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Original Research

Heavy Metals Contamination in Soils of a Small Town with Intensive Road Traffic

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Abstract

There is very little information on soil pollution in small towns in Poland. This research was conducted in 2010 to determine the degree of soil contamination by select heavy metals (Cd, Pb, Ni, Co, Cu, Cr) in Grajewo – a small town with intensive road traffic in northeastern Poland. Analyzed soils were mostly alkaline and characterized by very low clay fraction and humus content, which makes them not resistant to heavy metals contamination. According to the guideline established by IUNG and regulations of the minister of the environment concerning the standards for soil quality and land quality, the top layers of analyzed soils (0-20 cm) were polluted by cadmium, mostly at a low level (class II). Increased content (class I) in a substantial part of the town was also found in the case of nickel. The concentrations of lead, cobalt, copper, and chromium in soils generally corresponded to the natural content. The content of almost all determined heavy metals was correlated, which may indicate the same source of origin.

Keywords: heavy metals, small town, urban soils, soil contamination

Introduction

An extremely important current consequence of the development of our civilization is the degradation of the natural environment, mainly manifesting in the form of accumulation of many pollutants. One of the most significant environmental pollutants is heavy metals. Included in high concentrations in air and water, they negatively affect the soil and living organisms. Also, taken in excessive amounts from soil by plants, they enter the food chain and toxicly interact with animals and humans in a cumulative way, causing serious diseases [1-3]. The availability of heavy metals in soil for plants depends on many factors, but the most important are: soil pH, texture, and humus content in soil [1, 4-6].

In many places around the world urban areas, industrial areas, and lands located close to mine ores or big traffic routes have increased levels of heavy metals, especially lead and cadmium [1, 2, 7-17]. Generally in Poland the heavy metals hazard is rather low - the vast majority of soils (79% of agricultural lands) are characterized by natural content of these ingredients. Contaminated agricultural soils can be found only locally, mainly in the southern and southwestern parts of the country [1, 18]. This issue is different in soils of urban, industrial, traffic, and mining areas (SUITMA). The highest contamination is noted in industrial and mining sites [1, 2]. Areas located along the busy traffic routes outside cities also often have a significantly higher content of heavy metals in soils in comparison to unpolluted ones, but not always [19, 20]. Many studies have shown the problem of high levels of heavy metals in urban areas in different parts of the country [21-33]. Almost all of them concern big cities and there is very little information on soil pollution in small towns (below 50,000 inhabitants), which are prevalent in Poland [34, 35].

The aim of this study was to determine the degree of soil contamination by select heavy metals (Cd, Pb, Ni, Co, Cu, Cr) in Grajewo town, located in Podlaskie Voivodeship

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in northeastern Poland. The recent results of the monitoring of arable soils in Poland indicate a lack of contamination by these heavy metals in Podlasie Region [36]. However, in urban areas close to major roads and active industrial plants we can expect increased concentrations of at least some of these metals.

Study Area

Grajewo is a communal town occupying an area of almost 19 km^2 with a population over 22,000. It is located in areas generally considered as low polluted, between the Great Masurian Lakes and Biebrza National Park. There are a few forests, the largest of which stands in the southeastern part of town. Enclaves of urban greenery, allotment gardens, and lawns occupy minor areas.

Due to its location we can observe intensive road traffic in the town (average traffic volume in the center – over 11,000 vehicles per day), especially on the two main roads running in the direction of north-south (Białystok-Ełk) and east-west (Warsaw-Łomża-Suwałki) [37]. In Grajewo there is a centralized heating system (installed power 40.7 MW) that covers 62% of the urban area. Some workplaces in the town have their own boiler rooms based on coal. Among the industrial plants harmful to the environment the most important are: MLEKPOL Dairy Cooperative, a leader in the dairy industry in the country, and PFLEIDERER Grajewo S.A. – producer of wood-based materials used in the furniture, interior, and construction industries. They are located in the southern part of Grajewo. Because of the dominance of western winds [38], the pollution emitted from these plants are deposited in the town to a small extent. In addition, there are many small objects – boiler rooms in individual residential buildings and little ones in institutions and business entities.

