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ANNA HOŁTRA (ORCID: 0000-0001-7999-3719)[1], ŁUKASZ ŁOŚ[1]

RISKS OF POTENTIALLY TOXIC ELEMENTS (PTEs) IN ROAD SOILS AND NOISE BARRIER DUST FROM THE LINEAR EMISSION IN ŻAGAŃ, POLAND

The investigation report concerns anthropogenic enrichment of road soils under a noise barrier and road dust collected from its surface with potentially toxic elements (PTEs). Circular traffic and slower car access to the roundabout on the busy bypass in Żagań indicate that soils closer to the roundabout contain nearly twice as much of metals as the road dust. Further from the roundabout, the situation is reversed, primarily regarding lead and copper content in road dust. The recorded concentrations of Pb, Cu, and Zn are permissible in road soils, but in two locations, they exceed the allowed limits for soils in residential areas near the DK12 national road. The individual and integrated pollution indices confirm a deterioration in the quality of soil and dust samples. The Nemerow index indicates that 80% of road soils and 90% of noise barrier dust are heavily polluted. Lower PTE pollution is observed at the endpoints of the barrier. A potentially high ecological risk has been estimated in the soil near the roundabout; therefore, environmental monitoring should be continued. No health risk is currently present, which is important for the safety of residents living behind the barrier, within 80 m of a road.

1. INTRODUCTION

The intensive development of road networks and transport causes increasing contamination of the atmosphere and soils with heavy metals along roadways and in the immediate vicinity of communication routes. According to data from the Central Statistical Office, the number of passenger cars in Poland has grown more than fourfold over the past 30 years. In the early 1990s, there were 5.3 million registered vehicles, and by the end of 2024, this number reached 22.9 million [1]. Besides road infrastructure, traffic volume, and driving conditions, the amount of linear emissions is also influenced by the topography and land use. Characteristic indicators used to assess the environmental

[1]Wrocław University of Science and Technology, Faculty of Environmental Engineering, Wybrzeże Wyspiańs-kiego 27, 50-370 Wrocław, Poland, corresponding author A. Hołtra, email address: anna.holtra @pwr.edu.pl

condition along communication routes are primarily road soils [2–7] and dust collected directly from the road surface [8]. Road dust trapped on vertical noise barriers adjacent to these routes is also included in monitoring efforts [9, 10].

Road transport primarily causes soil contamination with heavy metals and also soil acidification, which consequently leads to greater dissolution of heavy metals and their uptake by plants. Potentially toxic elements (PTEs) present in particulate matter suspended near communication routes mainly originate from tire abrasion, wear of vehicle structural components, fuel combustion, oil and grease leaks, and additionally from traffic accidents, repair and maintenance works on road infrastructure, road de-icing, and spraying of grassy verges. They can also be washed off the road surface by rainfall or dispersed with water as splashes from vehicle wheels. The pathway of PTE transport largely determines the range of contamination. Surface runoff is responsible for transporting PTEs within the road strip for a distance of 5 m from the road; splashed rainwater may carry them up to 10 m, and air transport can reach beyond 50 m, depending on the size of road dust particles, as respirable dust may reach even a distance of several hundred meters. These transport ranges of PTEs also define the boundaries of areas with potentially elevated contaminant levels in the surface soil layer [7]. Transport can be responsible for up to 53% of metal emissions [8, 9].

Noise barriers locally reduce the dispersion of heavy metals [3–6]. Particularly high metal concentrations at the base of the barrier result from weather conditions – rainfall and snowmelt wash dust pollutants off the barrier surface, causing soil enrichment. Levels of PTEs near the noise barrier also depend on its distance from the road. Corrosion of steel panels with galvanized elements constitutes an additional factor in anthropogenic soil contamination, especially when in contact with road salt. Generally, significantly higher levels of heavy metals are recorded in the area between the road and the noise barrier due to the blockage of air masses carrying pollutants from road transport. Unfortunately, the barrier does not completely prevent the spatial migration of contaminants, but rather changes their deposition location. Air turbulence generated by the vertical barrier contributes to irregular transport of dust far beyond the barrier, resulting in higher levels of PTEs at distances of 20 m, and even up to 50 m, posing an environmental risk [3, 5]. In comparison, without a noise barrier, a decreasing distribution of traffic pollutants is observed, but over a larger area affecting the soil, with the highest metal concentrations found closer to the road, at a distance of 8 m [2, 4, 5].

