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Effect of traffic routes on the trace element concentration in plants in the Warsaw agglomeration

Abstract: This work presents the results of an analysis of concentration levels of selected trace metals (Pb, Zn, Cu, Cd) in plants and soil near the main roads of the Warsaw agglomeration. The aim of the study was to assess the degree of contamination by selected trace elements of plants growing at different distances from the road (directly at the roadside and 50 meters away from the road) and to examine the relationship between the concentration of the tested parameters in the soil and their content in the plant. It was found that the lack of clear differentiation in the levels of all heavy metals in plants depending on the distance from the road was associated with the possibility of considerable pollutant migration. In addition, it was found that dandelion usually reveals higher concentrations of heavy metals than meadow-grass.

Keywords: trace elements, Warsaw agglomeration, transport

INTRODUCTION

The 21st century has brought Poland rapid developmental changes. The more intense and accelerated anthropogenic activities, however, greatly affect the natural environment through impoverishment and pollution. One of the primary, and particularly evident nowadays, means by which humans affect the environment is transport (Walczak and Chutko 2014). Its functioning and the continuous development of transportation networks exert a considerable impact on the quality status of the environment (Indeka and Karaczun 2000). It is estimated that about 50% of pollutants in Poland come from this sector (Curzydło 1995). The occurrence of traffic-related pollutants is linear in character; they occur in the immediate vicinity of busy roads (Plak et al. 2010, Sławiński et al. 2014). It has been found that dust and gas pollutants can occur up to a distance of 500 m away from the road, and their evidently harmful effects are apparent for up to 150 m from the road. Along with other pollutants, heavy metals find their way into the air and soil, and may then accumulate in plants (Świercz et al. 2011). These elements migrate very slowly in the soil and are therefore the most persistent contaminants. This is because they do not undergo chemical or biological degradation, but may be included in the trophic chain and, consequently, pose a threat to the health of both humans and animals (Dziadek and Waclawek 2005, Fijałkowski et al. 2012, Ociepa-Kubicka and Ociepa 2012,

Grobelak et al. 2013). Their occurrence is associated with the emission of vehicle exhaust fumes, chemical compounds from fuels, lubricants and oils, compounds resulting from incomplete combustion, leakage of fluids from faulty installations, dust emissions, the wearing of tyres, brake linings, clutch discs and road surfaces, but also through road crashes, the use of de-icing salt in winter, and the work carried out in connection with the construction or repair of road surfaces (Hewitt and Rashed 1990, Huang et al. 1994, Chłopek 2002, Forman et al. 2003, Sławiński et al. 2014). The highest levels of contamination with heavy metals are recorded in cities with large populations and dense transportation networks associated with them (Binggan and Yang 2010). Large numbers of moving vehicles and congested traffic cause higher-than-normal concentrations of these elements both in the soil and plants.

The Warsaw agglomeration is a prime example of environmental pollution caused by transportation routes. As the largest and most populated city in Poland it is also one of the most extensively developed transportation hubs. It is a place crisscrossed by not only local but also national and international roads. The road network in Warsaw is about 2315.6 kilometres in length. Because of its central geographical location, it is also exposed to high-intensity traffic. This is evident both in the city centre and also on the exit roads from Warsaw, where traffic jams can be observed every day (Dmochowski et al. 2011).

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FIGURE 1. Location of soil sampling sites near the main exit roads from Warsaw (website 4)

Despite the presence of road pollutants, transportation routes are constantly being developed to meet the functional needs of society. Since 2007, the General Directorate for National Roads and Motorways has put into operation 3,612.7 km of new or rebuilt roads. And the National Road Construction Programme for the years 2014-2023 envisages the construction of additional 4000 km of express roads (website 1). With the development of the transportation network the number of motor vehicles on the roads is also growing. Currently, about 3 million vehicles are sold annually in the richest countries of Europe, with about 200 thousand being sold in Poland. As a result, Poland has now three times as many vehicles as in the 1970s. However, one should take into account the fact that in Europe 80% of automotive pollutants are emitted by older vehicles, even though they constitute only 20% of the total number of vehicles (there is a higher percentage of older cars in Poland) (website 2). Considering the large number of vehicles making use of an inadequate road infrastructure, it can easily be concluded that transportation routes pose a serious threat to the environment in terms of pollution with heavy metals.

