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THE IMPACT OF ROAD SALTING ON THE ROADSIDE SOIL CONDITION WITH DIFFERENT LEVELS OF MAINTENANCE

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Abstract. Salts used to reduce road icing alter the chemical composition of soil and induce ion imbalance, potentially leading to geochemical anomalies in roadside soils. This environmental problem is relevant in Lithuania due to the large amounts of technical salt spread on roads annually. This study investigates the relationship between road maintenance intensity (K3, K4, K5, and K5ž) and heavy metal concentrations in roadside soils. The research was conducted in the Biržai district, selecting nearby roads to ensure relative homogeneity of natural conditions and reduce potential distortions from external factors. The results show that higher concentrations of certain heavy metals are associated with more intensively maintained roads compared to background levels. These findings suggest that intensive use of road de-icing salts can significantly affect roadside soil quality and highlight the need for more environmentally friendly maintenance practices.

Keywords: heavy metals, road salting, roadside soil, maintenance levels.

1. Introduction

During the winter season, de-icing agents are widely used for road maintenance, the most common of which is sodium chloride (NaCl). This practice is used to ensure traffic safety and reduce the risk of accidents. It also has a long-term environmental consequence (Górecka et al., 2023). Intensive use of salts is characteristic of both Lithuania and other countries with moderate and cold climates, with quantities reaching hundreds of thousands of tons each year (AB "Kelių priežiūra", n.d.). Although salt effectively melts ice and snow, it enters the environment during spreading and migrates into roadside soils, surface and groundwater, thus affecting natural ecosystems (Asensio et al., 2017; Nelson et al., 2009).

Scientific research shows that chloride salts (NaCl, $MgCl_2$, $CaCl_2$) used for road gritting alter the chemical composition of the soil, increase the concentration of sodium and chloride ions, disrupt cation exchange processes, and promote soil salinization (Norrström & Bergstedt, 2001; Green & Cresser, 2008; Aghazadeh et al., 2012). These processes deteriorate soil structure, reduce porosity and water infiltration, and weaken microbial activity as well as plant resistance to environmental stress (Hofman et al., 2012; Jamshidi et al., 2020). In addition, the impact of salts is associated with changes in the nitrogen cycle, pH fluctuations, and a decline in biodiversity in roadside ecosystems. Long-term salt accumulation can lead to vegetation loss, changes in vegetation, and destabilization of the entire soil ecosystem (Gerasimov et al., 2021; Beral et al., 2023).

Particularly concerning the ability of salts to mobilize heavy metals such as lead (Pb), cadmium (Cd), copper (Cu), zinc (Zn), and nickel (Ni), which enter roadside soils through transportation, brake and tire wear, and other anthropogenic sources. Chloride ions can form soluble complexes with metals, thereby increasing their mobility in the soil and migration into groundwater. This synergistic interaction between salts and heavy metals increases the ecological risk, as metals at high concentrations are toxic, bioaccumulative, and persistent in the environment (Councell et al., 2004; Davis et al., 2001; Hosseini & Sobhanardakani, 2024).

Table 1. Road maintenance levels in Lithuania (source: AB „Kelių priežiūra", n.d.)

Level of maintenance	Roads
1	Major highways (A1, A2, VIA Baltica, etc.)
2	Regional and national roads with higher traffic intensity
3	Lower priority regional and national roads
4	District roads with less than 1,000 vehicles per day
5 ir 5ž	Very low traffic intensity roads (5) and local gravel roads (5ž)

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In Lithuania, road maintenance during the winter season is organized according to established maintenance levels, with priority given to highways and roads with the heaviest traffic (Table 1; AB "Kelių priežiūra", n.d.). Although this system effectively ensures traffic safety, it also involves the continuous and large-scale use of salt. This in the long term can have a significant impact on the quality of roadside soil and the condition of the environment. In the context of climate change, increasing urbanisation and growing transport intensity, the relevance of this problem is only increasing (Jandová et al., 2020; Kazlauskienė & Brukštutė, 2015).

The aim of this study is to assess the differences in heavy metal concentrations in roadside soil in the city of Biržai at different road maintenance levels (K3, K4, K5, and K5ž). Our study is aimed to determine the variation in heavy metal concentrations in different winter maintenance intensity categories and to compare the obtained values with background and limit concentrations. This study is important because there is currently a lack of data on how different levels of winter road maintenance intensity and salt use affect roadside soil contamination in smaller Lithuanian towns. There are no level 1 and 2 maintenance roads in the Biržai district, so lower category roads constitute the main infrastructure, but their impact on the environment has barely been studied to date. The selected road sections differ in terms of traffic and winter maintenance intensity and salt use, while the K5ž level road, where salt is not used, provides an opportunity for comparison as a control. The results of the study will provide important information on the links between winter road maintenance practices and heavy metal accumulation and may be useful in shaping environmental management decisions and planning further research in similar climatic conditions.