Alterations in the chemical composition of road soils and their acidification can cause severe disturbances in physicochemical properties and biological activity. Consequently, this leads to a depletion of plant cover in areas with excessive concentrations of trace elements. Moreover, the chemical form of a metal determines its mobility in the soil and bioavailability, thereby defining the degree of its toxicity [11]. Linear emissions should be monitored for public health reasons. Along transportation routes, cyclists and pedestrians are most at risk of exposure to PTEs from road dust, as well as residents living within the range of pollution from busy roads [8]. The accumulation of toxic elements in the body, such as lead, copper, and zinc, may cause kidney and liver diseases, induce changes in the nervous, digestive, skeletal, and cardiovascular systems, and contribute to the development of cancer [12].

The research aimed to evaluate the effectiveness of the noise barrier at the Żagań bypass in reducing linear emissions and environmental exposure to selected PTEs. The total concentrations of Pb, Cu, and Zn, considered key tracers of traffic-related emissions, were analyzed in samples of road dust collected from the surface of the noise barrier and in soil samples along the national road barrier. Contamination of road dust and soil samples was assessed by determining pollution indices, and risk assessment factors were calculated to forecast the environmental toxicology of the road dust and soils.

2. MATERIALS AND METHODS

Study area. The research material consisted of road dust from the surface of a noise barrier and soil samples collected along a section of National Road 12 (DK12) in Żagań, Lubusz Voivodeship. DK12 is a city bypass opened in February 2006. According to general traffic measurement data, the traffic volume on the studied road section reaches approximately 7184 vehicles per day [13]. The barrier is a metal structure 268 m long and 3.1 m high on a grassy embankment with a height ranging from 1.5 to 2.5 m. Behind the noise barrier, along locations 1–3, there is a green belt (8 m wide), a sidewalk, a bicycle path (5 m wide), and an undeveloped area. In the remaining measurement points, locations 4–10, single-family houses are present 40–80 m from the barrier.

Fig. 1. Sampling locations
along the DK12 section in Żagań [mapy.geoportal.gov.pl]

Samples were collected at 10 points spaced approximately every 30 m along the road line, 2 m from its edge (Fig. 1). At each location, three independent subsamples were taken from the surface layer, with subsample points spaced about 2 m apart along the barrier line. All samples were collected in 2022.

Sample preparation. To prepare a representative soil sample weighing 0.1 kg, three individual subsamples were collected from the topsoil to a depth of 0.15 m using a plastic shovel and placed in plastic containers. To obtain a homogeneous sample, the collected material was thoroughly mixed, cleared of larger fractions, air-dried, and sieved through a plastic sieve with a mesh size below 1 mm. A blank sample was collected from a forested area approximately 250 m from the road. It represented the local geochemical background, free from anthropogenic input.

Road dust samples were collected from a 2 m high by 5 m wide surface of the noise barrier, using a nylon brush and plastic scraper. Dust samples weighing about 10 g were placed in plastic containers. In total, 21 environmental samples were collected for physicochemical and spectroscopic analysis at the Environmental Research Laboratory at the Faculty of Environmental Engineering, Wrocław University of Science and Technology. Procedures followed the standard guidelines of PN-ISO 10381-5:2009 *Soil quality – Sampling – Part 5: Rules of procedure for testing urban and industrial areas regarding soil contamination*, and PN-ISO 11464:1999 *Soil quality – Preliminary preparation of samples for physicochemical tests*.

Analytical procedure. Soil suspensions were prepared from a 10 g sample in 25 cm^3 of distilled water or 1 M KCl solution. Weighing was performed using a WAA 160/C/1 precision balance (Radwag, Poland). After 24 hours, the exchangeable acidity and the electrical conductivity were measured in the decanted liquid using a CPC-505 stationary multifunction meter (Elmetron, Poland). The test procedure was based on PN-EN ISO 10390:2022-09 *Soil, treated bio-waste and sewage sludge – Determination of pH*, and PN-ISO 11265:1997 *Soil quality – Determination of electrical conductivity*.