The aim of the study was to assess the degree of contamination with selected trace elements of plants growing along exit roads from the Warsaw.

MATERIALS AND METHODS

The study was conducted near five exit roads from Warsaw. All of them are national roads that carry heavy automobile traffic. Samples were collected in the towns/villages of Łomianki, Sękocin, Żabieniec, Marki, Stara Miłosna (marked Terespol because of the name of the route, which runs through the estate).

The annual average daily traffic (AADT) on these routes is from over 18 thousand to as many as 60 thousand vehicles per day (Table 1).

Samples for the determination of trace elements were collected in June 2016. There were a total of 10 sampling points from which the test material originated. The samples were collected in close proximity to the road and at a distance of 50 m away from it in a straight line, where there were mostly meadows and wasteland. Soil samples were collected from a depth of 0–20 cm. The soil sampling locations were also used to collect plant material from the aerial parts of the common dandelion (*Taraxacum officinale*) and smooth meadow-grass (*Poa pratensis* L.). The plant samples were washed in distilled water, dried and then ground.

TABLE 1. Locations of sample collection and annual average daily traffic of motor vehicles there (website 3)

Item	Road No.	Route	Sampling location (Fig. 1)	Annual average daily traffic (AADT) of motor vehicles*
1	7/E77	Gdańsk - Chyżne	Sękocin	23.458
2	79	Warszawa - Katowice	Żabieniec	30.075
3	7/E77	Gdańsk - Chyżne	Łomianki	52.466
4	S8/E67	Suwałki - Wrocław	Marki	43.874
5	2/E30	Kukuryki - Świecko	Terespol	22.082

The soil material was dried at room temperature and then sieved through a 2 mm-mesh sieve. The plant samples were also dried and then ground. Next, the soil pH was measured potentiometrically in 1 mol·dm⁻³ KCl solution. The concentrations of trace metals (copper, cadmium, zinc, lead) in soil after extraction with 0.01 mol·dm⁻³ CaCl₂ and in plants after mineralization in a mixture of concentrated HNO₃ and HClO₄ were determined by atomic absorption spectrometry (AAS). The amounts of the selected heavy metals were determined with a Thermo Elemental SOLAAR M6 spectrometer.

Statistical analyses were performed using Statgraphics 5.1 software. The results were subjected to an analysis of variance at a significance level of $p = 0.05$ and to a correlation analysis.

RESULTS AND DISCUSSION

The content of heavy metals in plants ranged from below the level of determination for lead to 189.3 mg·kg⁻¹ for zinc. The levels of trace elements at a

given distance from the road were always higher for the common dandelion than for the smooth meadow-grass.

The highest levels of copper were recorded at the roadside in Sękocin. In the other locations they were lower. The copper concentration in plants decreased significantly with the distance from the road in Sękocin and Marki. However, in Żabieniec and Terespol no significant differences in the levels of copper were observed in dandelion plants. In Łomianki, in turn, the copper content did not differ significantly in the smooth meadow-grass. The lowest concentration of copper in plants was found in Łomianki 50 meters away from the road (Fig. 2).

According to Kabata-Pendias and Pendias (1999) the normal copper content in plants is in the range 3–15 mg·kg⁻¹ DW. Research by Potarzycki et al. (1999) on the amounts of heavy metals in plants in the zone of influence of the Poznań-Świecko transport route did not show copper levels as high as the values for the Warsaw agglomeration. Research by Dzierżanowski and Gawroński (2011) along General Władysław Sikorski Avenue in Warsaw showed that the highest

amounts of copper accumulated directly next to this thoroughfare and decreased with the distance away from it. Sławiński et al. (2014) concluded that elevated levels of copper might result from the increased traffic nearby.

