant and widespread issue. The detection of metals in groundwater warrants urgent attention as a critical hazard to human well-being [10].

Source control, the first step on the way to preventing pollution in the ambient air, is a key action in minimizing the presence of pollutants in snow or rainwater, and the potentially negative effects on the ecosystem that accompany them [11]. Source control policies are widely acknowledged as the most cost-effective management tool for diffuse, low-level contaminants. There is, however, a pressing need for further development of this contamination control tool [12]. Examples of successful legislative actions that have led to effective source control include the phasing-out of lead from gasoline. In recent years, a number of environmental policies have been introduced, including the reduction of the copper content in vehicle brake pads in the United States (US EPA, 2015) and elsewhere [13]. These examples demonstrate the potential for reducing the penetration of copper and lead into water and soil. In order to plan the implementation of source-based control policies, it is essential to have an adequate understanding of the sources of pollution in both urban and rural areas of precipitation [11].

OBJECTIVE

The main aim of this study is to examine the influence of anthropogenic factors on the level of snow pollution, which will enable a more comprehensive understanding of the processes involved in environmental pollution. The study will also assess the impact of chemical properties of snow cover in two contrasting locations: the urban area of the city of Lublin in eastern Poland, and the rural area of Bystrzyca. Furthermore, the study calculated the Enrichment Factor (EF) and ecological risk indices (RI) in order to evaluate the contamination and potential ecological risks posed by the metals.

MATERIALS AND METHODS

Study area. The study was conducted in a rural area within the Lublin Province in eastern Poland. A total of ten measurement points were selected in each of the following locations selected for sampling: Bystrzyca (1, 7, 8), Charlęż (2), Swoboda (3), Dziuchów (9), Kolonia Bystrzyca (4), Sobianowice (6, 5). Nine sampling points were situated in proximity to communication routes. The control sample (10) consisted of snow samples collected from an area distant from communication routes. In the case of the city of Lublin, the sampling sites were located near the main streets, characterized by heavy traffic (samples No. 11–15, 18 and No. 20, 10), and housing estate roads with low traffic (tests No. 16, No. 17). The control sample (No. 19) consisted of snow taken from the green areas of the Lublin University of Technology campus, which is situated at a considerable distance from communication routes. The locations of the sampling sites are presented in Table 1. The location of the sampling sites was determined by the assumption of diversity in traffic intensity which, in turn, informed about the expected amount of pollutants present in the snow. Figures 1 and 2 present a map indicating the locations of the sampling points.

Sampling. Samples of snow were collected using a spatula made of polypropylene, and placed in a glass bottle with a capacity of 1,000 cm^3. The surface layer of snow was collected from a rectangular area measuring 50 cm x 70 cm. The air temperature during sampling ranged from -7 °C to -12 °C, with a collection time of 14 – 16 hours. Samples were collected from areas in close proximity to roads at a distance of approximately 2 m from the edge of the road. Snow sampling was conducted between 7 – 22 January 2024. Subsequently, the samples were transported to a laboratory and stored at 4 °C until analysis. A total of 95 samples were collected for subsequent data analysis. The control sample locations selected were distant from major roads and industrial activities to represent areas with minimal pollution. This selection helps in establishing a baseline for comparing polluted samples.

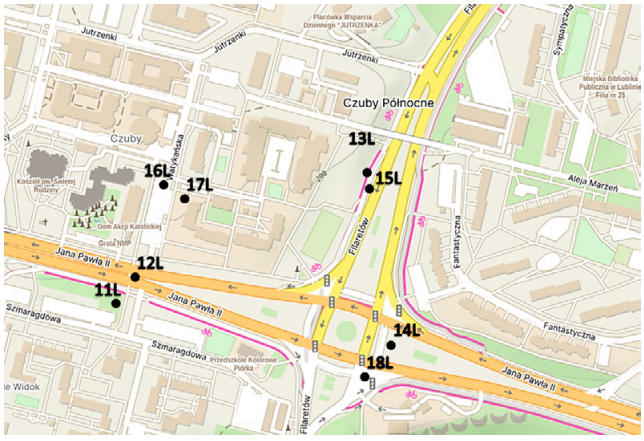
Table 1. Description of the surroundings of the sampling sites