From each homogeneous sample, 0.2 g was transferred to a teflon vessel, and 8 cm^3 of 65% ultrapure nitric acid (PN-ISO11465, 1999) was added. They were then placed in a multi-station microwave mineralizer START D (Milestone, Italy) and subjected to a two-stage closed-system digestion process with a linear temperature increase to 140 °C during the first stage for 2 min and 200 °C during the second stage for 15 min, while maintaining a maximum pressure of 20 MPa and a microwave power of 800 W. The mineralized samples were filtered into volumetric flasks and diluted with ultrapure water to a specified volume.

The contents of Pb, Cu, and Zn elements in the filtrates were determined by the flame or graphite furnace atomic absorption spectroscopy using an iCE3500 Thermo SOLAAR spectrometer (ThermoScientific, USA), according to the standard guidelines of PN-ISO11047:2001 *Soil quality – Determination of cadmium, chromium, cobalt, copper, lead, manganese, nickel and zinc in soil extracts with aqua regia by flame method and electrothermal atomic absorption spectrometry*. Measurements were performed three times, and the device performance was controlled using a blank reagent sample containing only nitric acid. Solutions of the certified reference materials (CRMs) for metals (Sigma-Aldrich, USA) were used for the calibration curve and the method validation. Chemical analyses were performed in the Laboratory of Environmental Research at the Faculty of Environmental Engineering, Wrocław University of Science and Technology.

Data analysis. Basic statistics and visualizations were performed using Microsoft Excel software for Windows. The assumed individual and integrated pollution indices were discussed by Hołtra and Zamorska-Wojdyła elsewhere [14]. Parameters for assessing the health risk of adult and child exposure to metals from non-dietary sources were calculated using formulas presented by Hołtra et al. [15].

3. RESULTS AND DISCUSSION

3.1. TOTAL CONTENT OF PTEs

Figure 2 shows the concentrations of PTEs in soil samples from the surface layer and road dust collected from the vertical surface of the noise barrier. Closer to the roundabout (locations 1–3), soils contain nearly twice as many metals as road dust. The largest difference in PTE levels occurs at location 2, where soil holds 13 times more Pb, 9 times more Cu, and 11 times more Zn than noise barrier dust. Further from the roundabout (locations 4–10), an inverse relationship is observed, with approximately double the amounts of Pb and Cu detected in the barrier dust. Only at locations 8 and 10, Pb in dust is 3-fold and 4-fold higher than in soils, respectively, and also Cu at location 10 is 7-fold higher. However, only slightly more Zn is found in road soils, apart from location 7, which shows four times more zinc in soil than in dust. The exception occurs at location 10, where road dust contains four times more zinc than the soil.

The recorded PTE concentrations in all samples are within acceptable limits for public road soils of group IV, according to the recommendations of the Polish Regulation of the Environment Minister dated September 1st, 2016, with maximum permissible levels of 600 mg/kg for Pb and Cu, and 2000 mg/kg for Zn [15]. However, the presence of a vertical obstacle results in heterogeneous transport of metals with air masses beyond the noise barrier, which may lead to the deposition of pollutants in residential areas located 40–80 m away in Żagań. Therefore, the obtained PTE concentrations were also compared with their threshold levels for group I of soils, acceptable in residential areas. The maximum permissible concentrations of Zn (500 mg/kg) or Pb and Cu (200 mg/kg) are exceeded in soils from two sampling locations. At location 2, concentrations of all tested metals are approximately three times higher (Pb 573, Cu 685, and Zn 1645 mg/kg), and at location 7, the zinc content (991 mg/kg) is twice the permissible level according to the Polish standard. At the remaining locations, the concentrations of all analyzed PTEs are lower than the permissible values, so it can be assumed that heavy metals appearing in soil as a result of road use will not affect the quality of soils located nearby.