The highest cadmium concentrations were recorded at the roadside in Łomianki. In the other locations they were lower. The cadmium content in plants decreased significantly with the distance from the road in Sękocin, Łomianki and Marki. In Terespol there were no significant differences in the level of cadmium in the common dandelion with the distance from the road. In Żabieniec, by contrast, the cadmium content in both the common dandelion and the smooth meadow-grass increased with the distance from the road and was significantly different. The lowest cadmium content was found in plants at the roadside in Żabieniec (Fig. 3).

According to Kabata-Pendias and Pendias (1999), the normal cadmium content in plants is in the range 0.05–0.2 mg·kg⁻¹ DW, and above 5 mg·kg⁻¹ DW it becomes toxic to plants. Research by Kaszubkiewicz and Kawałko (2009) on agricultural land and

FIGURE 2. Copper content in plants, depending on the sampling site and distance from the road

FIGURE 3. Cadmium content in plants, depending on the sampling site and distance from the road

grasslands in the district of Jelenia Góra exposed to contamination with heavy metals showed that the average cadmium content in plants in that region was $0.22 \text{ mg} \cdot \text{kg}^{-1} \text{ DW}$. Comparing the results presented here with the studies of the above-mentioned authors, it can be concluded that the tested plants contained elevated amounts of cadmium. This can be due to the particularly easy assimilation of this element by plants. Research by Potarzycki et al. (1999) had shown elevated levels of cadmium at the roadside as well as within the whole area analyzed. The highest levels of cadmium in Łomianki and Marki may be related to the heavy automobile traffic occurring there (the highest values of AADT among the sampling locations).

The highest levels of zinc were recorded at the roadside in Marki. In the other locations they were lower. The zinc content in plants increased significantly with the distance from the road in Żabieniec and Łomianki. In Sękocin, the zinc content in the common dandelion increased significantly with the distance from the road, whereas in the smooth meadow-grass it decreased. In Terespol, however, the zinc content decreased significantly in the common

dandelion, whereas in the smooth meadow-grass there was no significant difference. The lowest level of zinc was found in plants at the roadside in Łomianki (Fig. 4).

According to Kabata-Pendias and Pendias (1999), the normal zinc content in plants is in the range $15\text{--}70 \text{ mg} \cdot \text{kg}^{-1} \text{ DW}$, and above $100 \text{ mg} \cdot \text{kg}^{-1} \text{ DW}$ it becomes toxic to plants. Research by Dzierżanowski and Gawroński (2011) showed that the largest amounts of zinc accumulated directly next to the traffic route and decreased with the distance away from it. Based on the results of the present study, it can be stated that zinc can accumulate at considerable distances away from the road. The highest zinc level in Marki is associated with the very heavy traffic there, although such a high level was not observed in Łomianki, where the traffic intensity is similar to that in Marki.

The highest concentrations of lead were found in plants at the roadside in Sękocin. In the other locations they were lower. The lead content in plants was always the highest at the roadside in all the locations. In Żabieniec and Terespol, the level of this element significantly decreased with the distance away from the road, both in the common dandelion and in the

FIGURE 4. Zinc content in plants, depending on the sampling site and distance from the road

FIGURE 5. Lead content in plants, depending on the sampling site and distance from the road

smooth meadow-grass. In Sękocin, Łomianki and Marki, no lead was found in the meadow-grass (Fig. 5).