DESCRIPTION OF SAMPLING SITE		DESCRIPTION OF SAMPLING SITE	
Sampling site No.	Village		Lublin city
1B	School and Education Centre in Bystrzyca	10L	Nadbystrzycka Street 40, a site away from the Lublin Politechnik Lubelska 02 stop (further from the road)
2B	Charlęż (place close to the street)	11L	Czuby, behind the pedestrian crossing on Jana Pawła II Street, from Szmaragdowa Street (further from the road)
3B	Swoboda (crossroads)	12L	Czuby, close to the pedestrian crossing, intersection of Jana Pawła II Street and Watykańska Street (close to the road)
4B	Kolonia Bystrzyca	13L	Filaretów Street, on the slope behind the Fantastyczna 01 bus stop (further from the road)
5B	Sobianowice entrance to the school	14L	Czuby Południe, the intersection of Filaretów Street and Jana Pawła II Street (further from the road)
6B	Sobianowice place next to the shop	15L	Filaretów Street, near the Fantastyczna 01 bus stop (close to the road)
7B	Crossroads Bystzyca and Leonów	16L	20 Watykańska Street, estate road (close to the road)
8B	Bystrzyca parking next to the cemetery	17L	20 Watykańska Street, corner of the Watykańska 9 building next to the estate road (further from the road)
9B	Dziuchów miejsce next to the bus stop	18L	Czuby Południe, the intersection of Filaretów Street and Jana Pawła II Street (close to the road)
10B	Checkpoint away from traffic	19L	Control sample, green areas of the Lublin University of Technology
		20L	Nadbystrzycka 40, near the Politechnika Lubelska 02 bus stop (close to the road)

Figure 1. Map of sampling points located in rural areas [14]

Analytical procedures. The snow samples collected were dissolved and aliquoted into 5 mL volumes in Teflon vessels within a digestion system, followed by the addition of 5 mL of HNO_3 (69–70% Romil Super Purity Acid). The digestion process was conducted using the Topex Preekem microwave digester. The determination of trace element contents was performed utilizing the Agilent 8900 ICP-MS/MSQQQ inductively coupled plasma–mass spectrometry system, equipped with an SPS-4 autosampler and an ISIS 3 sample introduction system (Agilent Technologies, Waldbronn, Germany), according to the PN-EN ISO 17294–2:2016–11 standards [15]. Quantitative elemental analysis was carried out using the external calibration method. For the calibration, Environmental Calibration Standard 2A by Agilent Technologies was employed. Accuracy was ensured through the use of standards and blanks during ICP-MS analysis. Regular calibration with known standards helps in maintaining the reliability of the measurements.

Data analysis. Enrichment Factor (EF) is an indicator used to assess the degree of pollution in environments, such as soil, water or air, especially in relation to heavy metals. Its calculation allows assessment of whether a given pollutant is the result of anthropogenic activity, or is naturally present. The enrichment factor is calculated as the ratio of the concentration of metals in the test sample to the reference sample (Al):



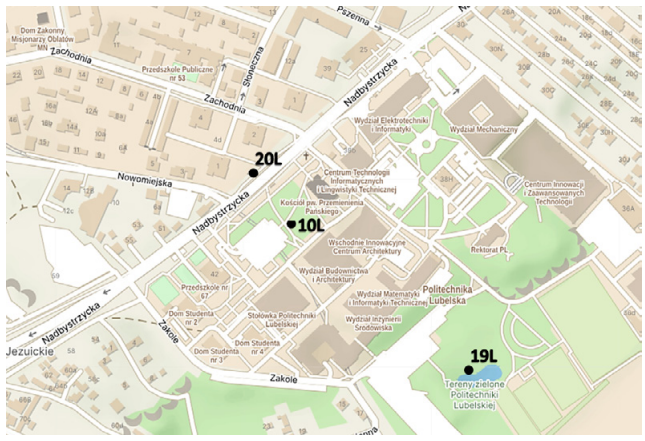


Figure 2. Maps of sampling points located in urban areas [14]

$$EF = \frac{\frac{C}{Al}sample}{\frac{C}{Al}background}$$

where $\frac{C}{Al}sample$ is the ratio of the concentration of the element of interest, (C) to reference element (R) in the snow samples, and $\frac{C}{Al}background$ is the ratio of the concentration of element of interest (C) to reference element (R) in the geochemical background.

