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Original Research

Trends in Lead and Cadmium Content in Soils Adjacent to European Highway E30

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Abstract

Results of lead and cadmium contents in soil adjacent to European highway E30 in the East of Poland were presented in the study. Soil samples were collected at three distances: 0, 50, and 100 m from the track, and at two depths: 5-15 cm and 35-45 cm. Soil pH, content of silt and clay particles, organic matter content, types of underlaying rock and land use methods were tested. The total contents of lead and cadmium were analyzed by AAS method. Lead content ranged from 9.70 mg·kg^{-1} to 155.75 mg·kg^{-1} of dry matter (on average 103.38 mg·kg^{-1}) in the strip directly adjacent to the roadside. The values were significantly larger than those from further distances. The lead content in soils beyond the road strip did not exceed the limit value of 100 mg·kg^{-1} in soil used for farming purposes. The cadmium content, however, ranged from 0.016 to 0.909 mg·kg^{-1}, and it did not significantly depended on the distance from the road. The largest cadmium content, significantly different from others, in soils located to the east of the industrial district of Siedlce was proved, but the content did not exceed the limit of 1 mg·kg^{-1} in soil of agricultural area. The study was a part of complex research concerning the environmental monitoring that was conducted by co-authors of the paper.

Keywords: lead, cadmium, roads, soil, atomic absorption spectrometry

Introduction

Lead and cadmium belong to heavy metals of anthropogenic origin and they are extremely dangerous for people and animals. Application of the metals and their compounds in cars results in their emission to the environment. Although their application in car elements has been reduced recently, there are still many cars in Poland in which friction-disks of brakes and other parts are made of cadmium [1]. Lead compounds have also been used as anti-knock substances in petrol, which has resulted in depositing the chemical element in roadsides for many years. Thanks to the ban on using lead tetraethylene, the amount of lead, which was emitted to the environment in fumes, has been reduced [2]. According to statistics, the annual deposit of the chemical element in soil amounts to approximately 5,000,000 t [3].

The lead content in roadsoils depends on distance from the road, traffic density and structure, and the region in the world [4-10]. Research, carried out on the same stretches of roads have presented the possibility of determining a tendency toward changes in lead content in soil as a result of changes in the traffic density and technological progress in motorization [4, 11-12]. An exclusion of some land from agricultural areas was the result of contamination of agricultural area adjacent to roads due to toxicity of agricultural products for consumers [13, 14]. The protection of organisms in biocenosis adjacent to tracks of communication [15] and to water [16-18] is of great importance, as well.

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The aim of our study was to determine the effects of traffic on lead and cadmium contents in soils of agricultural areas adjacent to the Polish part of European highway E30, as well as to evaluate the effect of natural conditions on distribution of the chemical elements in roadsoils.

Material

Soil samples were collected in 2009 from roadsoils along E30 (50 km in length) in places marked in Fig. 1. The track, connecting Cork in Ireland with Omsk in Russia, belongs to the most important communication routes in Europe, and in Poland it runs along motorway A2 and then along road No. 2. The area where samples were collected belongs to the Mazovian Voivodeship located in the Middle-East of Poland about 60 km to the East of Warszawa. E30 runs here across the plain of the South-Podlasie Lowland, which is crossed by land depression of some small rivers. It is typically an agricultural region without large areas of forests. The soil was mainly formed from fluvioglacial materials that originated from Warta substage of the Middle-Polish glaciation period. Fluvioglacial sand and terminal moraine clay predominate in the soil. The ground under the roadway was piled up with homogeneous rock material in 1990-92. Western winds (18.2%) and southwestern winds (13.0%) prevail in the region.

Daily traffic on section 1-5 was recorded and it amounted to 13,000 cars in 2000; 16,000 cars in 2005, on sections 5-7 – 5,240 and 6,350 cars, respectively; and on section 7-11 – 5,020 and 6,050 cars, respectively. The traffic on the tested parts of the road was not considerably lower than that in the previous years. Lately the traffic density on the road has increased by about 5%.