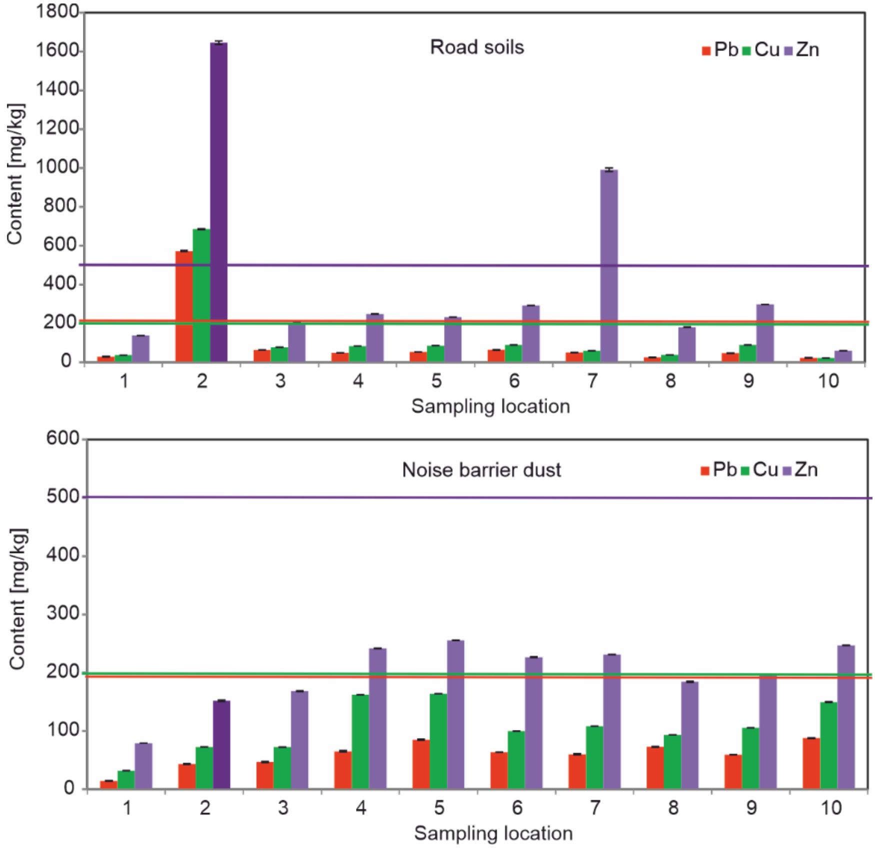

Fig. 2. PTE concentrations in environmental samples with horizontal threshold lines according to the Polish standard for soils in residential areas of group I [15]

An assessment of the risk of heavy metal migration from the surface layer into the soil profile, based on the acid-base characteristics of the soils, indicates a potential problem at the terminal points of the noise barrier (locations 1 and 10). pH measurements in 1 M KCl solutions show low soil acidity in both extreme locations, with pH slightly below 6.5. This may pose a risk of leaching and migration of PTEs with rainwater and meltwater, as well as their uptake by plant roots. In the remaining locations, the soils are neutral or alkaline (pH above 7.2 at location 2), suggesting that PTEs are bound within the sorption complex with organic or mineral matter in the surface layer. Electrical conductivity measurements of soil solutions indicate low salinity, around 25 mS/m.

3.2. ENVIRONMENTAL EXPOSURE TO PTEs

The impact of anthropogenic emission of PTEs from road traffic on road soils and noise barrier dust was assessed by calculating pollution indices, comparing the metal concentrations in the samples with the local geochemical background. Background values in mg/kg are 14.8 (Pb), 29.5 (Cu), and 45.3 (Zn).

The geoaccumulation index (I_{geo}) indicates that 90% of the road soil and all noise barrier dust samples are enriched in zinc, followed by slightly smaller populations of lead and copper (Table 1). The exceptions are the terminal points on both sides of the noise barrier, which are slightly polluted or unpolluted by the selected element. Most of the tested samples are moderately contaminated (2nd class) with zinc (road dust 90% / soils 50%), lead (80/60%), and copper (70/20%). The soil at location 2 is highly to extremely polluted with metals (4th–5th classes).