Methods

Within the Grajewo town limits we set 21 evenly distributed posts, mainly situated along the traffic routes. Soil samples from top 0-20 cm layer were collected for analysis in 2010 (Fig. 1). These points were usually located on lawns (10 samples) and arable lands (7 samples), and more rarely, on permanent grasslands (4 samples). Soil samples were averaged by mixing, dried at room temperature, and then sifted through a 2 mm sieve to determine particle size distribution by Casagrande'a method in Prószyński's modification. Fractions and textures of soils were set according to the classification of the Polish Society of Soil Science from 2008 [39]. Other analyses were carried out in materials sifted through 1 mm mesh. Soil pH in H_2O was determined using the potentiometric method, organic carbon content by the Tiurin method.

Select heavy metals content (Cd, Pb, Ni, Co, Cu, and Cr) was determined by AAS method using a GBC AVANTA after prior digestion of soil in a mixture of concentrated nitric acid and 70% perchloric acid. Box and whisker plots of heavy metals content in the soils and Spearman rank correlation matrix were made using STATISTICA 10 software.

The heavy metals content was related to guidelines prepared by the Institute of Soil Science and Plant Cultivation (IUNG in Polish) [40] and Regulation of the Minister of the Environment from 9 September 2002 concerning the standards for soil quality and standards for land quality [41].

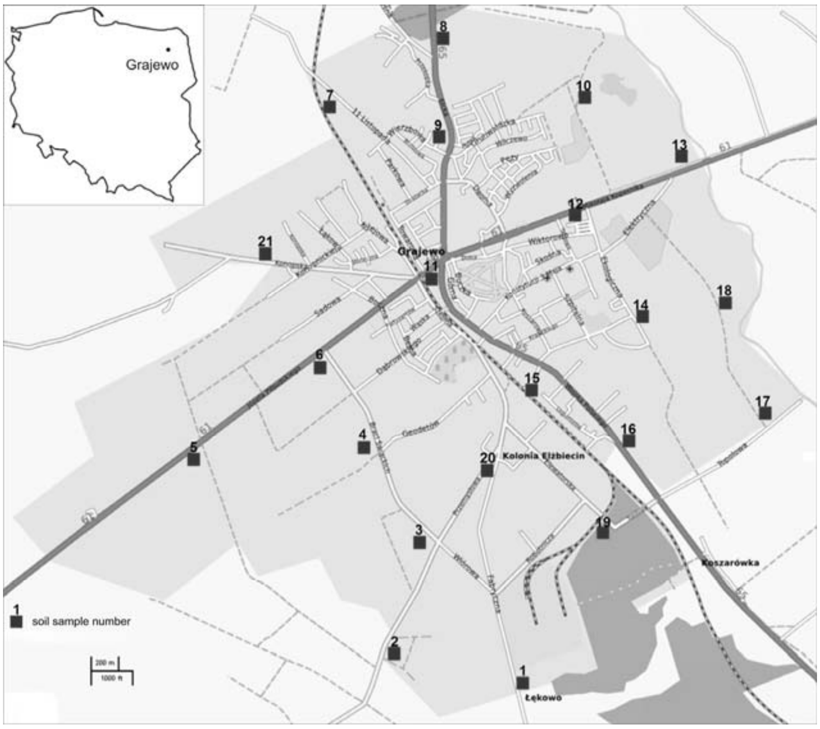

Fig. 1. The location of the soil sampling sites.

Table 1. Granulometric composition, pH in water, and humus content in study soils.

No.	Fraction (%)				Soil textural classes	pH in H_2O	Organic C $g \cdot kg^{-1}$
	2.0-0.05 mm	0.05-0.002 mm	<0.02 mm	<0.002 mm			
1	90	9	8	1	slightly loamy sand	8.32	45.71
2	92	8	6	0	loose sand	8.37	70.44
3	91	8	7	1	loose sand	6.42	113.08
4	94	6	4	0	loose sand	8.14	330.00
5	80	19	10	1	loamy sand	6.36	91.76
6	79	18	11	3	loamy sand	8.35	151.20
7	90	8	7	2	slightly loamy sand	7.31	143.08
8	89	9	8	2	slightly loamy sand	8.74	25.45
9	92	7	4	1	loose sand	8.87	120.00
10	94	5	6	1	loose sand	7.49	220.00
11	94	5	5	1	loose sand	8.62	19.46
12	87	11	9	2	slightly loamy sand	8.3	120.00
13	91	8	6	1	loose sand	8.32	28.12
14	95	5	3	0	loose sand	7.58	44.35
15	89	11	5	0	slightly loamy sand	7.39	168.00
16	89	10	6	1	slightly loamy sand	8.33	432.00
17	89	10	4	1	slightly loamy sand	5.25	148.00
18	92	8	3	0	loose sand	7.91	253.85
19	95	5	3	0	loose sand	8.39	113.68
20	82	17	9	1	loamy sand	7.90	166.67
21	72	26	14	2	loamy sand	6.98	213.91

Results and Discussion

In the top layers of the analyzed soils the sands were formed, mostly loose sands (10 samples) or slightly loamy sands (7 samples) (Table 1). The content of clay (<0.002 mm; fraction having the greatest importance in sorption of contaminants) was very low and did not exceed 3%. Silt fraction (0.05-0.002 mm) was present in the soils at from 5% to 26%.