According to Kabata-Pendias and Pendias (1999), the normal lead content in plants is in the range 1–5 mg·kg⁻¹ DW, and above 30 mg·kg⁻¹ DW it becomes toxic to plants. Research by Bomze (2004) on the heavy metal content depending on the distance away from the traffic route (related to the passage of vehicles) showed that the lead content in plants was in the range 1.36–5.79 mg·kg⁻¹ DW. Studies by Dzierżanowski and Gawroński (2011) showed that the largest amounts of zinc accumulated directly next to the traffic route and decreased with the distance away from the road. The highest lead content at the roadside may be associated with the movement of vehicles.

The study also examined the levels of active forms of trace elements available to plants (Table 2). Using those values, correlation was determined between the levels of heavy metals in soil and in plants (Table 3). In each case, with the exception of lead due to the lack of content in the soil at the distance of 50 meters, positive correlation was found, which means that the more available forms of heavy metals there are in the soil, the higher the level of these elements is found in plants (in the common dandelion and meadow-grass). The correlation analysis at a significance level of 0.05 or less showed a strong correlation for the common dandelion and the amounts of copper, cadmium and zinc in it. Other heavy metals in plants correlate at a low level and are not statistically significant.

CONCLUSIONS

1. The presence of transportation routes contributes to increases in plant heavy metals concentration.

2. The concentration of copper, cadmium and lead in plants generally decreases with distance from the road. There was no clear relationship between plant zinc content and the distance from the road.
3. There was a positive correlation between the active forms of heavy metals in soil and their concentration in plants.
4. The common dandelion is relatively more susceptible to the accumulation of trace elements than smooth meadow-grass.

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TABLE 2. Heavy metals content in soil (mg·kg⁻¹)

Sampling location	Cu		Cd		Zn		Pb	
	0 m	50 m	0 m	50 m	0 m	50 m	0 m	50 m
Sękocin	0.070	0.049	0.012	0.005	0.632	0.660	0.014	n.d.
Żabieniec	0.059	0.003	0.003	0.007	0.617	0.360	0.013	n.d.
Łomianki	0.074	0.047	0.003	0.009	0.366	0.689	0.000	n.d.
Marki	0.051	0.024	0.028	0.010	1.162	0.554	0.000	n.d.
Terespol	0.023	0.099	0.002	0.003	0.219	0.620	0.108	n.d.
mean	0.055	0.044	0.009	0.007	0.599	0.576	0.027	n.d.
LSD0.05	0.005		0.0006		0.08		0.01	

n.d. – not detected.

TABLE 3. Correlation coefficients between the heavy metals content in soil and plants

Plant	Cu		Cd		Zn		Pb	
	0 m	50 m	0 m	50 m	0 m	50 m	0 m	50 m
Dandelion	+0.58**	+0.60**	+0.48*	+0.70**	+0.82**	+0.64**	+0.29*	n.d.

n.d. – not detected.

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Received: March 20, 2017

Accepted: June 5, 2017

Associated editor: B. Rutkowska

Ocena oddziaływania ciągów komunikacyjnych na zawartość pierwiastków śladowych w roślinach na przykładzie aglomeracji warszawskiej

Streszczenie: W pracy przedstawiono wyniki badań zawartości wybranych metali śladowych (Pb, Zn, Cu, Cd) w roślinach i glebie przy głównych ciągach komunikacyjnych aglomeracji warszawskiej. Celem przeprowadzonych badań była próba oceny stopnia zanieczyszczenia wybranymi pierwiastkami śladowymi roślin położonych w różnych odległościach od drogi (bezpośrednio przy drodze i 50 metrów od drogi) oraz do zbadania zależności między zawartością badanych parametrów w glebie a ich zawartością w roślinie. Stwierdzono, iż brak wyraźnego zróżnicowania zawartości wszystkich metali ciężkich w roślinach w zależności od odległości od drogi związany jest z możliwością znacznej migracji zanieczyszczeń. Ponadto stwierdzono, że mniszek pospolity pobiera większe ilości metali ciężkich w porównaniu do wiechliny łąkowej.

Słowa kluczowe: pierwiastki śladowe, aglomeracja warszawska, transport