Table 1

Assessment of sample contamination by individual and integrated pollution indices

No.	Road soils									Noise barrier dust									Index classification				
	I_{geo}			*PI*			*PLI*	PI_{Nem}	*RI*	I_{geo}			*PI*			*PLI*	PI_{Nem}	*RI*					
	Pb	Cu	Zn	Pb	Cu	Zn				Pb	Cu	Zn	Pb	Cu	Zn				I_{geo}	*PI*	*PLI*	PI_{Nem}	*RI*
1																			0	1st	1st	1st–2nd	1st
2																			1st	2nd	2nd	3rd	2nd
3																			2nd	3rd	3rd	4th	3rd
4																			3rd	4th	4th	5th	4th
5																			4th	5th	5th		5th
6																			5th		6th		
7																			6th				
8																							
9																							
10																							

The values of single pollution indices (*PI*) confirm the I_{geo} indices assessment, regarding both the number of samples contaminated with PTEs in the considered populations and the distribution of metals in the samples, following the sequence Zn > Pb > Cu (Table 1). The difference in the assessment of sample contamination levels results from whether the mathematical formulas include a correction for metal fluctuations due to lithogenic effects, as well as from the classifications with different numbers of classes for both indices. According to the *PI* indices, the tested samples are generally 1–2 classes more contaminated with metals compared to the I_{geo} indices. Consequently, a predominance of strong to very strong contamination of the tested samples with zinc (90% of both road dust and soils), lead (80/70%), and copper (70/30%) is noted. The *PI* indices at the terminal measurement points of the barrier indicate moderate or low levels of pollution.

The pollution load index (*PLI*) is calculated to confirm the anthropogenic impact on the environment through the input of PTEs into road soils and dust. The analyzed results indicate a deterioration in the quality of all tested samples (Table 1).

The analysis of the results of the Nemerow pollution indices (PI_{Nem}) shows that 90% of dust samples and 80% of road soils are heavily polluted by all the considered PTEs together (Table 1). The highest PI_{Nem} indices are recorded in soils at locations 2 and 7, being 11.5-fold and 3.5-fold higher, respectively, than those for dust at the corresponding locations. The terminal measurement points of the noise barrier indicate moderate or slight pollution of soils, as well as road dust from location 1. In some cases, the values of integrated pollution indices slightly exceed the threshold values of the classification range; therefore, differences in the assessment of the contamination of the tested samples can be observed at some points.

The potential ecological risk index (*RI*) is used to assess the biological risk based on the sample pollution by PTEs, metal toxicity, and the environmental response to individual elements. In soil at location 2, a strong potential ecological risk is observed, with the *RI* value of 345, due to a considerable for Cu (116) and a high for Pb (193) ecological risk factor (E_r). Detailed values of all E_r are not shown in the paper. At the remaining measurement points, no risk to the biocenosis is observed in the studied area in Żagań (Table 1).

