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Original Research

Assessment of Heavy Metal Content in Soils Adjacent to the DK16-Route in Olsztyn (North-Eastern Poland)

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Abstract

The paper discusses the problem of the impact of the road on the content of heavy metals in soil and the impact of land use on limiting the migration of these xenobiotics. The area submitted to the research stretched along Sielska Street in Olsztyn, which is a section of the DK 16 route connecting Olsztyn and Ostróda. This area varies in terms of land relief, land use and plant cover. Soil samples were taken on both sides of the street at a distance of 1, 10 and 20 m from the road. The content of trace elements (Cd, Cr, Ni, Co, Cu, Pb, Zn, Mn and Fe), soil reaction (pH), salinity (EC) and total organic carbon (TOC) were determined in the soil. The enrichment factor (EF) was calculated. The content of heavy metals in soil was relatively low and did not exceed the relevant standard values [1]. Significantly higher content of Cd, Cu, Zn and Mn and the EC value were noted on the northern side of the street, which to some extent could be attributed to the position of this area along an outward bend of the road. Values of EF obtained for: Cd, Pb, Zn, Cu, Co, and Ni may indicate their anthropogenic accumulation in soil. Moreover, the study showed that appropriate management of the land (a green belt, a hedge, trees) can reduce the translocation of heavy metals over larger distances.

Keywords: communication area, enrichment factor (EF), land management, soil pollution, trace metals

Introduction

The development of transportation infrastructure, especially in urbanised areas, where constant population growth is observed, exerts pressure on the natural environment, including air, water and soils [2-5], as well as on human health [2, 4-5]. Large quantities of organic pollutants [6], as well as heavy metals [5], mainly Pb, Cd, Zn, Cu, Mn and Fe [7], detected in areas along roads and streets implicate the persistence of these substances in the natural environment and their tendency to bioaccumulate [5-6]. Because of toxicity and negative influence of heavy metals on health and people [2, 4-5, 8], soil contamination with these elements is still considered as an important environmental problem [2-5, 8]. Heavy metals like Cr, Zn, Pb and Cu emitted due to road traffic are mainly found on particulate matter suspended in the air, where they are a serious threat to the environment [2, 9]. Emission of pollutants from expressways is

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relatively low, but due to frequent pulling down and accelerating [10], it grows in these areas where roads pass through urban agglomerations [10-12], as a result of which trace elements accumulate in soil [13]. The principal sources of heavy metals along transportation routes, apart from exhaust fumes, are the wear of tyres, car brake and clutch linings, as well as the wear of road surface and other road facilities and construction elements [2, 9, 12, 14-15]. The wear of car brake shoes causes mainly the emission of Cu [9, 16-17], Pb [2], Zn and Cr, while the wear of tyres results in the emission of mainly Zn and Pb [2, 9, 16]. Concentrations of trace elements in soil along roads are the highest in the ground directly adjacent to a street or a road, and decrease at a growing distance from thereof [3, 10, 12, 18]. The spatial distribution of this pollution is also dependent on the prevalent direction and power of wind, type and duration of atmospheric precipitations, the intensity of traffic [18-19]. and localisation of buildings [18], and – to a lesser degree – on the use of road salt (Helmreich et al. 2010) [19]. Following a number of measures taken to reduce emissions (e.g. the ban on lead petrol), the unit emission of pollutants from motor vehicles has decreased, which nevertheless has not decreased substantially the input of pollutants generated by road transportation [2], because the number of vehicles has increased [2, 7]. The highest concentrations of pollutants caused by the emission of exhaust fumes from cars occur near the ground (Adamiec et al. 2016) [9]. Therefore, the belts of land along roads should be properly managed and planted with the plant species capable of phytoremediation, which beside the aesthetic role will mollify the risk of pollution by acting as an effective barrier limiting the translocation of xenobiotics to the environment (Czubaszek and Bartoszuk 2011; Widłak et al. 2017) [20-21].

The purpose of this study has been to assess the impact of road traffic on the content of heavy metals in soils of the areas adjacent to urban transportation routes, using Sielska Street in Olsztyn as an example. Additionally, a comparison was made of the effects of land management on the translocation of these elements.