2. Materials and methods

2.1. Description of the study area

The study was conducted in Biržai, a town located in northern Lithuania, in the Panevėžys district, near the border with Latvia. The town has a transition maritime-continental climate typical of mid-latitudes, characterized by cold winters, frequent snowstorms, and precipitation (Tadić et al., 2019). Due to these factors, salt is widely used on roads during the winter to ensure traffic safety (Table 2). The most commonly used mixtures are based on sodium chloride, which can affect the chemical and physical properties of roadside soil (Strelkute & Braduliene, 2014).

There are roads with different levels of maintenance in Biržai, ranging from intensively maintained main streets to roads of national importance. This creates favourable conditions for studying the impact of salt spreading on the condition of roadside soil depending on the intensity of road maintenance.

Table 2. Road maintenance levels with designated roads in Lithuania (source: AB „Kelių priežiūra“, n.d.)

Level of maintenance	Tasks performed	Materials used
1	24/7 monitoring, preventive and continuous gritting, intensive snow removal, road cleared within ≤ 2 hours, work repeated every ≤ 3 hours.	NaCl solution, moistened salt, $CaCl_2$ (up to –25 °C)
2	Maintenance 4–22 hours, preventive and operational gritting, work ≤ 3 hours, repeated every ≤ 5 hours.	NaCl solutions, $CaCl_2$, lower rates
3	Maintenance 4–19 hours, no preventive spreading, spreading only when slippery conditions arise, snow and snow drifts permitted.	NaCl solutions, salt-sand mixtures (DSM 1:1–1:10)
4	Maintenance 6–18 hours, spread only in case of danger, priority is passability	Salt-sand mixtures (DSM), usually dry.
5 ir 5ž	Maintenance 9 a.m.–6 p.m., spreading only in extreme conditions, priority is passability.	DSM is used very sparingly, only when necessary.

2.2. Research object

Since there are no roads of maintenance levels 1 and 2 in Biržai District, the soil of roads of maintenance levels 3, 4, 5, and 5ž was selected as the object of the study:

- A 50-kilometer section of road No. 124 Kupiškis–Vabalninkas–Biržai was studied for level 3 maintenance roads.
- The section of road with maintenance level 4 was selected on road No. 1305 Rinkuškiai–Juostaviečiai–Nemunėlio Radviliškis, on a 2–3 kilometer section.
- The section of road with maintenance level 5 was selected on road No. 1317 Biržai–Obelaukiai, on a 1 kilometer section.
- A section of road with a maintenance level of 5ž was selected on road No. 1314 Biržai–Anglininkai–Papilys, on a 4-kilometer section, which serves as a control, as no salt or salt-sand mixtures are used on these roads in winter, and snow is only cleared (Figure 1).

The selection of these sections was determined by the different intensity of traffic and winter road maintenance works, taking into account the recommendations of road maintenance workers, as well as the accessibility of roadside soil. There are no sidewalks next to the roadway on the selected sections – the roadside consists of a 1 m wide roadside verge, usually covered with gravel, beyond which the natural roadside soil begins. These conditions made it possible to directly study the effect of salt spreading on roadside soil, reducing the influence of other urban factors.

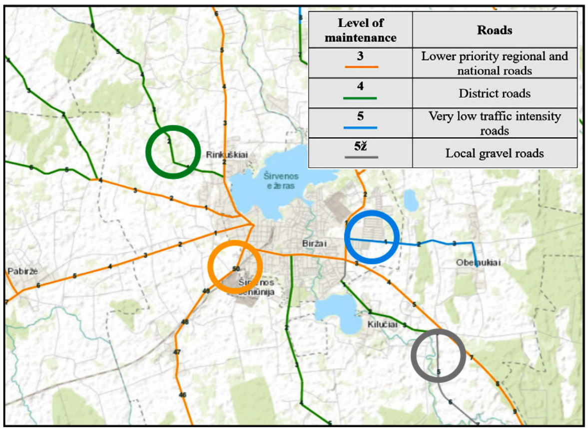

Figure 1. Circles indicate road sections where soil samples were collected (source: map from the website of AB "Kelių priežiūra", n.d. (Road Maintenance) entitled "Road maintenance levels")

2.3. Sample collection

Soil samples were collected in April, after winter road maintenance work. Samples were taken from the top 0–20 cm layer of soil, in accordance with established soil sampling standards and using the "envelope method". The envelope principle means that soil for a single sample is taken from five points: four sampling points are selected at the corners of a conditional rectangle, and the fifth is at the center of this rectangle, thus forming a pattern that corresponds to the envelope principle.