The pH in H_2O of analyzed soil samples ranged from 5.25 to 8.87 (Table 1). Most of the soils were characterized by alkaline reaction – pH above 7.2 (17 samples). There was no soil with a strong acidic reaction – pH below 4.5. Organic carbon content in samples widely fluctuated from 19.46 to 385.09 $g \cdot kg^{-1}$ d.m., but most of the soils were characterized by low content of up to 200 $gC_{org} \cdot kg^{-1}$ d.m. (Table 1). Amounts greater than 270 $gC_{org} \cdot kg^{-1}$ d.m. were found only in small areas in the eastern part of town.

The heavy metal content in soils of Grajewo is shown in Table 2, and box and whisker plots with statistical parameters are presented in Fig. 2.

The total amount of cadmium in the topsoils ranged from 0.91 to 3.58 $mg \cdot kg^{-1}$ d.m. (mean 1.65 $mg \cdot kg^{-1}$ d.m.), and it was significantly higher than the average content of this metal in the Polish soils, equal to 0.22 $mg \cdot kg^{-1}$ d.m. [42]. With regard to the guideline established by IUNG in Pulawy [40], most analyzed soils were characterized by low cadmium contamination. There was no level corresponding to the natural content of this element on the study area. Several places located in different parts of the town were characterized by moderate cadmium contamination, and in one place high contamination was found near the street in the northern part of Grajewo.

The lead content in the analyzed soils varied in a wide range from 7.41 to 47.63 $mg \cdot kg^{-1}$ d.m. (mean 21.01 $mg \cdot kg^{-1}$ d.m.), but most of them had some amounts of lead greater than average content of that element in unpolluted soils of our country, estimated at 18 $mg \cdot kg^{-1}$ d.m. [1]. According to the IUNG guideline [40], the lead content was close to the geochemical background in almost all sites, except for one point with higher content in the northeastern part of town.

Table 2. Heavy metals content in soils in mg·kg^{-1} d.m. and soil contamination classes by IUNG [40] and Regulation of the Minister of the Environment [41] (only Co).

No.	Cd		Pb		Ni		Co		Cu		Cr	
	mg·kg^{-1}	class	mg·kg^{-1}	class	mg·kg^{-1}	class	mg·kg^{-1}	class	mg·kg^{-1}	class	mg·kg^{-1}	class
1	2.72	III	12.00	0	11.50	I	4.34	0	8.00	0	4.15	0
2	1.34	II	24.40	0	8.65	0	3.63	0	8.35	0	<0.01	0
3	1.03	II	13.72	0	10.39	I	3.58	0	6.27	0	1.76	0
4	2.04	III	18.56	0	20.31	I	10.16	0	22.60	I	4.76	0
5	1.12	II	23.84	0	13.93	I	5.34	0	10.49	0	4.08	0
6	1.46	II	20.40	0	11.57	0	5.03	0	12.59	0	2.93	0
7	1.06	II	15.99	0	11.80	I	4.38	0	10.64	0	2.12	0
8	3.58	IV	24.46	0	17.79	I	12.61	0	14.34	0	7.53	0
9	1.87	II	29.29	0	11.77	I	4.74	0	8.18	0	<0.01	0
10	2.19	III	47.63	I	16.81	I	6.48	0	19.53	I	7.14	0
11	1.62	II	11.88	0	10.89	I	5.27	0	10.04	0	2.79	0
12	1.57	II	22.21	0	12.76	I	5.26	0	12.10	0	0.58	0
13	1.34	II	10.55	0	12.67	I	5.25	0	7.97	0	0.09	0
14	1.48	II	29.47	0	13.28	I	5.32	0	12.12	0	5.37	0
15	1.47	II	29.58	0	10.37	I	3.12	0	7.19	0	<0.01	0
16	1.83	II	20.72	0	11.77	0	4.40	0	7.76	0	<0.01	0
17	1.19	II	23.70	0	7.09	0	1.52	0	3.66	0	<0.01	0
18	2.12	III	12.64	0	12.69	I	5.63	0	12.18	0	<0.01	0
19	1.76	II	28.70	0	13.87	I	5.34	0	12.20	0	1.24	0
20	0.96	I	14.08	0	9.71	0	3.87	0	7.20	0	<0.01	0
21	0.91	I	7.41	0	10.33	0	4.02	0	4.49	0	<0.01	0