Materials and Methods

Localisation of the Research Site

Olsztyn, the capital city of the Province of Warmia and Mazury, has a population of 173 000 [22]. The number of motor vehicles registered in the city, according to the City Council data, is over 118 000 [23]. The town is intersected by the following roads: state roads DK16 and S51, and provincial roads 597 and 598. The area chosen for this study is located along Sielska Street (DK16), which connects the city centre with Dajtki, a housing estate and an airfield (Olsztyn-Dajtki), and is a section of a road leading to Ostróda. According to data provided by the General Directorate of State Roads and Motorways, the year-average traffic flow on this road is 12.2 thousand vehicles per 24 h^{-1} [24]. Fig. 1, Fig. 2 show the location of our field investigations (GPS 53º46'13"N; 20º25'41"E) and the sampling sites.

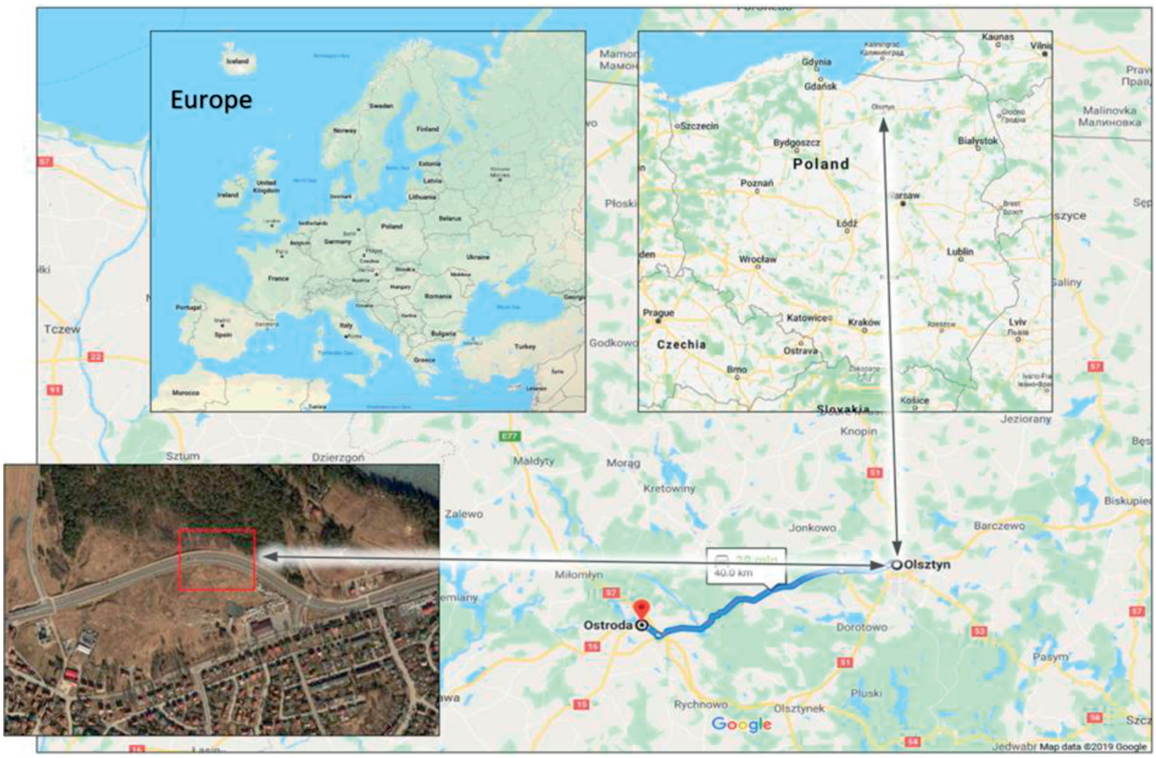


Fig. 1. Location of the assessed area on Poland's map (Google 2018).

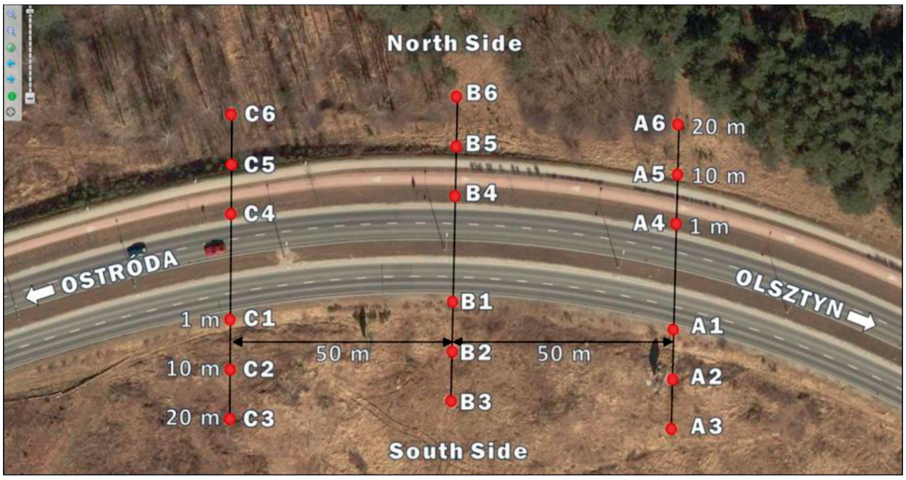


Fig. 2. Soil sampling sites along Sielska Street, Olsztyn (Geoportal 2018).