Methods

Soil samples were collected on both sides of the road in 11 places 5 km apart. In each place we took samples at two depths: 5-15 cm and 35-45 cm, as well as at three points: side-space – 2 m from the road side, and at the distance of 50 and 100 m from the road. A textual group of soil formation in each sample was determined and the basic parameters such as soil pH in H_2O and in KCl, as well as the content of organic matter, were analyzed after drying the soil and sieving it through a 1 mm mesh [19-21]. The samples were dry mineralized at 450ºC and then dissolved in 10% HNO_3 in order to analyze the lead and cadmium contents [22]. The lead and cadmium contents were tested by atomic absorption spectrometry, and electrothermic activation of samples were applied [23]. Reagents, analytical methods, and apparatus used in the analyses are shown in Tables 1 and 2. The analyses diagram is presented in Fig. 1.

Internal models for quality control were used to verify the accuracy of the analyses performed. It was assumed that 85-115% of the real value should be recovered from the

Table 1. Chemical reagents.

Chemical reagents	Purity	Producer
KCl	pure for analysis	POCh
HNO_3	ultra-pure	POCh
Standard of Pb, Cd	spectral pure	Merck
Standard of pH	-	POCh
Water	demineralized	-

Table 2. Analytical methods and apparatus used in analysis.

Determinant factor	Methods	Apparatus
Granulometric composition	Boyoucose and Casagrande method modified by Prószyński	-
Organic content	Tiurin method	-
Soil reakction (pH)	Electrometric method	Elmetron CP-215
Mineralization	Dry mineralization	Nabertherm L3/11
Content of Pb and Cd	AAS	Varian Spectra AA20

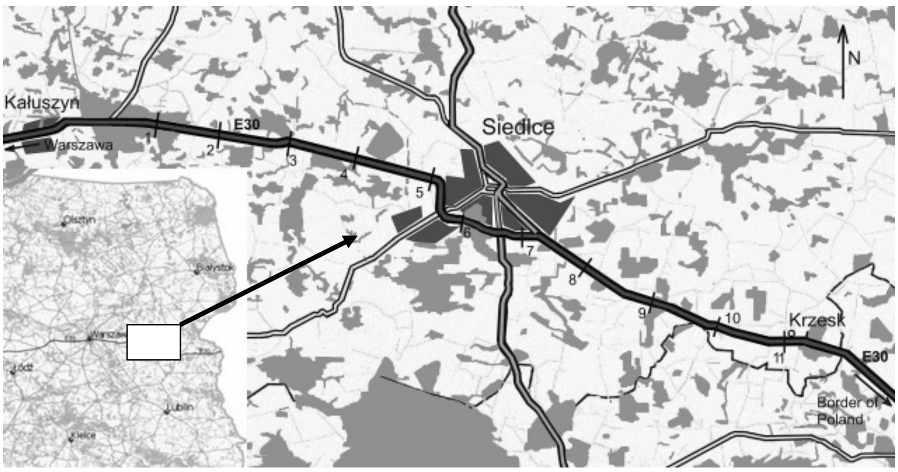


Fig. 1. Schematic representation of the studied sites of the E30 road.

Table 3. Properities of soil at sample points.

Point Number	Side of road	Species of use	Soil texture	Content of dust fraction [%]	Content of organic mater [%]	pH on	
						H_2O	KCl
1	left	fallow land	WLS	9.3	0.89	4.75	4.53
	right	fallow land	WLS	8.7	0.78	5.95	5.66
2	left	orchard	S	9.8	2.13	5.59	5.72
	right	fallow land	LS	17.4	1.23	6.02	5.42
3	left	meadow	S	13.4	1.45	6.37	6.34
	right	meadow	LS	19.6	2.34	7.10	6.62
4	left	fallow land	SL	33.7	1.13	5.31	4.70
	right	meadow	LS	18.4	2.21	6.05	5.44
5	left	fallow land	P	4.2	0.56	5.45	4.77
	right	meadow	LS	16.4	1.97	5.86	5.58
6	left	fallow land	WLS	8.7	0.65	5.13	4.79
	right	fallow land	WLS	8.2	0.93	5.37	4.83
7	left	agricultural use	SS	33.7	2.17	6.06	5.44
	right	agricultural use	LS	13.2	2.01	5.37	5.01
8	left	meadow	LS	12.7	3.15	5.50	5.13
	right	agricultural use	LS	14.3	3.01	5.27	4.67
9	left	fallow land	LS	12.4	1.76	6.89	6.82
	right	follow land	WLS	7.9	2.03	6.41	6.20
10	left	meadow	SS	33.4	1.63	6.29	5.97
	right	agricultural use	LS	12.5	1.75	5.59	5.53
11	left	agricultural use	LS	18.5	2.13	5.67	5.40
	right	meadow	ML	47.4	1.64	5.13	4.94

WLS – weakly loamy sand, S – sand, LS – loamy sand, SL – sandy loam, SS – sandy silt, ML – medium loam

models tested. Two models of quality control were prepared and used in each sample series.