Contamination classes: 0 – natural content, I – increased content, II – low contamination, III – moderate contamination, IV – high contamination, V – very high contamination

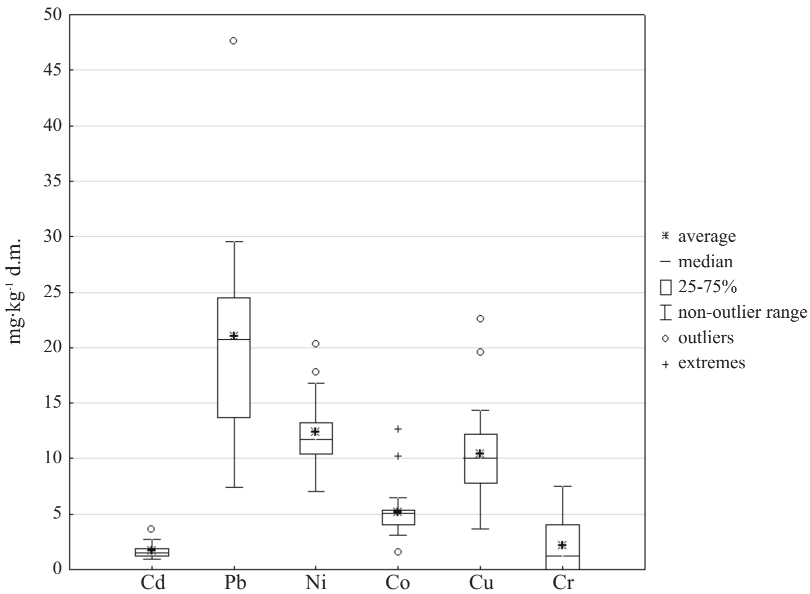

Fig. 2. Box and whisker plots showing heavy metal concentration ranges in analyzed soils.

Table 3. Spearman rank correlation coefficients between some soil properties and soil content of heavy metals.

	Ni	Co	Cd	Cr	Cu	Pb	$C_{org.}$	pH_{H_2O}	Φ<0.02	Φ<0.002
Ni	1									
Co	**0.9168**	1								
Cd	**0.5584**	**0.6103**	1							
Cr	**0.6744**	**0.6391**	0.3993	1						
Cu	**0.8181**	**0.8623**	**0.5987**	**0.6765**	1					
Pb	0.3103	0.1740	0.3077	0.1709	0.3259	1				
$C_{org.}$	0.0272	-0.0155	-0.0039	-0.3339	0.0298	0.0298	1			
pH_{H_2O}	0.1825	0.3280	**0.5748**	0.0674	0.3748	0.0766	-0.3358	1		
Φ<0.02	-0.1654	-0.1935	**-0.4426**	0.0756	-0.1784	-0.3184	0.0235	-0.1916	1	
Φ<0.002	-0.0586	-0.0614	-0.2194	0.1516	-0.0580	-0.2941	-0.0097	-0.0076	**0.7760**	1

Correlations significant at $p<0.05$ are in bold

The analyzed soils were characterized by nickel content in the range from 7.09 to 20.31 mg·kg^{-1} d.m. (mean 12.38 mg·kg^{-1} d.m.), which was slightly higher than the average content in Polish soils – 6 mg·kg^{-1} d.m. [1]. These amounts qualify the vast majority of soils in Grajewo to class I for nickel pollution (increased content). In some soils, mainly located in the centre of the study area, content of this metal was low.

The average amount of cobalt in Polish sandy soils is 5 mg·kg^{-1} d.m. [1]. Analysis of soils in Grajewo has shown the cobalt content within the limits 1.52 to 12.61 mg·kg^{-1} d.m. (mean 5.20 mg·kg^{-1} d.m.). In the case of cobalt IUNG has not developed indicator content in soils [40]. All of the obtained values were within the limits set by Regulation of the Minister of the Environment of 9 September 2002 on standards for soil quality and standards for land quality [41].