Enrichment Factor Interpretation: EF < 2 suggests that the metal comes primarily from natural sources; EF = 2–5 indicates moderate enrichment. EF > 5 is an indicator of significant enrichment, which may indicate significant anthropogenic impacts [16].

The Environmental Risk Index (RI) allows for a comprehensive assessment of the environmental risk associated with heavy metals. The RI for all tested metals is calculated as the sum of the risk coefficients for individual metals – D.

For each heavy metal, an ecological hazard factor is calculated, which takes into account both the toxicity of the metal and its concentration in the tested environment:

$$E_{ri} = T_{ri} \cdot c_i$$

where T_{ri} is the metal toxicity factor, c_i is the measured concentration of heavy metal in snow (e.g. in mg/kg). The following values of the toxicity factor for individual metals are assumed to be: T_{ri}: Cd = 30; Pb = 5; Cu = 5; Zn = 1. Classes of RI according to Håkanson (1980): ≤ 90: low; 90 – 180: moderate; 180 – 360:strong; 360 – 720: very strong; ≥ 720 highly strong [16].

RESULTS AND DISCUSSION

The content of metals in snow samples collected in the city of Lublin and from the rural area (Bystrzyca, Lublin Province) is presented in Table 2. The order of metal content in snow in the city of Lublin was as follows:

Na > Fe > Ca > Zn > Al > Mg > K > Mn > Cu > Cr > V > Pb > Cd > Mo.

In rural areas, the order of metal content in snow was as follows:

Na > Fe > Ca > Al > K > Mg > Zn > Mn > Cr > Cu > V > Pb > Cd.

The mean concentrations of the majority of the tested metals (Na, Mg, Al, Ca, V, Cr, Mn, Fe, Cu, Mo, Cd, Pb) in snow samples were found to be higher in urban than in rural areas. This is consistent with the expectation that urban areas will have higher levels of pollution due to factors such as industrial activity, road traffic emissions and higher population density. The sodium and iron concentration values in snow samples exhibit particularly high concentrations in urban areas, which can be attributed to the use of road salt (for sodium) and industrial activities or corrosion of infrastructure (for iron). The results of analysis of the snow samples indicate that several elements, including potassium (K), magnesium (Mg), and lead (Pb), exhibit lower coefficients of variation in urban areas compared to rural areas, or very similar values. This suggests that these elements have more uniform concentration levels across samples within an urban area.

Table 2. Elemental composition of meltwater within the city of Lublin and country Bystrzyca

Elements			Mean	Standard deviation	Min	Max	Coefficient of variation
Na	mg/l	Rural areas	94.35	127.17	0.76	506.33	1.35
		Urban areas	429.37	705.87	1.40	2700.08	1.64
Mg		Rural areas	2.00	1.51	0.03	6.67	0.76
		Urban areas	4.68	7.03	0.13	29.84	1.50
Al		Rural areas	3.99	4.83	0.09	23.62	1.21
		Urban areas	5.90	7.35	0.14	26.58	1.25
K		Rural areas	2.74	3.42	0.10	15.88	1.25
		Urban areas	2.88	2.64	0.21	10.56	0.92
Ca		Rural areas	13.94	11.99	0.39	48.16	0.86
		Urban areas	27.14	35.93	1.50	147.91	1.32
Zn		Rural areas	0.16	0.21	0.01	1.11	1.29
		Urban areas	0.42	0.49	0.07	2.05	1.17
V	µg/l	Rural areas	8.63	9.07	0.04	40.96	1.05
		Urban areas	17.16	23.08	0.13	89.95	1.35
Cr		Rural areas	14.40	24.91	0.51	159.48	1.73
		Urban areas	25.53	32.59	1.12	125.34	1.28
Mn		Rural areas	141.86	183.27	2.46	868.79	1.29
		Urban areas	177.06	220.93	4.56	853.39	1.25
Fe		Rural areas	3598.52	3778.78	1.11	15836.86	1.05
		Urban areas	7737.68	10307.17	78.10	38736.12	1.33
Cu		Rural areas	18.59	18.24	0.81	100.74	0.98
		Urban areas	94.35	112.74	7.16	431.75	0.76
Mo		Rural areas	0.43	0.42	0.08	2.51	0.97
		Urban areas	1.25	1.77	<0.005	6.78	1.41
Cd		Rural areas	0.27	0.18	0.01	0.65	0.65
		Urban areas	0.37	0.34	0.01	1.46	0.91
Pb		Rural areas	7.52	6.46	0.69,	29.72	0.86
		Urban areas	14.21	15.81	1.25	67.28	1.11

Although metal concentrations in snow are generally lower in rural areas, contamination is still discernible, as evidenced by the concentration values of all the elements tested. The smallest observed difference in concentrations between urban and rural areas was for magnesium (Mg) and potassium (K). This may indicate the influence of the natural soil composition of settlement units located in the same region.