The study included two factors, namely: I – distance from a sampling site to the street (1, 10 and 20 m), and II – sampling on two sides of the street (northern and southern).

The area to the north of the street is a levelled ground, which comprises a bicycle lane, a pavement, and green belts with a hedge; at its end it borders with a woodland. The southern side of the road is an open area, rather unkempt and hardly landscaped, with a steep slope, covered with low-growing rudimentary plants, and adjacent to the housing estate called Dajtki.

Three lines: A, B and C, were set over the research area, and soil sampling sites, denoted as 1, 2 and 3 on the southern side and 4, 5 and 6 on the northern side of the street, were established along these lines, at a distance of 1, 10 and 20 m from the edge of the street. The distance between the lines was 50 m.

Laboratory Analyses

Soil for analyses was taken on 25 May 2018, from the arable humus horizon (0-25 cm), using an Egner sampler. At each designated site, an area of 1 m^2 was delineated, from which 5 representative soil samples were taken. Having been mixed, these samples created a proper composite sample for a given site. Soil was transported to the laboratory of the Department of Environmental Chemistry at the UWM in Olsztyn, air-dried, passed through a sieve with the mesh size ø = 1 mm, and placed in cardboard boxes at room temperature.

For determination of heavy metals, soil samples were digested in a microwave oven MARS 6 (CEM Corporation, USA), in Teflon vessels MARS Xpress, in a mixture of acids: 65% HNO_3 + 38% HCl, in a 4:1 ratio [25]. The total forms of trace elements: lead (Pb), cadmium (Cd), chromium (Cr), nickel (Ni), copper (Cu), zinc (Zn), cobalt (Co), manganese (Mn) and iron (Fe) were determined on a SpectrAA-240FS Fast Sequential Atomic Absorption Spectrometer, using MERCK standard solutions containing 1000 mg of trace element·dm^{-3}. Analyses conducted, according to the protocol US-EPA3051 [26].

Soil pH was determined with a potentiometric method in 1:2.5 (w/v) soil/1 M KCl solution using a pH electrode SenTix61 and pH Meter 538 WTW [27].

Electrical conductivity (EC) was determined in a 1:2 (w/v) soil/deionized water mixture with a Hanna Instruments HI 8733 Multi-Range Portable EC Meter.

The total organic carbon (TOC) content was determined with a Shimadzu TOC-L analyser coupled with a solid sample module SSM-5000A.

All determinations were made in three replicates for each sample.

The content of heavy metals (Cd, Pb, Cr, Co, Ni, Cu and Zn) was compared with the threshold values contained in the Regulation of the Minister for the Environment of 1 September 2016 on assessment of the earth's surface pollution [1]. In compliance with this document, the area selected for this study is a transportation zone, where the admissible levels of heavy metals in soil are: 15 mg Cd, 200 mg Co, 500 mg Cu, 500 mg Ni, 600 mg Pb, 1000 mg Cr and 2000 mg Zn·kg^{-1}.

The determined concentrations of elements (Cd, Cr, Cu, Co, Ni, Zn, Pb and Mn) served to calculate the enrichment factor (EF), which defines the source of origin of elements in soil [5]. The following formula was applied:

$$EF_{Me} = \frac{(C_{Me1}/C_{Fe1})}{(C_{Me0}/C_{Fe0})}$$

...where:
C_{Me1} – content of the analysed metal in the tested sample;
C_{Me0} – content of the analysed metal in parent rock;
C_{Fe1} – content of iron in the analysed sample;
C_{Fe0} – content of iron in parent rock [5, 28-30].

Iron was used as a reference metal because it only slightly responds to anthropogenic pressure. The parent rock content of the metals considered in this study corresponds to the average one for Polish soils, i.e. 0.18 mg Cd, 27.0 mg Cr, 7.1 mg Cu, 4.0 mg Co, 10.2 mg Ni, 30.0 mg Zn, 9.8 mg Pb, 289.0 mg Mn and 12900 mg Fe·kg^{-1} of soil [31].