Table 2

Health exposure to PTEs by hazard indices

Road soils						
Index	Children			Adults		
	Cu	Zn	Pb	Cu	Zn	Pb
ADD_{ing}	4.2×10^{-4}	1.4×10^{-3}	3.2×10^{-4}	1.8×10^{-4}	6.1×10^{-4}	1.5×10^{-4}
ADD_{inh}	2.3×10^{-8}	7.7×10^{-8}	1.8×10^{-8}	1.3×10^{-8}	4.4×10^{-8}	1.0×10^{-8}
ADD_{derm}	2.3×10^{-6}	7.9×10^{-6}	1.8×10^{-6}	3.7×10^{-6}	1.2×10^{-5}	2.9×10^{-6}
HQ_{ing}	1.0×10^{-2}	4.7×10^{-3}	9.2×10^{-2}	4.6×10^{-3}	2.0×10^{-3}	4.1×10^{-2}
HQ_{inh}	5.7×10^{-7}	2.6×10^{-7}	5.0×10^{-6}	3.3×10^{-7}	1.5×10^{-7}	3.0×10^{-6}
HQ_{derm}	2.0×10^{-4}	1.3×10^{-4}	3.4×10^{-3}	3.1×10^{-4}	2.0×10^{-4}	5.5×10^{-3}
HI	1.0×10^{-2}	4.8×10^{-3}	9.5×10^{-2}	4.9×10^{-3}	2.2×10^{-3}	4.7×10^{-2}
Noise barrier dust						
Index	Children			Adults		
	Cu	Zn	Pb	Cu	Zn	Pb
ADD_{ing}	3.5×10^{-4}	6.5×10^{-4}	2.0×10^{-4}	1.5×10^{-4}	2.8×10^{-4}	8.4×10^{-5}
ADD_{inh}	1.9×10^{-8}	3.6×10^{-8}	1.1×10^{-8}	1.1×10^{-8}	2.0×10^{-8}	6.1×10^{-9}
ADD_{derm}	2.0×10^{-6}	3.7×10^{-6}	1.1×10^{-6}	3.0×10^{-6}	5.6×10^{-6}	1.7×10^{-6}
HQ_{ing}	8.7×10^{-3}	2.2×10^{-3}	5.6×10^{-2}	3.7×10^{-3}	9.3×10^{-4}	2.4×10^{-2}
HQ_{inh}	4.8×10^{-7}	1.2×10^{-7}	3.1×10^{-6}	2.7×10^{-7}	6.7×10^{-8}	1.7×10^{-6}
HQ_{derm}	1.6×10^{-4}	6.1×10^{-5}	2.1×10^{-3}	2.5×10^{-4}	9.3×10^{-5}	3.2×10^{-3}
HI	$8.9\cdot10^{-3}$	$2.2\cdot10^{-3}$	$5.8\cdot10^{-2}$	$4.0\cdot10^{-3}$	$1.0\cdot10^{-3}$	$2.7\cdot10^{-2}$

The estimated health exposure of residents to PTEs through non-dietary routes from linear emission along the DK12 road, with a roundabout and noise barrier in Żagań, indicates no adverse effects on the considered populations of children and adults. This is evidenced by very low values of the hazard quotients (*HQ*) and the hazard indices (*HI*), below one (Table 2). However, the *HI* indices indicate that, primarily, lead poses a health risk, followed by copper and zinc. The analysis of the average daily potential dose (*ADD*, in mg/kg·d) shows that children are at a higher risk of accidental PTEs intake than adults. Comparing the exposure routes, it is noted that the health risk largely depends on the ingestion route of metal intake.

Road soils and road dust enable the monitoring of environmental pollution from linear emissions along communication routes. Analysis of the results confirms that the area between the road and the noise barrier is exposed to the deposition of PTEs in the environmental components studied.

Assessment of PTE load in soils near the noise barrier shows that in Żagań, Lubusz Voivodeship, zinc and lead levels are much lower, 429 and 97 mg/kg, respectively, than in soils along the S86 expressway in the city of Tychy, Silesian Voivodeship, Poland (Zn 1739 and Pb 128 mg/kg) [4]. The 16-fold higher daily traffic intensity in Tychy compared to Żagań certainly affects the higher average zinc concentration (4-fold) in road soils, which is also likely associated with runoff of contaminants from the barrier surface and the industrial character of the Tychy agglomeration.

In soils near noise barriers located along the Central Katowice–Gliwice highway, between the cities of Chorzów and Zabrze in the Upper Silesian urban area, lead content is nearly twice as high (243 mg/kg) as in Tychy [6], despite daily traffic intensity being only half. The opposite applies to zinc (946 mg/kg), which is twice as low in soils along the Katowice–Gliwice Road. Surprisingly, copper in road soils along the Katowice–Gliwice Road (78 mg/kg) is also 1.6 times lower than in Żagań (127 mg/kg), despite a 7-fold higher traffic intensity between the main cities of the Upper Silesian conurbation. In soils along road 5 in Wrocław, Lower Silesian Voivodeship, PTE levels are lower than those observed in Żagań, namely 302 (Zn), 54 (Pb), and 92 (Cu) mg/kg, with median values of I_{geo} indicating moderate pollution by Zn [3]. The PTE contents in road soils near a barrier outside the built-up area along the A1 motorway in Grudziądz, Kuyavian-Pomeranian Voivodeship, after 6 years of road use, are very low for Zn (27), Cu (7), and Pb (1.3 mg/kg), and are not polluted according to the assessment of the geoaccumulation index [5].