Ten composite soil samples were collected at each selected road section, taking them every 25 meters. Soil samples were taken using a plastic trowel to avoid possible metal contamination. Five soil samples taken using the envelope principle were thoroughly mixed in a plastic bucket. Final sample was taken from the resulting homogeneous mass, which was packed into a sealable plastic bag. This procedure was repeated 10 times on each of the four road sections studied, resulting in a total of 40 soil samples collected for the study.

Salt samples obtained from the Biržai department of AB "Kelių priežiūra" (Road Maintenance) were used for the experimental studies.

2.4. Preparation of soil and salt samples for analyses of heavy metal concentrations

The collected soil samples were first prepared for laboratory testing to ensure reliable and comparable results for the determination of heavy metals. The samples were spread on Petri dishes and dried to a constant weight at 105 °C in a thermostatic drying oven (MMM Medcenter Einrichtungen GmbH, Germany). Drying was used to remove moisture from the soil, which affects the accuracy of determination of chemical element concentration.

The dried soil samples were ground using a homogenizer (Spec sampleprep, USA). The samples were ground in order to obtain a homogeneous soil fraction, reduce particle size, and ensure that the analysed sample represented the entire sample. Homogenisation is particularly important in the analysis of heavy metals, as the distribution of these elements in the soil and salt may be uneven.

2.5. Detection of concentrations of heavy metals

The concentration of heavy metals in soil and salt samples was determined using energy dispersive X-ray fluorescence spectrometry (ED-XRF). Elemental analysis of samples was performed at the Lithuanian Geological Survey (LGT) using SPECTRO XEPOS ED-XRF spectrometric equipment. This method is widely used in environmental pollution studies due to its reliability, speed, and ability to determine the concentrations of many chemical elements at the same time.

The principle of the ED-XRF method is based on the fact that the sample is exposed to primary X-rays, which excite the atoms of the chemical elements in the sample. SPECTRO XEPOS EDXRF equipment is highly sensitive and sufficiently accurate for soil contamination studies, and the non-destructive nature of the method reduces the risk of additional sample processing and possible errors.

Cr, Ni, Cu, Zn, As, Sn, and Pb were selected for further analysis in our research. These metals were chosen because of their frequent association with road transport activities and winter road maintenance (Tou et al., 2022).

2.6. Determination of the revised limit value (RV_p) for chemical substances

The RV_p for a chemical substance in soil is used to more accurately assess soil contamination with heavy metals, taking into account the physical and chemical properties of the soil. Unlike the base limit value, the RV_p allows the limit concentrations of heavy metals to be adjusted according to the actual content of clay particles and organic matter in the soil, which determine the sorption, mobility, and biological availability of metals (Ministry of Health of the Republic of Lithuania, 2004). The adjusted limit value is calculated according to the equation:

$$RV_P = RV \times \frac{A + (B \times M(\%)) + C \times OM(\%))}{A + (B \times 10) + (C + 3}, \qquad (1)$$

where *M* (%) is the percentage of clay particles (smaller than 0.002 mm) in the soil being tested. In cases where the clay particle content of the soil is more than 50% or less than 10%, the values 50% or 10% are entered into the formula, respectively; *OM* (%) – the organic matter content of the soil (%). In cases where the determined content of organic matter in the soil is more than 10% or less than 3%, the values 10% or 3% are entered into the formula, respectively. *A*, *B*, *C* – coefficients whose values depend on the concentration of heavy metals (Lietuvos Respublikos aplinkos ministerija, 2005).

2.7. Determination of geochemical background values (B_n)

Determining B_n is an important and frequently used tool in assessing contamination by heavy metals in roadside soil, as it allows natural and anthropogenic metal concentrations to be distinguished and enables a more accurate assessment of contamination levels and potential ecological risks. The geochemical threshold helps to differentiate between elements of geogenic origin and pollution caused by anthropogenic activity (Dung et al., 2013). The geochemical values were calculated by the following equation: Geochemical background value (B_n) = Median ± 2 × MAD (Zhang & Zhang, 2019).