The results were statistically analyzed using Statistica 6.0. Three-factor analysis of variance was used to determine the effects of factors (side of the road, distance from the road, soil depth) on contents of chemical elements in soil. A detailed comparison between mean values was conducted using Tukey test at $p \leq 0.05$. When the effect of the quantitative factor (distance) was found, orthogonal contrasts were used to estimate the character of the effect. Correlation coefficients were calculated according to Sperman rank between the contents of lead and cadmium and soil characteristics, as well as between their contents and traffic density [24].

Discussion

Basic characteristics of soil samples were presented in Table 3. The samples were mainly collected from waste

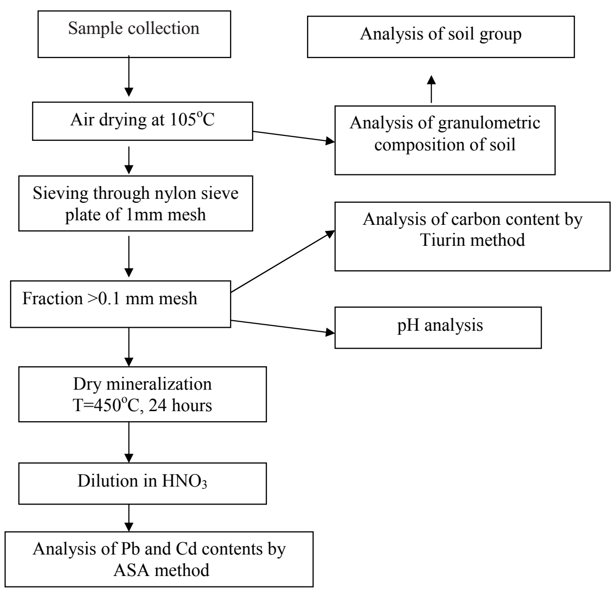


Fig. 2. Sample analysis diagram.

Table 4. Parameters of content of lead in investigated soils.

Distance [m]	Left side		Right side	
	Topsoil	Subsoil	Topsoil	Subsoil
0	$\frac{(81.30-137.60)\ 91.31a \pm 16.74}{17.4}$	$\frac{(98.15-155.75)\ 132.49b \pm 20.13}{15.2}$	$\frac{(66.20-135.65)\ 101.65a \pm 20.37}{20.0}$	$\frac{(82.10-155.95)\ 105.11a \pm 21.66}{20.6}$
50	$\frac{(8.80-47.10)\ 30.04a \pm 13.99}{46.56}$	$\frac{(12.65-45.90)\ 34.43a \pm 14.09}{40.9}$	$\frac{(9.85-34.20)\ 17.91a \pm 7.49}{41.8}$	$\frac{(9.60-33.65)\ 18.36a \pm 7.25}{39.47}$
100	$\frac{(12.65-45.90)\ 25.87a \pm 12.95}{50.0}$	$\frac{(12.00-44.70)\ 30.65a \pm 11.36}{37.1}$	$\frac{(9.70-30.85)\ 16.67a \pm 5.91}{35.5}$	$\frac{(10.35-36.30)\ 17.47a \pm 9.24}{52.9}$

$\frac{(x\min - x\max)\ \bar{x} \pm s}{V}$ ...where: x min – minimum value [mg·kg^{-1}]; x max – maximum value [mg·kg^{-1}]; $\bar{x}$ – mean [mg·kg^{-1}]; s – standard deviation [mg·kg^{-1}]; V – variable coefficient [%],

a, b – values differ significantly at p=0.05

lands (18 samples), meadows (12 samples) and agriculturally utilized areas (10 samples), and their main characteristics were typified by a large variability of underlying rock. Soils that were formed from sand of post-glacial origin prevailed in the samples. The content of silt and clay particles ranged from 8.7 to 47.4%, whereas the organic matter content in the upper part of soil ranged from 0.56 to 3.15%. The soil pH of the samples was measured in water and amounted to 4.75-7.10, while in KCl it was 4.53-6.62. Most soils were characterized by acid reaction. Soils in the region directly adjacent to the road were formed from weakly loamy sand (content of silt and clay particles 8.3-9.7) of slightly differentiated properties (Table 1), low organic matter content (0.43-0.56%) and acid reaction (pH_{H_2O}=5.2-5.6; pH_{KCl}=5.0-5.3).