Statistical Analysis

The results were processed statistically with a two way ANOVA test at the level of significance of $\alpha = 0.05$, using a Statistica v.13.0 software package (StatSoft Polska, Kraków). Microsoft Excel of Office 365 software (Microsoft Polska, Warsaw) was used to calculate standard deviation (SD), coefficient of variation (CV) and simple Pearson's correlation coefficient (r).

Results and Discussion

The content of trace elements in the topsoil sampled from the analysed sites was varied and dependent on the side of the road and distance from the road edge (Figs 3-4). On average, it equalled: 0.37 mg Cd, 3.17 mg Co, 4.97 mg Cr, 6.93 mg Ni, 7.47 mg Cu, 11.63 mg Pb, 35.44 mg Zn, 150.8 mg Mn and 6006 mg Fe·kg^{-1} of soil. The determined concentrations of the metals, compared with values noted in soils of urban areas exposed to transportation pressure, were convergent with values reported by others [13-14, 18], same as the concentrations of Ni and Co [29]. In the majority of cases, however, the levels of trace elements in soil along Sielska Street were lower than given in the literature. This was true for Pb [4-5, 13-15, 18, 20], Ni [4-5, 18, 20], Cd [5, 20, 29], Co [4], Cu [4-5, 12-13, 15], Zn [4-5, 12-13] and Mn [4-5]. Few samples yielded metal content higher than cited in the literature [4, 11, 20, 29]. The high level of discrepancy between the results obtained in this study and the ones reported by the quoted authors may be due to the localisation of research areas, hence different local conditions, metal content of the parent rock, degree of anthropopressure, distance between sampling sites and the road, and intensity of traffic flow.

In the presented study, one of the factors having influence on the content of trace metals was found to be the position of the sampling sites relative to the world sides. The content of Cd, Cu, Zn and Mn was significantly higher in soil samples from the sites located to the north of the street than from the ones on the southern side. As for the remaining metals, i.e. Pb, Cr, Ni, Co and Fe, the position of the sampling sites relative to the world sides did not have a significant meaning.

Significant dependence was demonstrated for Cd, Cu and Zn concerning the distance from the sampling site to the road and their soil content. Significantly higher levels of these metals in sites located closer to the road suggest the flow of vehicles as the source of these elements in soil. No such dependence was determined for Pb, Cr, Ni, Co and Mn. Regarding iron, its average soil content increased at further distance from the road.

In the case of Pb, Cd, Cr, Cu, and Zn, the correlations between the distance of a sampling site and the road versus the location of sampling sites relative to the world sides indicate the presence of an additional factor which affected the absorption of the pollutants by the analysed soil. The content of these metals on the northern side was always significantly the highest at a distance of 1 m from the road, while on the southern side either no such dependence was observed, or the levels of these metals at a distance of 1 m were lower than at 10 or 20 m away from the road. The reason could be the fact that the northern side is situated on the outward part of a bend in the road. Another cause might be the direction of prevalent winds (south-west) [11, 14, 19].

Moreover, the northern part of the road is overgrown with trees, which by obstructing blasts of wind contribute to a greater deposition of Pb, Cd, Cr, Cu and Zn at sites located nearer the street. The obtained results confirm research other authors who also showed a decrease in metal content with the increase of the distance from the street [3-4, 10, 12, 18, 20]. Other factors which influence the content of metals in soil are: the intensity of road traffic [4, 10, 12, 18, 20] the landscaping and land relief as well as the planting of appropriate plants [20-21]. Positive observations made in this study confirm the benefits of the landscaping carried out on the northern side of the road. The green belts and the hedge which separate the street from the bicycle lane and pavement have proven to be a significant element, which plays an aesthetic and noise-cancelling role but also limits the range of emission of pollutants. Adequately selected plant species which have phytoremediation properties can serve as an ornamental component and mollify the risk caused by urban pollution [21]. The area to the north of the street is also enclosed by woodland, with Scots pine as the dominant tree species. Any plant cover, and especially forest, is an excellent buffer zone towards such elements as Pb, Cd, Cr, Ni, Zn, Cu, Mn and Fe [18, 20]. In most cases, except Cd, the soil on the southern side of the road was observed to demonstrate a tendency for higher concentrations of metals at larger distances from the street. However, the analysis of variance revealed that significant changes occurred only with respect to Cr and Fe. The results obtained in our study may have some connection with the lack of thoughtful landscaping and management of this area, its land relief and the remains of some loose materials (building rubble, earth), which may have had some impact on the chemical condition of soil. Additional pressure was caused by the nearby residential estate composed of detached houses, the fact also mentioned by other researchers [11, 18].