2.8. Geo-accumulation index (I_{geo})

I_{geo} is used to assess heavy metal contamination in roadside soil in various studies. This index allows the degree of contamination to be assessed by comparing the existing metal concentrations with natural background levels. It is often used in conjunction with other contamination indicators such as the Contamination Factor (*CF*) or Enrichment Factor (*EF*) (Table 3).

Table 3. Classification of geoaccumulation index (I_{geo}) in relation to soil quality

I_{geo}	I_{geo} classes	Soil quality
$I_{geo} \le 0$	0	Unpolluted
$0 < I_{geo} \le 1$	1	Unpolluted to moderately polluted
$1 < I_{geo} \le 2$	2	Moderately polluted
$2 < I_{geo} \le 3$	3	Moderately polluted to highly polluted
$3 < I_{geo} \le 4$	4	Highly polluted
$4 < I_{geo} \le 5$	5	Highly polluted to very highly polluted
$I_{geo} > 5$	6	Very highly polluted

For example, in a roadside soil study in Aizawl (Mizoram, India), I_{geo} was used in conjunction with other indices to determine the average level of contamination by heavy metals such as copper, iron, manganese, nickel, lead, and zinc. This index helped to identify anthropogenic sources such as vehicle emissions and industrial activities, and to monitor fluctuations in contamination due to seasonal factors and the impact of the pandemic (Lallawmzuali et al., 2024). Pollution levels are divided into seven core classes forthe index of geo-accumulation, which are enlisted in Table 3 (Müller, 1969). The equation for computation of I_{geo} is as follows:

$$I_{geo} = \log_2 \frac{C_n}{B_n \times 1.5}, \tag{2}$$

where C_n represents the concentration of the specific heavy metal being analysed, 1.5 is a constant used to account for possible natural fluctuations and minor environmental variability, and B_n denotes the geochemical background concentration of particular heavy metal.

2.9. Contamination Factor (CF)

The *CF* is calculated using the equation below, is a method for determining and assessing the degree of contamination by heavy metals. For example, in the soils of Beni-Mellal, irrigated with wastewater, *CF* was used in combination with other indices (geo-accumulation index, enrichment factor) to determine the level of heavy metal contamination, which ranged from moderate to high. (Barakat et al., 2020). It is calculated as:

$$CF = \frac{C_{sample}}{C_{background}}, \tag{3}$$

where $C_{background}$ is the background value of trace elements in earth crust (Table 4) and C_{sample} is the concentration of the elements found in samples. If the $CF \le 1$, low contamination; $1 < CF \le 3$, moderate contamination; $3 < CF \le 6$, considerable contamination; and $CF > 6$, very high contamination (Gope et al., 2017).

Table 4. HM background concentrations in Lithuania (source: Lietuvos Respublikos aplinkos ministerija, 2005)

HM	Cr	Ni	Cu	Zn	As	Sn	Pb
$C_{background}$ (mg/kg)	30	12	8.1	26	2.5	2	15

2.10. Pollution Load Index (*PLI*)

PLI is often used in soil surveys to assess contamination by concentrations of heavy metals and to identify sources of contamination, as well as to evaluate ecological risk (Lallawmzuali et al., 2024). PLI was calculated for a single location and zone using *CF*:

$$PLI_{for\ a\ site} = (CF_1 \times CF_2 \times \ldots \times CF_n)^{\frac{1}{n}}; \tag{4}$$

$$PLI_{for\ a\ zone} = (PLI_{site\ 1} \times PLI_{site\ 2} \times \ldots \times PLI_{site\ n})^{\frac{1}{n}}, \tag{5}$$

where *n* is the total number of heavy metals and *CF* is each heavy metal's contamination factor. $PLI < 1$ means that there is no pollution; $PLI = 1$ means that there is only a baseline level of pollution; and $PLI > 1$ means that the quality of the site has deteriorated (Gope et al., 2017). This method has also been used by other authors in their analysis of heavy metals in roadside soil (Ahmed et al., 2016).

2.11. Enrichment Factor (*EF*)

EF is a widely used and appropriate method for assessing contamination by heavy metals in roadside soil, allowing the degree of enrichment and possible anthropogenic origin to be determined (Owhoeke et al., 2023). *EF* is calculated by normalizing the concentrations of the metals under investigation according to a reference element that is stable and little affected by anthropogenic activity. In this study, aluminium (Al) was chosen as the reference element due to its stability and prevalence in the Earth's crust. It is a primary element of crustal (earth's crust) origin, which is generally affected by anthropogenic sources, and therefore its concentration in the environment is relatively constant and representative of the natural background (Zhao et al., 2014). EF of heavy metals in the soil of all selected sites was quantified by the following equation:

$$EF = \frac{\left(\dfrac{C_n}{C_{Ref.(\mathrm{Al})}}\right)}{\left(\dfrac{B_n}{B_{Ref.(\mathrm{Al})}}\right)}, \qquad (6)$$

where C_n is the target heavy metal, *Ref.* is the reference element, which is Al for the current study, and Bn is the geochemical background value (Arooj et al., 2025).