Lead content ranged from 8.80 to 155.75 mg·kg^{-1} of dry matter in soil. The values on the left side of the road were 8.80-155.75 mg·kg^{-1}, whereas those on the right ranged from 9.60 to 155.75 mg·kg^{-1} (Fig. 3, Table 4).

The analysis of variance showed that the distance, side of the road, and soil depth significantly affected the lead content in soil. Basic characteristics such as dependence between the side of the road and soil depth, the distance and soil depth, and the side of the road, the distance and soil depth were found to be significant (Tables 5 and 6, Figs. 4 and 5). Moreover, regression equations (Figs. 4, 5) showed an increase in lead content in soil at a distance of 80-100 m from the road. This was also confirmed by other studies [25-26].

Soil on the left side of the road was characterized by significantly larger lead content (58.30 mg·kg^{-1}) than on the

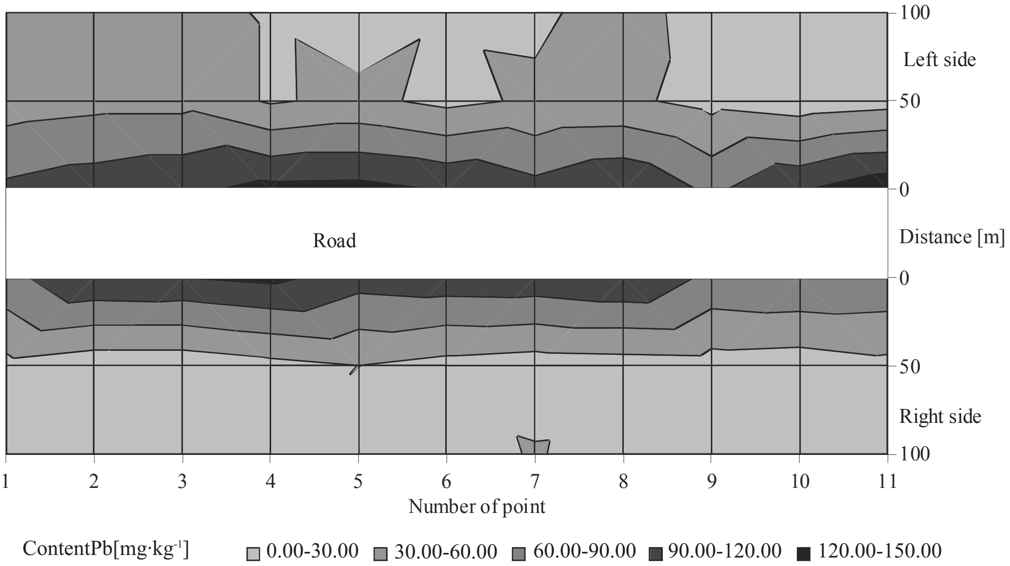


Fig. 3. Content of lead in soils adjacent to the E30.

Table 5. Mean lead content in soil in relation to distance and depth.

	0	50	100	Mean
Topsoil	98.98a	23.98a	21.27a	48.08a
Subsoil	118.80b	26.40a	24.06a	56.42b
Mean	108.89b	25.19a	22.66a	

a,b – values differ significantly at p≤0.05

Table 6. Mean lead content in relation to the side of the road and depth.

	Topsoil	Subsoil
Left	50.74a	65.85b
Right	45.41a	46.98a

a,b – values differ significantly at p≤0.05

right (46.20 mg·kg^{-1}). This was the result of the western and southwestern winds that predominate in the area. It was also proved that more lead was accumulated in the lower part of the soil (56.42 mg·kg^{-1}) than in the upper part (48.08 mg·kg^{-1}) (Table 3). The lead content was also analyzed in other regions of Poland [4, 18, 26]. The dependency, however, was not proved in tropical countries [10, 11, 27, 28]. It could be explained by the fact that lead in the upper parts of soil were intensively rinsed, which was activated by acid reaction of soil, as well as by low colloid and organic matter contents in the soil tested [25].