The coefficients of variation (Tab. 2) are typically higher in urban areas for a number of metals. This indicates that there are greater fluctuations in concentration levels in urban areas, which may be attributed to the uneven distribution of pollution sources and varying local conditions.

Figures 3 and 4 shows the concentrations of Cr, Cu, Cd, Pb at individual measurement points. In the rural area, the highest concentration was observed at point 4B, which is a location in Kolonia Bystrzyca, a site situated in a cultivated field, remote from traffic.

In the urban environment, the highest concentration of particles was observed at measurement points 12, 15, and 18L, which were situated at bus stops on streets in Lublin city with high volumes of traffic.

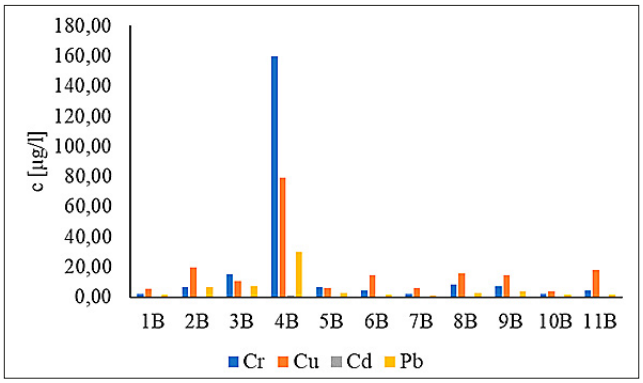


Figure 3. Metal concentration in snow samples collected in rural areas of Bystrzyca

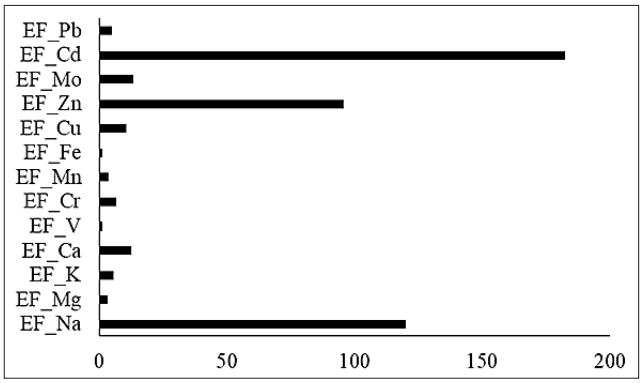


Figure 5. Enrichment factor values of metals in rural areas of Bystrzyca

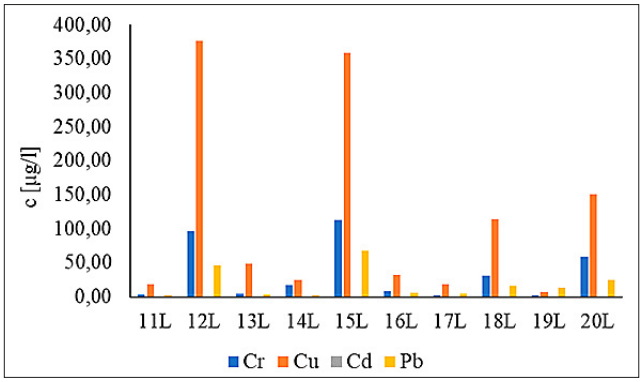


Figure 4. Metal concentration in snow samples collected in Lublin

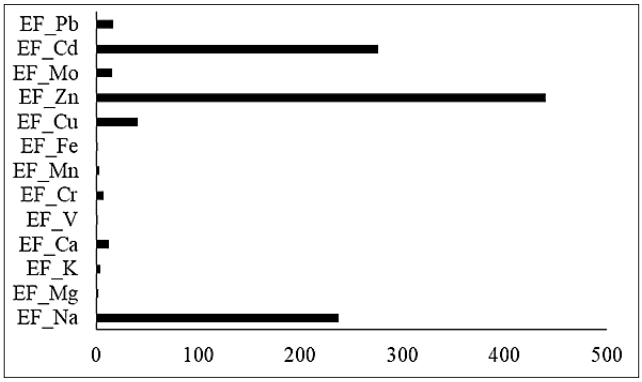


Figure 6. Enrichment factor values of metals in snow samples collected in Lublin city