3. Discussions and results

3.1. Chemical composition analysis of salt samples

Pure salt samples used for road maintenance, it was found that pure salt, used for preparing for mixture, has relatively low concentrations of heavy metals (Table 5).

Table 5. Chemical composition of salt samples

HM (mg/kg)	Cr	Ni	Cu	Zn	As	Sn	Pb
Salt for DSM	6.7 ± 0,4	–	3.1 ± 0.9	2.9 ± 0.6	–	2.3 ± 0.4	0.3 ± 0.4
DSM	9.1 ± 0.3	2.0 ± 0.6	7 ± 0.9	9.1 ± 0.7	–	2.4 ± 0.4	7.1 ± 0.4

No nickel (Ni) or arsenic (As) was detected in either salt sample as well lead (Pb) levels were low. Significantly higher concentrations of heavy metals were found in the salt and sand mixture (DSM). In addition, nickel (Ni) was detected only in the DSM sample, indicating that sand is the main source of heavy metals in the mixture. The results obtained suggest that the use of salt and sand mixtures may pose the greatest potential environmental risk, especially on more heavily trafficked roads.

3.2. Analysis of heavy metals in roadside soil at different levels of road maintenance

Samples were collected in the spring after the winter work season had ended and the snow had melted. Ten soil samples were taken from each roadside section with different maintenance levels, for a total of 40 samples. After analysing 40 samples for concentrations of heavy metals using the ED-XRF method, the concentrations of heavy metals in the roadside soil were determined. Cr, Ni, Cu, Zn, As, Sn, and Pb were selected for further analysis due to their frequent association with road transport activities and winter road maintenance works (Tou et al., 2022).

When assessing heavy metal concentrations according to road maintenance categories (in descending order of priority: K3, K4, K5, K5ž), it was found that the highest concentrations of most elements were recorded in the K3 zone (Figure 2): Cr (72.18 mg/kg) exceeds the Revised Limit Value (RLV = 55.3 mg/kg) set by HN 60:2015 and significantly exceeds the background concentration (30 mg/kg); Zn (162.32 mg/kg) does not exceed the RLV (180.7 mg/kg), but exceeds the background level (26 mg/kg) by more than six times. Similarly, Cu (33.13 mg/kg), Pb (34.38 mg/kg), Ni (22.42 mg/kg), As (3.87 mg/kg), and Sn (4.02 mg/kg) do not exceed the respective limit values (46.4; 62.9; 32.1; 13.5 and 6.4 mg/kg), but in all cases are higher than the background values (8.1; 15; 12; 2.5 and 2.1 mg/kg). Although category K4 has a higher monitoring priority than K5, the concentrations found in it are lower in most cases (e.g., Cr – 33.56 mg/kg; Zn – 73.56 mg/kg) and do not exceed the RLV, but remain higher than the background values. Meanwhile, in category K5, the concentrations of some metals (e.g., Zn – 91.55 mg/kg; Ni – 23.82 mg/kg; Pb – 25.97 mg/kg) are higher than in K4, although the monitoring priority is lower. This may be related to the sampling location – the soil was collected from a ditch where pollutants accumulate and have limited migration and leaching possibilities, unlike in other categories where samples were taken from a flat surface (fields), which creates more favourable conditions for metal dispersion. Category K5ž acts as a control, as road salt is not used in winter; relatively lower concentrations are found here (e.g., Cr – 34.48 mg/kg; Zn – 88.60 mg/kg; Pb – 23.17 mg/kg), which do not exceed the limit values, but most still exceed the background level, indicating a general anthropogenic impact.