The amount of lead in soil depended on the side of the road, which was indicated by a significant interaction between the side and depth. Statistically similar lead contents in the upper and lower parts of soil on the right side of the road were found. On the left side, however, significantly more lead in the lower part of soil (65.85 mg·kg^{-1}) than that in the upper part was proved (Table 6). The significance of triple interaction showed that lead contents in soil layers were differentiated on both sides of the road and they depended on the distance from the road. The comparison between mean values proved that significantly more lead was accumulated in lower parts of the soil only on the left side of the road and in the strip that was directly adjacent to the road. The parabolic character of the dependences was found and it could be explained by changes of road direction in relation to wind rose [15].

Studies showed that most lead was accumulated in soil adjacent to the road (Table 4). There was a significant decrease in the content of the chemical element together with an increase in distance from the road. The average lead content 50 m from the road was lower by 83.70 mg·kg^{-1} than in soil of the roadside that was directly adjacent to the road. Lead content 100 m from the road amounted to 22.86 mg·kg^{-1}. Correlation analysis did not show any dependences between lead content in soil and soil characteristics such as pH, type of land use, organic matter content, and the content of silt and clay particles. Any dependencies between lead content in soil and traffic density on the tested road were not found, as well.

Cadmium content in soil samples ranged from 0.016 to 0.909 mg·kg^{-1}, on average 0.228 mg·kg^{-1} of dry matter (Table 7, Fig. 5). The average cadmium content in soil of the tested road amounted to 0.207 mg·kg^{-1}, with minimum 0.017 and maximum 0.604 mg·kg^{-1}. Beyond the road the average amount of cadmium in soil amounted to 0.239 mg·kg^{-1} and ranged from 0.016 to 0.909 mg·kg^{-1} of dry matter. The average contents of the chemical element in soil 50 and 100 m from the road amounted to 0.256 and 0.221 mg·kg^{-1}, respec-

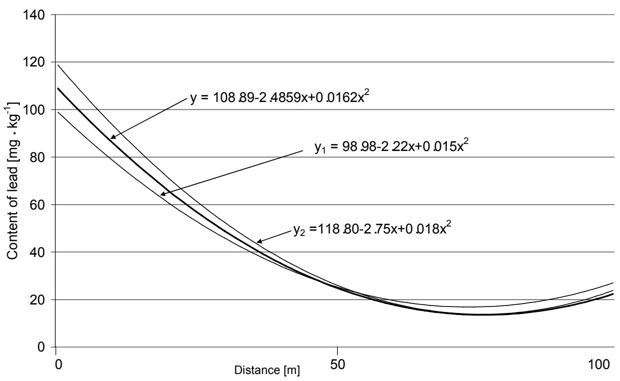
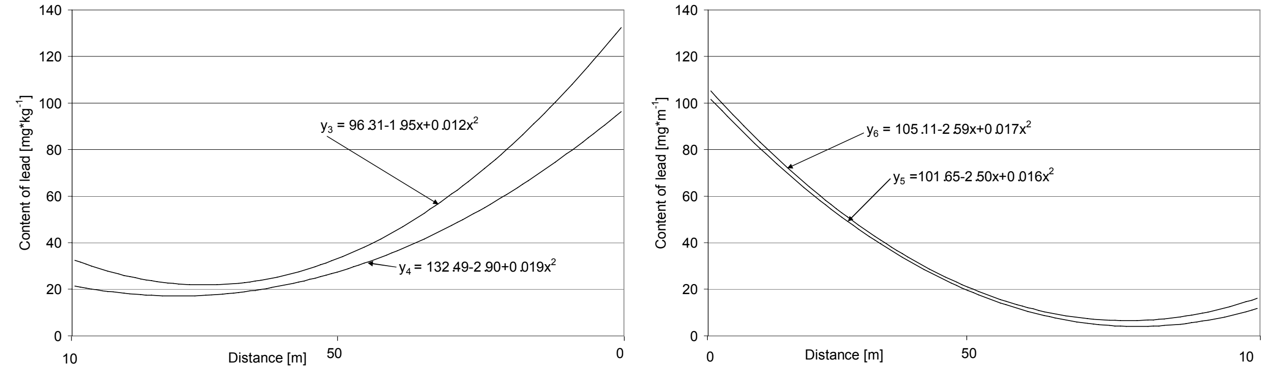


Fig. 4. Regression equation for lead content.
y – total content; y_1 – content in topsoil; y_2 – content in subsoil



left side right side

Fig. 5. Regression equation for influence of side of road on lead content.
y_3, y_5 – content in subsoil; y_4, y_6 – content in topsoil

Table 7. Parameters of statistical characteristics of cadmium content in investigated soils.