Another factor that might have affected the level

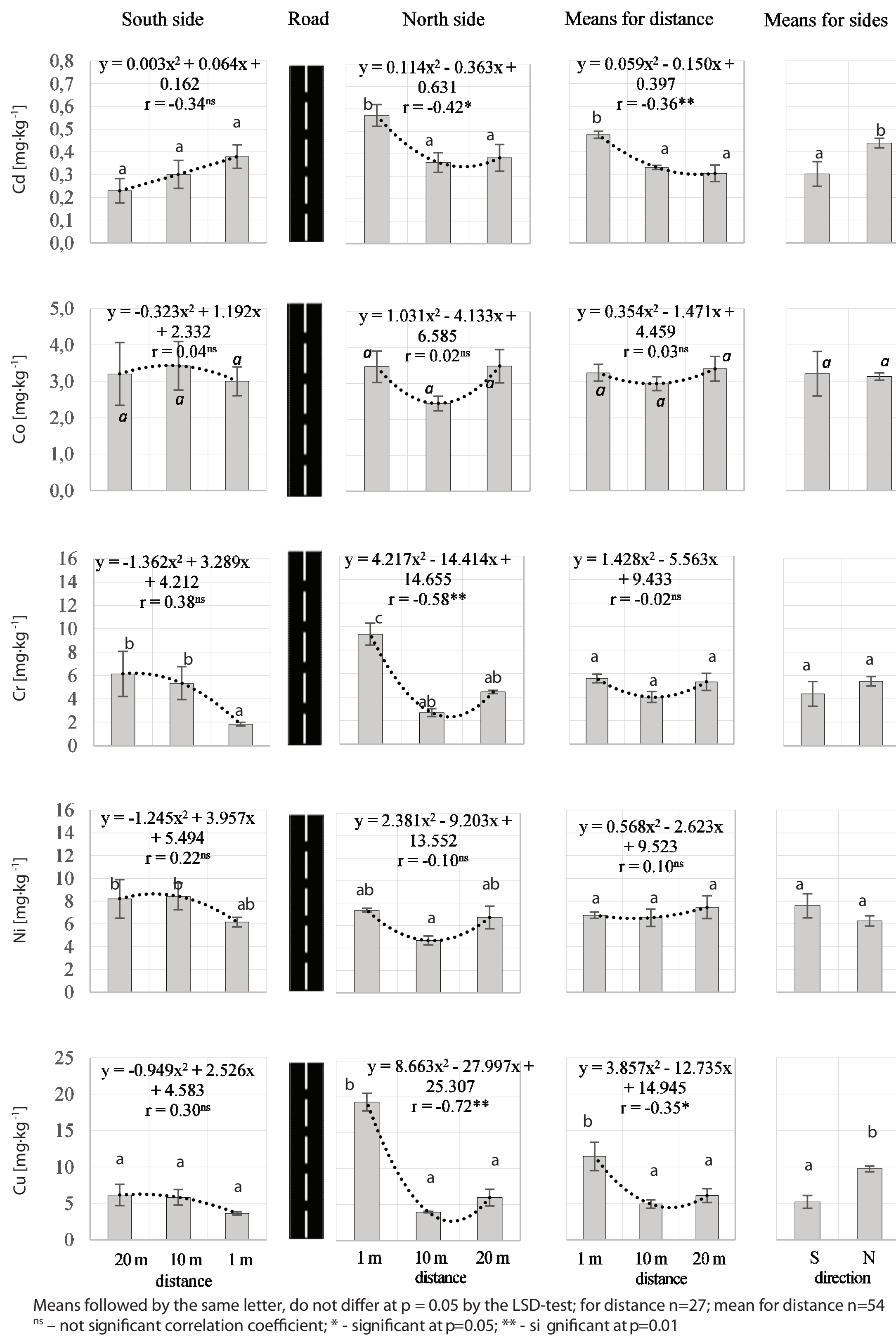
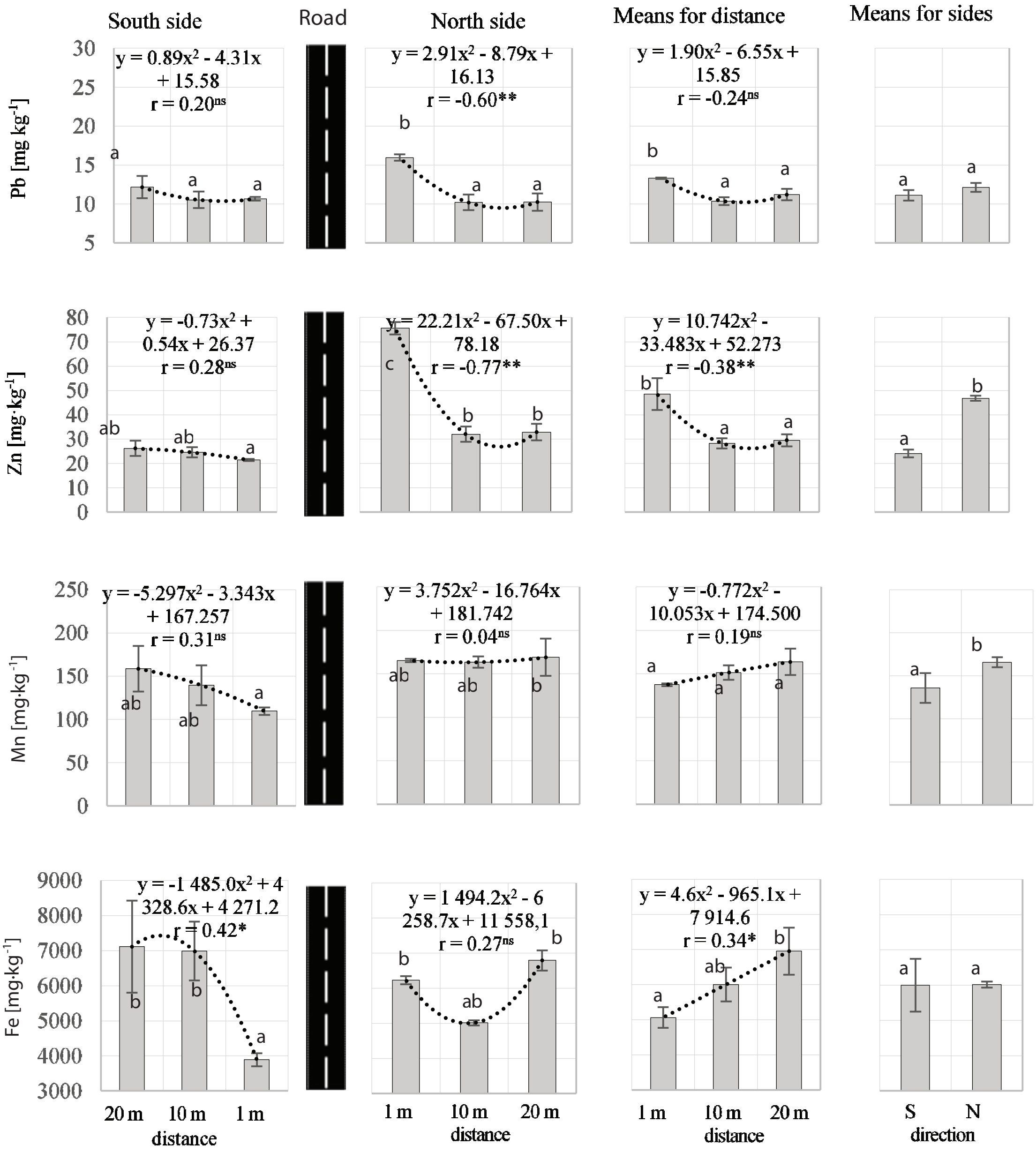