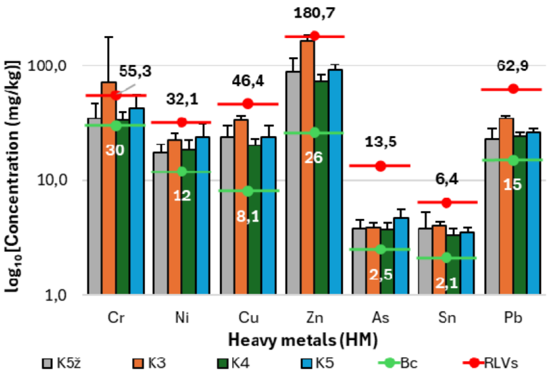

Figure 2. Concentrations of heavy metals
(Cr, Ni, Cu, Zn, As, Sn, W, and Pb)

After normalizing concentrations relative to K5ž (control) (K5ž = 1), the most pronounced enrichment of heavy metals was found in the K3 category, which is most intensively gritted in winter (Figure 3).

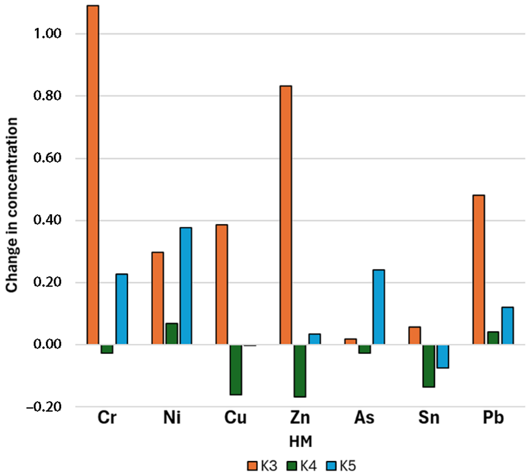

Figure 3. Relative values of heavy metal concentrations (normalized to K5ž) in the soil of roadside verges of different road maintenance categories

Zn stands out in particular (≈1.8 times higher than in the control), as do increased concentrations of Pb (≈1.5 times), Cu (≈1.4 times) and Ni (≈1.3 times); the concentration of Cr was also more than twice as high as in K5ž. Meanwhile, in category K4, the relative values of most elements are close to 1 or lower (Cu, Zn, Sn <1), indicating poor or insignificant accumulation. In category K5, moderate enrichment was found (especially Ni, Cr, As, and Pb), but it was lower than in K3. The results obtained show a clear trend that more intensive road maintenance and the use of road salt are associated with higher accumulation of certain metals (especially Zn, Pb, and Cu) in roadside soil in the spring, after the winter season.

3.3. Determination of geochemical background values (B_n)

B_n determined using the median ± 2MAD method showed that in all road areas studied (K3, K4, K5, and K5ž), the median concentrations of Cr, Ni, Cu, Zn, As, Sn, and Pb fell within the established background value ranges (Table 6).

This indicates that no statistically significant outliers clearly indicate anthropogenic pollution were found. Although the variability of concentrations of some metals, especially Zn and Cr, was higher and characterized by wider Bn intervals, their levels did not exceed geochemical background limits. This distribution suggests that the concentrations of heavy metals in roadside soil after the winter season mainly reflect the natural background, and the possible impact of transport and winter road maintenance does not manifest itself as statistically significant pollution according to the method used.

Table 6. Determination of geochemical background values(B_n)by absolute deviation from median method

	K3		
HM	B_n Med.	Range of B_n	
Cr	39.4	−86.531	165.3
Ni	23.0	18.2772	27.7
Cu	33.7	26.8156	40.5
Zn	153.3	115.017	191.7
As	3.9	3.0935	4.7
Sn	4.0	3.5279	4.5
Pb	34.0	30.3609	37.6
Al	32 187.6	26 911.8	37 463.4
	K4		
HM	B_n Med.	Range of B_n	
Cr	32.4	23.9	40.8809
Ni	17.6	11.5	23.6913
Cu	19.5	14.4	24.6499
Zn	69.2	52.6	85.87
As	3.5	2.6	4.45816
Sn	3.3	2.4	4.1372
Pb	23.5	19.8	27.284
Al	35 379.9	28 296.8	42 462.9
	K5		
HM	B_n Med.	Range of B_n	
Cr	40.0	18.4	61.5276
Ni	20.7	9.7	31.7539
Cu	21.6	12.7	30.5194
Zn	90.1	73.5	106.819
As	4.4	3.3	5.52146
Sn	3.6	3.0	4.1737
Pb	26.7	22.9	30.5748
Al	39 544.7	27 446.0	51 643.3
	K5ž		
HM	B_n Med.	Range of B_n	
Cr	30.5	14.3	46.8
Ni	17.0	11.9	22.1
Cu	21.7	10.6	32.7
Zn	73.1	19.9	126.3
As	3.6	2.4	4.7
Sn	3.4	1.5	5.3
Pb	21.5	13,5	29.6
Al	31 706.3	25 739.1	37 673.6

3.4. Geo-accumulation index (I_{geo})

In all the sites studied, I_{geo} values mostly ranged between classes 0 and 2, so the soil is considered uncontaminated or moderately contaminated, with no very high or extreme contamination detected (Table 7).