Distance [m]	Left side		Right side	
	Topsoil	Subsoil	Topsoil	Subsoil
0	(0.181–0.604) 0.303 ± 0.136 44.9	(0.034–0.477) 0.196 ± 0.140 71.4	(0.109–0.399) 0.195 ± 0.093 47.6	(0.017–0.344) 0.193 ± 0.113 85.2
50	(0.093–0.830) 0.324 ± 0.314 71.7	(0.066–0.909) 0.290 ± 0.314 108.2	(0.020–0.543) 0.248 ± 0.182 73.5	(0.016–0.396) 0.162 ± 0.109 67.3
100	(0.018–0.519) 0.245 ± 0.168 68.6	(0.043–0.885) 0.281 ± 0.260 92.3	(0.063–0.510) 0.176 ± 0.160 90.5	(0.027–0.531) 0.182 ± 0.152 83.7

$\frac{(x\,\min - x\,\max)}{\frac{\bar{x} \pm s}{V}}$ ...where: x min – minimum value [mg·kg^{-1}]; x max – maximum value [mg·kg^{-1}]; $\bar{x}$– mean [mg·kg^{-1}]; s – standard deviation [mg·kg^{-1}]; V – variable coefficient [%],

a, b – values differ significantly at p=0.05

tively, and they did not differ significantly. However, the side of the road had a significant effect on cadmium content. Soil on the left side of the road was characterized by larger cadmium content, which amounted to 0.26 mg·kg^{-1} (Table 7).

The largest cadmium content was found in samples collected east of Siedlce (Point 9, Fig. 6), not far from the industrial district of the town. There are some metal industry plants in the district. No significant differences in the content of the chemical element in the upper and lower parts of soil were found. Cadmium content did not depend significantly on other soil parameters. There was, however, a tendency to accumulate larger amounts of the chemical element in soil of agricultural area, which could be related to the use of phosphate fertilizers that contain a large amount of cadmium in Poland [30].

The cadmium content in soil samples was characterized by a great fluctuation ($V_{\%}$=44.9-108.2%), considerably larger than in the case of lead content (Table 6). The result showed that there were other reasons for increasing cadmium content, apart from road traffic.

The lead contents in the studies were larger than characteristics for geochemical background accepted in the region of Poland [31, 32]. The result confirmed the existence of anthropogenic pressure processes. Results presented in Table 8 were comparable to results that were obtained by other Polish researchers in similar conditions. On the other hand, considerably larger values of lead content in roadside soils were found in other countries with similar traffic density [33-37]. The research results obtained in other studies [29, 33, 38-42] indicated that there was a strong relationship between the number of passing cars and

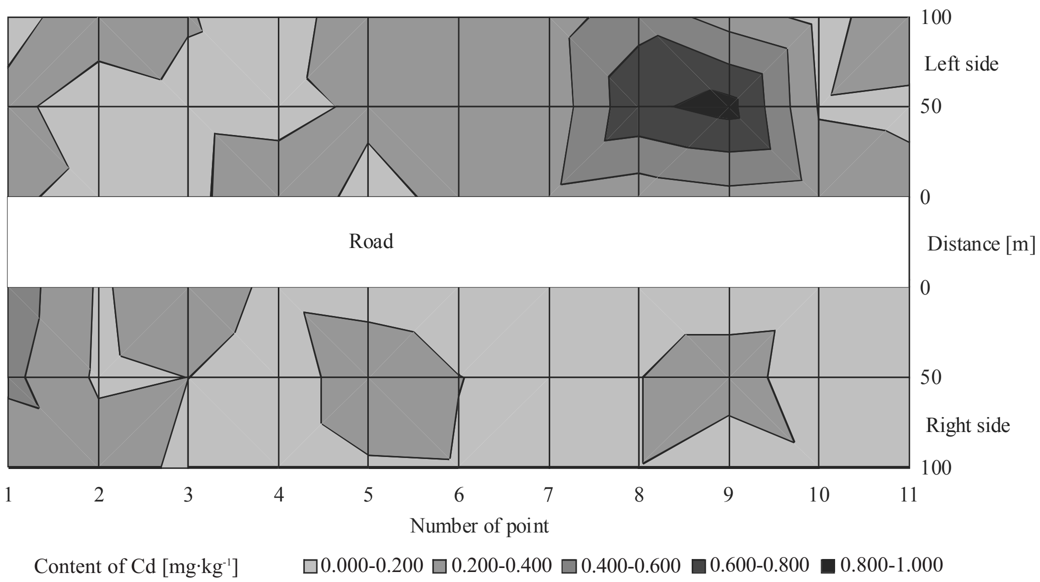


Fig. 6. Content of cadmium in soils adjacent to road E30.