The average concentrations of metals, including chromium (Cr), copper (Cu), cadmium (Cd) and lead (Pb), were determined in snow samples collected from site 4B. The Cr concentration was found to be 159.48, while the Cu concentration was 79.42 and Cd concentration – 0. The concentration of Pb was 29.72 µg/L, which exceeded the limit values for surface water purity class I set out in the Environmental Regulation of 21 July 2021 [17] (Cr and Cu=50, Cd=0.45, Pb=14 µg/l). Furthermore, samples taken at four points within the city also exceeded the limit. At point 12L, the concentrations of chromium (Cr), copper (Cu), cadmium (Cd) and lead (Pb) exceeded the respective limits by 46.18 µg/L, 326.21 µg/L, 0.52 µg/L and 31.84 µg/L. At point 15L, the concentrations of Cr, Cu, Cd and Pb exceeded the respective limits by 62.87 µg/L, 308.12 µg/L, 0.64 µg/L and 53 µg/L. The concentration of copper was 64.39 µg/L at point 18L, while the concentrations of cadmium and lead were 0.02 µg/L and 1.93 µg/L, respectively. At point 20L, the concentrations of chromium, copper, cadmium, and lead were 8.35 µg/L, 101.22 µg/L, 0.03 µg/L, and 10.31 µg/L, respectively.

Elevated levels of metals like Pb, Cd, and Cr are linked to serious health issues, such as neurotoxicity, kidney damage, and carcinogenicity. Chronic exposure to these metals can lead to conditions such as anaemia, respiratory problems, and cancer.

Figures 5 and 6 show the values of enrichment indices for the metals studied. Values of EF above 1 indicate enrichment above natural levels, which may be attributed to human activities

The enrichment factors (EF) of metals in snow samples can be used to distinguish between three groups of elements:

1) Elements with low enrichment factors (EF) of 1 – 10, including magnesium (Mg), potassium (K), calcium (Ca), vanadium (Va), chromium (Cr), manganese (Mn), and iron (Fe), were observed in both study areas. Lead was also present in rural areas. These elements are likely to have originated from mixed soil-anthropogenic sources.

2) Moderately enriched elements with EF values of 10 – 100, including calcium (Ca), molybdenum (Mo), and copper (Cu), were observed in both study areas, and lead in urban areas. These elements are likely to have originated from mixed soil-anthropogenic sources.

3) Highly enriched metals with EF values above 100, including sodium (Na) and cadmium (Cd), were observed in both study areas. These elements are likely to have originated from significant anthropogenic sources. The values of sodium and cadmium enrichment coefficients in snow samples are approximately twice as high in urban areas as in rural areas, while zinc and copper are approximately four times higher.

The EF value for cadmium is notably elevated in both study areas. The presence of elevated cadmium levels in the environment may pose a potential health risk to humans and ecosystems. With regard to calcium, vanadium, manganese, iron, and molybdenum, the enrichment rates in the snow samples studied are relatively similar between urban and rural areas, suggesting that these metals have comparable sources in both environments, potentially natural.

Many studies carried out in different parts of the world have detected the enrichment of snow cover with cadmium and zinc due to anthropogenic pollution. Kim et al. (2012) noted that dust in Asia was contaminated by Cd, Zn, Pb, Cu, As [18]. Dong et al. (2015) found that Zn and Cd were markedly enriched (EF values >100) in surface snow in China [19]. Kamani et al. (2014) in a snow cover study in Tehran, Iran, recorded maximum EF values for Zn, Pb and Cd [20]. Li et al. (2015) showed that atmospheric aerosols studied in

China were enriched in Se, Cd, Zn, Pb, As, Mo and Cu (EF > 100) [21].