Table 7. Classification and comparison of geo accumulation index (I_{geo})

I_{geo}	K3	K4	K5	K5ž
Cr	0.1	–0.4	–0.2	–0.5
Ni	0.3	0.0	0.3	–0.1
Cu	1.4	0.7	0.9	0.9
Zn	2.0	0.9	1.2	1.1
As	0.0	0.0	0.3	0.0
Sn	0.3	0.0	0.2	0.2
Pb	0.6	0.1	0.2	0.0

In the K3 monitoring category, the highest geo-accumulation was found for Zn ($I_{geo} = 2.0$), which is classified as class 2 (moderately contaminated), as well as Cu (1.4) – class 2. Pb (0.6), Ni (0.3), Sn (0.3), and Cr (0.1) were classified as class 1 (uncontaminated to moderately contaminated), while as (0.0) showed background levels (class 0). In zone K4, all metals were classified as grades 0–1, with the highest values found for Zn (0.9) and Cu (0.7), therefore the soil is assessed as uncontaminated to moderately contaminated. In zone K5, Zn (1.2) and Cu (0.9) showed class 1–2 contamination, while other metals remained in classes 0–1. The situation in zone K5ž is similar – Zn (1.1) and Cu (0.9) showed the highest geo-accumulation, but did not exceed the average contamination limits, while Cr (–0.5) and Ni (–0.1) corresponded to the level of uncontaminated soil. A general comparison of the zones shows that the highest geo-accumulation was found in zone K3, especially for Zn and Cu, while the lowest contamination level was recorded in zone K4.

3.5. Contamination Factor (CF)

CF showed uneven heavy metal accumulation intensity in different road maintenance categories (K3, K4, K5, and K5ž) (Table 8).

Table 8. Classification and comparison of contamination factor

CF	Cr	Ni	Cu	Zn	As	Sn	Pb
K5ž	1.1	1.4	3.0	3.4	1.5	1.8	1.5
K3	2.4	1.9	4.1	6.2	1.5	1.9	2.3
K4	1.1	1.5	2.5	2.8	1.5	1.6	1.6
K5	1.4	2.0	2.9	3.5	1.9	1.7	1.7

According to the general classification (CF ≤ 1 – low pollution; 1 < CF ≤ 3 – moderate pollution; 3 < CF ≤ 6 – significant pollution; > 6 – very high pollution), in all categories, the CF values of most of the elements studied (Cr, Ni, As, Sn, Pb) ranged from 1.1 to 2.3, which corresponds to a medium level of pollution. The highest pollution coefficients were found for zinc (Zn) and copper (Cu). In category K3, Zn CF reached 6.2, which indicates very high pollution, and Cu – 4.1 (indicates pollution). In categories K5ž and K5, Zn CF was 3.4 and 3.5 (indicates pollution), respectively, and Cu – 3.0 and 2.9 (moderate to significant pollution). In category K4, the CF values for all metals remained moderate (1.1–2.8), so this category has the lowest level of pollution compared to the others. In summary, it can be stated that the greatest anthropogenic impact was found on roads in category K3, especially due to the accumulation of Zn and Cu, while the concentrations of Cr, Ni, As, Sn, and Pb in all categories remain within the limits of moderate pollution.

3.6. Pollution Load Index (PLI)

PLI The PLI provides an integrated, comparable assessment of environmental quality across different road maintenance categories. The base value of the PLI is 1. If the index exceeds 1, this indicates a deterioration in environmental quality and the impact of anthropogenic pollution.

Analysis of sites showed that in category K3, the PLI ranged from 2.0 to 3.6, with the highest value (3.6) found at site 10, indicating the relatively highest overall pollution among all sites studied (Table 9). In category K4, the PLI ranged from 1.5 to 2.2, indicating a lower but still increased pollution load. In category K5, the values ranged from 1.7 to 2.8, with the highest value (2.8) found at site 2. In category K5ž, the PLI ranged from 1.4 to 2.3, with the highest values (2.3) recorded at locations 1, 4, and 6.