Table 8. Lead and cadmium contents in roadside soils in different regions of the world.

Country	Traffic density	Lead content	Cadmium content	References	Method
Poland Road No. 4, near Rzeszów	-	5 m 20.5-33.6 50 m 15.5-26.6 100 m 14.0-40.2	0.40-0.50 0.43-0.48 0.43-0.68	[34]	ICP – AES
Olsztyn	-	10 m 9.98-11.3 60 m 6.2-7.6 100 m 5.3-5.8	0.012-0.021 0.008-0.018 0.014-0.027	[35]	AAS
Poznań N-S road W-E road	6,000-8,000	near road 70.5-198.7 62.9-168.0	0.06-1.82 0.05-0.76	[36]	FAAS
England Road No. 35 Yorkshirre	-	50 m 25-1,198	0.3-3.8	[31]	AAS
Spain La Coruña	20,000	24-554	-	[32]	FAAS
Slovenia Ljubljana Zagreb	10,000 15,000	16-664	-	[33]	-
Australia Brisbane	69,000	1,950-3,800	-	[37]	AAS ICP X- Ray
Hungary Budapest	22,860	12-24	-	[38]	ICP
Estonia Tallinn	3,400-49,600	7.4-108	-	[39]	FAAS
Turkey Bursa	2,200-50,600	210	-	[40]	FAAS
USA Mission Pennisula	8,200-16,000	90-210	-	[41]	FAAS
Denmark Road No. 70, Rud Road No. 14, Vejenbred	22,000 29,000	3 m 1-6 20 m 11-12 3 m 83-223 20 m 42-48	-	[42]	AAS

the lead content in roadside soils. In the study presented, however, such a strong relation was not found due to different kinds of fuel, the number of vehicles that used unleaded petrol (which was difficult to assess), and other sources of lead, i.e. dustfall [10].

Cadmium content in this study was considerably larger than its amount for geochemical background in the region [32]. A strong anthropogenic pressure in the Siedlce region was found in other research [43]. The statistical analysis did not show any strong relationship between cadmium content and traffic on the E30 road. Cadmium is a component of some car elements such as brake disks, brake blocks, friction-disks of clutches, and paints [7]. A larger amount of the chemical element could be found in places where the car elements were intensively used, i.e. a railway crossing or on slopes. This could explain larger cadmium content on the sloping parts of the road in point 1 (Fig. 6). However, emission of particles containing the chemical element is usually considerably lower than the amount of cadmium that appeared during the burning of solid biolits [7].

Cadmium is also a component of many phosphate fertilizers and originates from apatites and phosphorites used for fertilizer production. The significant effect of applying the fertilizers on cadmium content in Polish soils has been proven in other studies [44].

Table 9. Maximum allowable concentrations of lead and cadmium in soil in Poland.

Reference	Samples from:	Lead	Cadmium
		mg·kg^{-1}	
Minister of the Environment	Protected areas	50	1
	Agircultural areas	100	4
	Industrial areas	200	10
Minister of Agriculture and Rural Development	Ecological farms	50-100	0.75-1.5

Comparison between the obtained lead content and standards, which are compulsory in Poland and the European Union (Table 9), showed that the road strip 50 m from the road must be excluded from plant growing in ecological agriculture, because a smaller distance cannot ensure high quality agricultural products [45, 46]. When it comes to cadmium, determining areas that must be excluded from cultivation requires analyses in each area that is planned to be cultivated.

Conclusions

1. Traffic on the tested road caused a significant increase in lead content (on average up to 103 mg·kg^{-1}) 50 m from the roadside. The chemical element content also significantly depends on the depth of sampling points and the side of the road.
2. The largest cadmium content (over 0.900 mg·kg^{-1}) in soil samples collected from areas located near the industrial district of Siedlce was proven.
3. There was no significant correlation between the amount of cadmium in roadside soils of E30 and distance from the road. No significant effect of other factors on cadmium content were found.
4. Lead (beyond the road strip) and cadmium contents did not exceed the limit values that are appropriate for cultivation. However, compared to geochemical analysis, larger contents of the chemical elements indicated a considerable anthropogenic effect in the region.

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