The main sources of copper (Cu) in the atmosphere include the combustion of fossil fuels, emissions from road traffic, fuel combustion, and combustion in industry. Zinc (Zn) and cadmium (Cd) emissions mainly come from solid waste burning furnaces, and are closely related to the combustion of fossil fuels. It is possible that the abrasion of car tyres and the production and storage of cadmium batteries may be other sources of cadmium emissions [11].

Figure 7 shows the calculated values of the potential ecological risk assessment (ERI) of metals in snow samples from rural and urban areas. The calculated ERI values for Cr, Cu, Cd and Pb in snow samples are below 40, indicating a low ecological risk. In contrast, the ERI values for zinc in snow samples range from 80 – 160, indicating a considerable ecological risk. The greatest discrepancies in the potential ecological risk assessment values of snow samples were observed between urban and rural areas for zinc (Eri_Zn) and copper (Eri_Cu), with urban levels being considerably higher (more than two-fold for copper and almost 2.5 times higher for zinc).

The ecological potential index values calculated for snow samples from the city of Lublin were 245.06, indicating a significant risk of ecological threat. Conversely, the values of the ecological potential indicator calculated for snow samples taken in rural areas were 92.86, indicating a moderate risk of ecological threat.

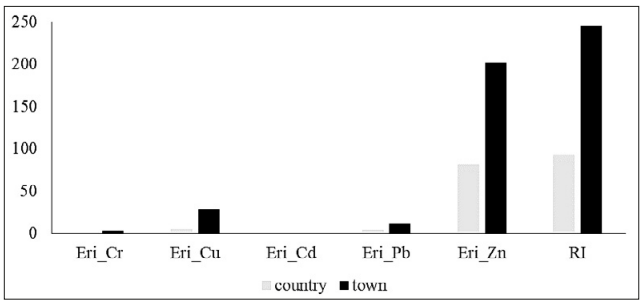


Figure 7. Potential ecological risk assessment (ERI) and risk index (RI) of metals in snow samples in rural and urban areas

These figures provide compelling evidence in support of the implementation of more stringent regulations governing industrial and vehicular emissions within urban areas. The findings indicate a necessity for the continuous monitoring of metal levels in both areas and further research into their sources and health impacts.

In order to assess the level of pollution relative to other locations, an analysis of data obtained from literature sources was conducted (Tab. 3. The deposition of metals in the snow in different cities exhibits considerable variability.

A comparative analysis of the metal concentrations in snow from different locations reveals significant variations in the concentrations of metals such as copper, zinc, cadmium, lead, manganese, iron and chromium. It is important to note that metals such as lead, zinc, nickel, cadmium, and copper, do not occur naturally in snow; therefore, the presence of even minimal amounts of these elements may indicate contamination [9].

A number of studies have reported elevated concentrations of heavy metals, including Pb and Cd, in snow samples collected from various locations. This is a cause for concern, given the toxicological impact of these metals on human health and ecosystems.

Comparison of the results of tests of snow samples in Białystok, north-east Poland, carried out by Bełsik et al. (2024), showed that the concentrations of Cu, Cd, Pb, Zn and Cr were higher at selected points than in snow samples taken in Lublin.

A study conducted by Yuan et al. in 2019 in Beijing, China, found that the concentrations of copper (Cu), iron (Fe), manganese (Mn), and zinc (Zn) were higher in the snow of than those of other metals. Among these metals, Zn exhibited the highest concentration [7]. A comparable trend was observed in the current study. This phenomenon can be attributed to two fundamental factors: 1) the reduction in Pb levels in gasoline over the past few decades has resulted in a corresponding decline in Pb concentrations, and 2) lead is present in a particle-bound form, whereas zinc is more commonly found in the dissolved state.

The monitoring of data is of significant importance in the context of environmental monitoring, with the potential to indicate the necessity for the implementation of policies designed to reduce emissions and pollution levels within urban areas. Furthermore, they emphasize the influence of human activity on the quality of the environment, even to the extent of affecting the composition of snow cover.