The amounts of copper in the soils were from 3.66 to 22.60 mg·kg^{-1} d.m. (mean 10.38 mg·kg^{-1} d.m.). Almost everywhere it was above the average content in the soils of the country – 6.5 mg·kg^{-1} d.m. [42]. These soils were characterized by a natural copper content, excluding two points with increased content, located in the southwestern and northeastern parts of town.

The chromium content varied from trace amounts to 7.53 mg·kg^{-1} d.m. (mean 2.12 mg·kg^{-1} d.m.), and it should be classified as natural content. It was usually less than the average concentration of chromium in Polish sandy soils, which is 7 mg·kg^{-1} d.m [43].

The major factor determining the concentration of metals in the soil solution, their mobility, and availability to plants is soil pH [44, 45]. To some extent the lower the soil pH the higher the mobility of heavy metal cations. Many metal cations are more soluble already in the soil solution below pH 5.5. Soil organic matter can efficiently cause the retention of metals, but this process is weaker at low pH [46]. The soil's ability to immobilize heavy metals increases with rising pH and peaks under mildly alkaline conditions [47]. If soil pH is higher than 6.5-7.5, the mobility of the majority of them increases because of the formation of the complex anions of these metals [6, 48]. The solubility and bioavailability of metals decreases with increasing content of organic matter and clay due to their increased adsorption. It follows that the most resistant to the effects of heavy metals are soils in the neutral range pH with high organic matter and clay content.

Surface materials in researched soils are sands, poor in mineral and organic colloids. They are characterized by a low cation exchange capacity, so they are not able to accumulate high amounts of heavy metals. In addition, the soil pH most of them is alkaline, which is, of course, better than acid reaction, but due to the above mentioned processes it is not sufficiently saving plants from heavy metals uptake.

The content of all determined heavy metals except Pb was correlated at medium or high level (r=0.56-0.92, Table 3), which may indicate the same source of origin. A similar relationship between these elements in soils was also noted by other authors [2, 10, 13, 15, 32, 40].

Lack of correlation between heavy metals content and properties of soil (organic carbon content, soil pH, soil particles <0.02 and particles <0.002 mm content; the exception – cadmium, which correlated at medium level with pH and with soil particles <0.02 mm) can be explained by an insufficient number of samples. When the number of analyses is high these parameters are often correlated [2, 19, 40].

The analyses indicate some contamination of the soils with cadmium and nickel, which was probably caused mainly by road traffic and power engineering. The total content of lead, cobalt, copper, and chromium was generally similar to the geochemical background.

Increased amounts of cadmium in most analyzed soils at minimum II contamination class are the most worrisome problem. Results of research carried out in other cities of Poland, such as Warsaw (near Czerniakowskie Lake) [31], Opole [32], Bydgoszcz [22], Białystok [30], and Zielona Góra [29], also have shown the cadmium contamination of soils. At the same time in the above-given cities other heavy metals, such as lead and copper, are usually present at natural or slightly increased concentrations (contamination class 0 or I).

Pollution degree of urban soils in the country varies in a wide range. Really high heavy metal content can be noted in some urban areas close to impactful industrial plants and big traffic routes. The example is the western part of Wrocław bordering metallurgical plants, where the degree of allotment garden soil contamination was generally average for lead and strong in the case of cadmium and copper [27]. Quite high concentrations of Cd, Pb, and Cu were also found in soils adjacent to very busy traffic routes in Warsaw city [26]. About 50% of the soil area of Poznań is characterized by concentrations of the heavy metals mentioned above, which exceeded the natural background and their permissible content [23]. In comparison, within almost all of the Puławy area, a town twice as big as Grajewo, pollution of soils by heavy metals was not found [34, 35].

Conclusions

1. According to the guideline established by IUNG [40] the top horizons of soils (0-20 cm) from Grajewo were mostly slightly contaminated by cadmium (class II) and in several posts – moderate (class III) or high (class IV).
2. Increased content (class I) in a substantial part of the town was also found in the case of nickel.
3. The concentrations of lead, cobalt, copper and chromium in soils generally correspond to the natural content.
4. The content of almost all determined heavy metals was correlated at a medium or high level, which may indicate the same source of origin.
5. Analyzed soils were mostly alkaline and characterized by very low clay fraction and humus content, which makes them not resistant to heavy metals contamination.
6. The conducted research indicates that the contamination of soils with some heavy metals, especially cadmium, concerns not only big cities, but also small towns with intensive road traffic, such as Grajewo.

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