Comparing the PTE results in noise barrier dust, it was noted that in Żagań, the average zinc concentration (198 mg/kg) is over 15.5 times lower than in dust from the dual carriageway Jedlińsk–Kamień–Falęcice of the E77 road in the Mazowieckie Voivodeship, Poland (avg. 3092 mg/kg) [10]. Extremely high pollution of the noise barrier dust was noted according to the I_{geo} index. Such a high zinc level exceeds the current Polish quality standard for soils in public road areas. The most dominant source of zinc in road dust from the surface of the noise barrier is probably corrosion of the galvanized protective coating, periodically intensified by the application of de-icing agents and blasting of the zinc coating. Average values of copper (106) and lead (60 mg/kg) in barrier road dust in Żagań are like the concentrations reported for the international E77 road, which are 152 (Cu) and 43.5 (Pb) mg/kg [10]. Road dust is highly to extremely polluted by Cu and moderately by Pb, according to the I_{geo} index. It is worth noting that the daily traffic intensity on the DK12 national road in Żagań is over 80 times lower than on the international E77 road Jedlińsk–Kamień–Falęcice, indicating that the PTE load is proportional to emission intensity.

4. CONCLUSIONS

The enrichment of the studied soils and road dust with PTEs confirms that the noise barrier captures air pollutants from linear emissions. The distance from the roundabout does not have a linear effect on the accumulation of PTEs in the analyzed sample populations. This enrichment might result from heterogeneous anthropogenic pressure related to traffic intensity, vehicle deceleration when approaching the roundabout, as well as traffic incidents and planned roadworks. Recently, increased traffic of military vehicles of different ages and technical conditions, heading towards the military unit beyond the mentioned roundabout, has been observed on the studied road section in Żagań. The placement of vertical noise barriers along transport routes in built-up areas, especially in urban agglomerations, may pose a potential risk to the environment and human health in the coming years. Therefore, it is recommended to repeat the environmental risk assessment. Anyway, our results show that:

- For soils at the base of the noise barrier:

– No heavy contamination with Pb, Cu, and Zn is noted based on the Polish Environmental Quality Standard for public and internal road soils. In two locations, there are exceedances of the permissible limits for at least one PTE, as established for soils in residential areas according to the Regulation of the Minister of the Environment of September 1st, 2016, item 1395. This is problematic due to the potential health risk for residents living in the vicinity of a busy road.

– The intensive use of the bypass in Żagań causes a significant enrichment of PTEs in soils located in the immediate vicinity of the busy national road DK12. Individual pollution indices show that 90% of soils are enriched with zinc and lead, and 70% of soil samples with copper. The Nemerow index indicates heavy pollution of soils, except at the terminal points of the barrier, where soils are moderately or slightly contaminated.

– Soil at location 2 is heavily polluted with all tested PTEs, and at location 7, there is strong zinc contamination. The high localized metal load in soils near the barrier is likely due to random traffic-related events, including runoff and splash water from the road surface, road infrastructure repair or modernization works, as well as barrier corrosion.

– At location 2, there is a strong potential ecological risk associated with the migration of PTEs, particularly lead and copper, when the soil becomes acidified.

- For road dust from the noise barrier surface:

– Due to its PTE content, road dust falls within the soil quality standards established for both transport and residential areas.

– Contamination from road transport strongly affects road dust. Concentrations of Pb, Cu, and Zn are increased compared to the corresponding local geochemical background values.

– The metal content in road dust is generally lower than in soils at the same sampling locations.

– All road dust samples are enriched with zinc, followed by 90% of the population showing increased levels of lead and copper. The cumulative Nemerow index clearly confirms heavy pollution of 90% of road dust, with PTEs moderately contaminating the initial sampling point near the roundabout.

– Increased traffic near the roundabout does not always correspond to higher accumulation of pollutants in road dust deposited on the barrier surface. Air mass movement at the open end of the barrier and above the roundabout with circular traffic likely promotes the dispersion of pollutants.

– The estimated environmental and human health exposure to PTEs present in road dust is low for residents living close behind the noise barrier.

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