The current study contributes to the understanding of the spatial distribution of pollutants and their sources, highlighting the need for targeted pollution control measures. Follow-up studies could focus on long-term monitoring and the effectiveness of implemented policies in reducing pollution levels. Based on the findings, policies should focus on reducing vehicular and industrial emissions, such as implementing stricter emission standards, promoting the

Table 3. Comparison of metal concentrations in snow from different locations (mg/l)

LOCATIONS	Cu	Zn	Cd	Pb	Mn	Fe	Cr	REFERENCES
Poznań (Poland)	2.03	18	0.08	4.93				[8]
Ostrowiec Świętokrzyski (Poland)	1.72	57.14	0.11	0.06	15.51	62.50	0.56	[22]
Świętokrzyskie National Park, (Poland)		66	-	0.1			0.1	[2]
Kielce (Poland)		49.1		0.5			0.3	[23]
Svirsk (Russia)		18	0.1	0.5			0.4	[24]
Tyumen (Russia)	11.6	34.1	0.08	4.8	32.9			[25]
Białystok (Poland)	18–522.2	419–1956.2	0.05–1.337	8.71–91.10			187.5–353.2	[9]
Current study Lublin (Poland)	9.43	42	0.37	4.21	17.70	77.37	0.25	
Current study Bystrzyca (Lublin) (Poland)	18.59	16	0.27	0.07	14.18	35.79	0.14	

use of cleaner fuels, and enhancing public transportation. Regular monitoring and public awareness campaigns are also recommended.

CONCLUSIONS

The study confirmed that metal concentrations in snow cover are significantly higher in urban areas compared to rural ones. This is attributed to industrial activities, increased vehicular emissions, and higher population density which contribute to greater environmental pollution.

Enrichment factors (EF) for certain metals like sodium (EF=237.97), zinc (EF=440.27), and cadmium (EF=276.49), were much higher in urban snow cover, indicating strong anthropogenic sources. These findings suggest that human activities, particularly industrial and traffic emissions, are major contributors to metal pollution in snow.

The potential ecological risk index (RI) calculated for rural areas (RI=92.86) was substantially higher than for urban areas (RI=245.034), pointing to a considerable ecological threat in urban settings due to the presence of heavy metals. Metals such as zinc and copper posed considerable ecological risks, emphasizing the need for stringent pollution controls.

The results underline the necessity for implementing and enforcing more rigorous pollution control measures in urban areas. These policies should specifically target the reduction of industrial emissions and vehicular pollutants to decrease the levels of harmful metals in the environment.

Continuous environmental monitoring and periodic risk assessments are critical to understanding the long-term trends and impacts of metal pollution. This will aid in the timely adjustment of environmental policies and help mitigate potential health risks associated with metal exposure.

Acknowledgement
The study was funded by research grants from the Polish Ministry of Education and Science in Warsaw, Poland. (Grant Nos. FD-20/IS-6/999, FD-20/IS-6/019, FD-20/ IS-6/021, FD-20/IS-6/050).