When evaluating the averages for the zones, the highest overall PLI was found in category K3 (2.2), followed by K5 (2.0), K5ž (1.8), and the lowest in K4 (1.7) (Table 10). Although the indices for all categories exceed the base value (PLI = 1), indicating a decline in environmental quality, the highest cumulative pollution load was found in K3 zones. It should be noted that the PLI does not allow for the assessment of the interaction of individual pollutants or possible toxicological consequences, but it provides a clear comparison of the overall contamination level between different areas and can be used to monitor spatial and temporal changes.

Table 9. Comparison of pollution load index for site ($PLI_{for\ site}$)

$PLI_{for\ site}$	K3	K4	K5	K5ž
1	2.4	1.5	1.8	2.3
2	2.3	1.6	2.8	1.7
3	2.4	1.8	1.8	1,5
4	2.5	2.2	1.7	2.3
5	2.2	1.5	2.0	1.6
6	2.0	1.8	1.8	2.3
7	2.3	1.8	2.3	1.9
8	2.3	1.8	2.2	1.4
9	2.6	1.5	2.3	1.6
10	3.6	1.7	1.7	1.4

Table 10. Comparison of pollution load index for zone ($PLI_{for\ zone}$)

	K3	K4	K5	K5ž
$PLI_{for\ zone}$	2.2	1.7	2.0	1.8

3.7. Enrichment factor (EF)

The results show that in all road maintenance categories (K3, K4, K5, and K5ž), the EF values of most of the metals studied range between 0.9 and 1.2, which corresponds to minimal or almost non-existent pre-enrichment (Table 11).

In category K3, Cr stands out (EF = 1.8), showing weak but relatively the highest enrichment among all metals tested, while Zn reaches 1.1, and Ni, Cu, As, Sn, and Pb remain close to the background value (EF ≈ 1.0). In category K4, the EF values of all metals are equal to 1.0, indicating a background level with no signs of additional accumulation. Very similar values (1.0–1.1) were found in category K5, while Sn and Pb EF (0.9) are slightly lower than 1, which may indicate natural geochemical variation. In category K5ž, slightly higher values of Zn (1.2), Cu (1.1), As (1.1), Sn (1.1), and Pb (1.1) were recorded, but they still fall within the minimum enrichment interval. The sequence of metal enrichment in descending order in the K3 zone is Cr > Zn > Ni = Cu = As = Sn = Pb, and in the K5ž zone – Zn > Cu = As = Sn = Pb > Cr > Ni.

Table 11. Classification and comparison of enrichment factor

EF	K3	K4	K5	K5ž
Cr	1.8	1.0	1.0	1.1
Ni	1.0	1.0	1.1	1.0
Cu	1.0	1.0	1.1	1.1
Zn	1.1	1.0	1.0	1.2
As	1.0	1.0	1.0	1.1
Sn	1.0	1.0	0.9	1.1
Pb	1.0	1.0	0.9	1.1

4. Conclusions

The study showed that the concentrations of heavy metals (Cr, Ni, Cu, Zn, As, Sn, and Pb) in the soil along roadsides with different levels of maintenance (K3, K4, K5, and K5ž) in the city of Biržai are related to the intensity of winter road maintenance. The highest concentrations of most metals were found in category K3, where more intensive maintenance is applied. Zn and Cu stood out in particular, while Cr exceeded the specified limit value. According to the geo-accumulation index (I_{geo}) and Contamination Factor (CF), Zn and Cu reached moderate or significant contamination levels in some places, while Zn showed very high contamination in the K3 zone according to CF. The Pollution Load Index (PLI) exceeded 1 in all zones, reaching its highest value in K3 (2.2) and its lowest in K4 (1.7), but even in the control zone K5ž (1.8), anthropogenic impact was detected. Geochemical background analysis (Median ± 2MAD) showed that the median concentrations did not exceed the background intervals, and the Enrichment Factor (EF) for most metals was close to 1, indicating minimal anthropogenic enrichment. The exception was weak for Cr enrichment in zone K3. It was found that metal concentrations in salt-sand mixtures are higher than in pure salt, so sand may be an additional source of metals. In summary, it can be stated that more intensive winter road maintenance is associated with higher Zn and Cu accumulation in roadside soil, but the overall pollution level remains from unpolluted to moderately polluted. Thus, the aim of the study – to assess the differences in heavy metal concentrations in roadside soil in the town of Biržai at different levels of road maintenance – was achieved, and the hypothesis that more intensive winter road maintenance leads to higher accumulation of heavy metals in the soil was essentially confirmed, especially with regard to Zn and Cu. Although in most cases the effect did not exceed the geochemical background limits.

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