Fig. 3. Content of trace elements (Cd, Co, Cr, Ni and Cu) in the analysed soil samples, depending on the side and distance from the street.

of accumulation of heavy metals in the analysed soils was the total content of organic carbon (TOC) (Table 1). When tracing the coefficients of correlation between the significantly higher TOC on the northern side (1.72%), and the content of trace elements, it was demonstrated that the only element which positively correlated with the TOC concentration was Zn (r = 0.28*) (Table 2). The literature, however, contains reports indicating that TOC is significantly correlated with the content of Cd, Cu, Ni and Pb [19]. The TOC level determined in our



Means followed by the same letter, do not differ at p = 0.05 by the LSD-test; n=9;
ns – not significant correlation coefficient; * - significant at p=0.05; ** - significant at p=0.01

Fig. 4. Content of trace elements (Cd, Co, Cr, Ni and Cu) in the analysed soil samples, depending on the side and distance from the street.

study was quite typical of urbanised areas [21, 32].

The northern side of Sielska Street was characterised by a significantly higher (by 19%) value of the EC (143 μS·cm-1) than the southern side (Table 1). This is certainly connected with its position on the outer bend of the road as well as the bicycle lane and footpath situated there. Higher salinity of soils closest to a road has been observed by other researchers [3, 7], and the reason is the application of sodium, calcium or magnesium chlorides in winter to minimise the risk of skidding by vehicles [32-33]. Values of the EC which are approximately the same as in our research have been observed in soils samples near streets of Wrocław [12]. Higher soil salinity along Sielska Street was significantly correlated with the content of Cd (r = 0.59**), Cr (r = 0.36**), Cu (r = 0.67**), Pb (r = 0.55**) and Zn (r = 0.67**) (Table 2), whereas the soil reaction was significantly correlated with the soil content of Cd (r = 0.45**), Co (r = 0.36**), Ni (r = 0.45**), Cu (r = 0.33**), Pb (r = 0.42**) and Mn (r = 0.34**) (Table 3). The soil reaction noted in our research (Table 1) in general agreed with the data reported by other authors [7, 21], or was slightly higher [12]. High soil reaction could be a barrier to the mobility of heavy metals and their translocation to the soil solution [21].

Despite the differentiated concentrations, the content of heavy metals in the soil of the analysed area along

Table 1. Selected physico-chemical properties of soil (means for distance and sides).

Physico-chemical properties of soil	Means for distance			r for distance	Means for side	
	1	10	20		south	north
TOC (%)	1.57^{ab}	1.87^{b}	1.47^{a}	$-0.09^{n.s.}$	1.55^{a}	1.72^{a}
EC (μS·cm^{-1})	219^{c}	99^{b}	77^{a}	-0.81^{**}	120^{a}	143^{b}
Reaction (pH)	7.46^{b}	7.23^{b}	6.86^{a}	-0.44^{**}	7.31^{a}	7.05^{a}

Means followed by the same letter, do not differ at p = 0.05 by the LSD-test; n = 54;
n.s. – not significant correlation coefficient (r); * - significant at p = 0.05; ** - significant at p = 0.01

Table 2. Correlation coefficients (*r*) between trace elements and selected physico-chemical properties of soil.

Physico-chemical properties of soil	Elements								
	Cd	Co	Cr	Ni	Cu	Pb	Zn	Mn	Fe
TOC	0.099	-0.135	-0.091	-0.116	0.171	0.105	0.283*	0.144	-0.068
EC	0.593**	0.249	0.356**	0.202	0.665**	0.552**	0.673**	0.093	-0.024
Reaction (pH)	0.449**	0.364**	0.161	0.450**	0.330**	0.420**	0.216	0.340**	0.115

TOC – total organic carbon; EC – electrolytic conductivity;
n.s. – not significant correlation coefficient (r); *-significant at p = 0.05; **- significant at p = 0.01

Table 3. Correlation coefficients (*r*) between selected trace elements.

Elements	Cd	Co	Cr	Ni	Cu	Pb	Zn	Mn
Co	0.645**							
Cr	0.517**	0.738**						
Ni	0.483**	0.863**	0.709**					
Cu	0.631**	0.489**	0.793**	0.460**				
Pb	0.588**	0.521**	0.663**	0.617**	0.756**			
Zn	0.617**	0.277*	0.585**	$0.222^{n.s.}$	0.912**	0.744**		
Mn	0.611**	0.784**	0.694**	0.730**	0.512**	0.617**	0.379**	
Fe	0.402**	0.809**	0.820**	0.874**	0.460**	0.558**	$0.248^{n.s.}$	0.827**

n.s. – not significant correlation coefficient (r); *- significant at p = 0.05; **- significant at p = 0.01

Sielska Street did not exceed the national threshold norms [1]. The value of the enrichment factor (EF) obtained in this study implicates the anthropogenic source of accumulation of some of the metals in soil (Fig. 5). The widest ranges of the EF were calculated for such elements as: Cd (2.17–7.11), Cu (1.42–5.59), Zn (1.57–5.21), Pb (1.94–3.69) and Co (1.24–2.41), while the narrowest ones were found for Ni (1.21–1.99), Mn (0.86–1.46) and Cr (0.23–0.71). The highest EF values, irrespective of the side of the street, were typically identified at the sites closest to the road. A value of the EF>1.5 implicates anthropogenic accumulation of elements [28]. In our study, such EF values (>1.5) were determined for 100% of the sampling sites for Cd, Pb and Zn, 67% for Co, 50% for Cu and 33% for Ni. Furthermore, in line with the suggestion expressed by Charzyński [30], considerable enrichment (EF>5) was found for Cu and Zn in sites located on the northern side (closest to the road) and for Cd at distances of 1 and 10 m. For the latter element, substantial enrichment was also noted on the southern side 1 m from the road.