REFERENCES

1. Onuchin A, Kofman G, Zubareva O, Danilova I. Using an urban snow cover composition-based cluster analysis to zone Krasnoyarsk town (Russia) by pollution level. Polish J Environ Stud. 2020;29:4257–4267. doi:10.15244/pjoes/118168
2. Szwed M, Kozłowski R. Snow cover as an indicator of dust pollution in the area of exploitation of rock materials in the Świętokrzyskie Mountains. Atmosphere (Basel). 2022;13. doi:10.3390/atmos13030409
3. Nawrot AP, Migała K, Luks B, Pakszys P, Głowacki P. Chemistry of snow cover and acidic snowfall during a season with a high level of air pollution on the Hans Glacier, Spitsbergen. Polar Sci. 2016;10:249–261. doi:10.1016/j.polar.2016.06.003
4. Dinu M, Moiseenko T, Baranov D. Snowpack as indicators of atmospheric pollution: The Valday Upland. Atmosphere (Basel). 2020;11. doi:10.3390/ATMOS11050462
5. Pizarro J, Vergara PM, Cerda S, et al. Contaminant emissions as indicators of chemical elements in the snow along a latitudinal gradient in southern Andes. Sci Rep. 2021;11:1–10. doi:10.1038/s41598-021-93895-1
6. He M, Yan P, Yu H, et al. Spatiotemporal modeling of soil heavy metals and early warnings from scenarios-based prediction. Chemosphere. 2020;255:126908. doi:10.1016/j.chemosphere.2020.126908
7. Yuan D, Liu Y, Guo X, Liu J. Characteristic contaminants in snowpack and snowmelt surface runoff from different functional areas in Beijing, China. Environ Sci Pollut Res. 2018;25:36256–36266. doi:10.1007/s11356-018-3501-1
8. Siudek P, Frankowski M, Siepak J. Trace element distribution in the snow cover from an urban area in central Poland. Environ Monit Assess. 2015;187:1–15. doi:10.1007/s10661-015-4446-1
9. Bełcik M, Grzegorzek M, Canales FA, Struk-Sokołowska J, Kaźmierczak B. Examination of interactions between heavy metals and benzotriazoles in rainwater runoff and snowmelt in an urban catchment in Poland. Water Resour Ind. 2024;31. doi:10.1016/j.wri.2023.100236
10. Mitra S, Chakraborty AJ, Tareq AM, et al. Impact of heavy metals on the environment and human health: Novel therapeutic insights to counter the toxicity. J King Saud Univ Sci. 2022;34:101865. doi:10.1016/j.jksus.2022.101865
11. Müller A, Österlund H, Marsalek J, Viklander M. The pollution conveyed by urban runoff: A review of sources. Sci Total Environ. 2020;709:136125. doi:10.1016/j.scitotenv.2019.136125
12. Nsenga Kumwimba M, Zhu B, Stefanakis AI, et al. Advances in ecotechnological methods for diffuse nutrient pollution control: Wicked issues in agricultural and urban watersheds. Front Environ Sci. 2023;11:1–37. doi:10.3389/fenvs.2023.1199923
13. Wallington TJ, Anderson JE, Dolan RH, Winkler SL. Vehicle emissions and urban air quality: 60 years of progress. Atmosphere (Basel). 2022;13. doi:10.3390/atmos13050650
14. Streetmap.pl. https://www.streetmap.pl/topo/.
15. International Organization for Standardization. PN-EN 15935:2022-01 Sludge, treated biowaste, soil and waste — Determination of loss on ignition.
16. Looi LJ, Aris AZ, Yusoff FM, Isa NM, Haris H. Application of enrichment factor, geoaccumulation index, and ecological risk index in assessing the elemental pollution status of surface sediments. Environ Geochem Health. 2019;41:27–42. doi:10.1007/s10653-018-0149-1
17. Regulation of the Minister of the Environment of 23 July 2008. Journal of Laws of 2008, No. 143, item 896.
18. Kim JE, Han YJ, Kim PR, Holsen TM. Factors influencing atmospheric wet deposition of trace elements in rural Korea. Atmos Res. 2012;116:185–194. doi:10.1016/j.atmosres.2012.04.013
19. Dong Z, Kang S, Qin X, et al. New insights into trace elements deposition in the snow packs at remote alpine glaciers in the northern Tibetan Plateau, China. Sci Total Environ. 2015;529:101–113. doi:10.1016/j.scitotenv.2015.05.065
20. Kamani H, Hoseini M, Safari GH, Jaafari J, Mahvi AH. Study of trace elements in wet atmospheric precipitation in Tehran, Iran. Environ Monit Assess. 2014;186:5059–5067. doi:10.1007/s10661-014-3759-9
21. Li T, Wang Y, Li WJ, et al. Concentrations and solubility of trace elements in fine particles at a mountain site, southern China: Regional sources and cloud processing. Atmos Chem Phys. 2015;15:8987–9002. doi:10.5194/acp-15-8987-2015
22. Jarzyna K, Kozłowski R, Szwed M. Chemical properties of snow cover as an impact. 2017:1591–1607.
23. Szwed M, Kozłowski R, Sliwa Z, Zeliaś A, Przybylska J, Ludew M. Hidden in snow: Selected aspects of chemical composition of an urban snow cover (Kielce, SE Poland). Ochr Sr i Zasobow Nat. 2023;34:1–10. doi:10.2478/oszn-2023-0004
24. Grebenshchikova VI, Efimova NV, Doroshkov AA. Chemical composition of snow and soil in Svirsk city (Irkutsk Region, Pribaikal'e). Environ Earth Sci. 2017;76:1–10. doi:10.1007/s12665-017-7056-0
25. Moskovchenko D, Pozhitkov R, Zakharchenko A, Tigeev A. Concentrations of major and trace elements within the snowpack of Tyumen, Russia. Minerals. 2021;11. doi:10.3390/min11070709