The calculated accumulation indices prove that the Pb, Cu, Zn, Cd, Co, Ni determined in our research belonged to elements whose emission and deposition were associated with the traffic flow of motor vehicles. Other than the elements mentioned above, an increase in the Cr content can be induced by road transportation, especially in soils within urban areas [29]. The EF values calculated in our study seem moderate compared with EF values noted in soils along transportation routes quoted in the literature [4, 10, 12-13].

The analysis of correlations demonstrated frequent,

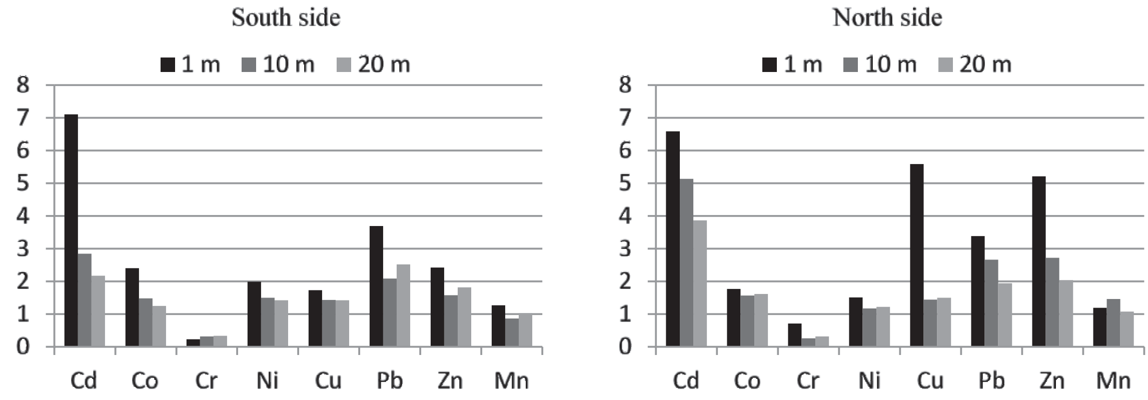


Fig. 5. Enrichment factors (EF) for heavy metals (Cd, Co, Cr, Ni, Cu, Pb, Zn, Mn) in the analysed soils.

highly significant correlations between the determined concentrations of the analysed elements, except the Zn:Ni and Zn:Fe relationships (Table 3). Same as in research reported by others, also conducted along transportation routes, significant correlations were observed between: Cd, Cu, Ni, Pb and Zn [19], Pb, Cd, Zn, Ni, Fe, Mn, Cu, Cr and Co [29], Pb, Cd, Zn, Ni, Fe, Mn and Cu [18], as well as Zn and Cu [12]. Such numerous and positive correlations indicate a common source of origin of the analysed elements, which is the motor traffic connected with road transportation.

Conclusions

The content of heavy metals in soil along Sielska Street was relatively low and did not exceed the threshold levels set for areas developed for transportation purposes. The EF values obtained for Cd, Pb, Zn, Cu, Co and Ni suggested an anthropogenic origin of these elements. The content of Cd, Cr, Cu, Pb and Zn in soils was positively correlated with the EC, while that of Cd, Co, Ni, Cu, Pb and Mn with the pH of soil, and Zn with TOC. The significant correlations between the metals demonstrated in this study prove their common source of origin, which in this case should is the motor traffic flow on the road. Higher levels of Cd, Cu, Zn, Mn and the EC value were observed on the northern side of the street, which is associated with its location on the outward bend of the road as well as the direction and velocity of prevalent winds. Moreover, a significant decrease in the content of Cd, Cr, Cu, Pb and Zn between the first and second sampling site was noted, and this difference may have been caused by the green belts, hedge and trees growing to the north of the street. On the southern side of the street, an increase in the soil content of metals was observed as the distance from the street increased. This may have been due to the lack of thoughtful landscaping on that side of the street, the land relief and an additional source of emission such as the proximity of a residential area composed of detached houses. The research results point to a substantial influence of properly designed landscaping (green belts, hedge, trees) in limiting the translocation of such pollutants as trace elements from transportation routes over larger distances.

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Conflict of Interest

The authors declare no conflict of interest.

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