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Original Research

Traffic Pollutant Indicators: Common Dandelion (*Teraxacum officinale*), Scots Pine (*Pinus silvestris*), Small-Leaved Lime (*Tilia cordata*)

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Abstract

Total amounts of lead (Pb), cadmium (Cd), copper (Cu), cobalt (Co), zinc (Zn), nickel (Ni), strontium(Sr), and chromium (Cr) were measured in surface levels of soil (0-20 cm) as well as in the plants *Taraxacum officinale*, *Pinus silvestris*, and *Tilia cordata* within distances of 5-10 m, 2.0 km, 3.5 km, and 5 km from a heavy traffic route in an open area. Our research showed that car exhaust gases coming from heavily trafficed routes in open areas affect the heavy metal content in plants up to distances of 2 km from the route. Specific influence of traffic concerning Sr content was observed in needles of *Pinus silvestris,* whereas elevated content of Zn was observed in other plants – leaves of *Tilia cordata* and *Taraxacum officinale*.

Keywords: heavy metals, bioindication, plants, *Taraxacum officinale*, *Pinus silvestris*, *Tilia cordata*, soil

Introduction

The sources of information – positive and negative – about processes occurring in the natural environment are mainly observations of the response of living organisms. One of the criteria to classify plant and animal organisms based on the stimulus-and-effect relationship is the ability to accumulate various substances in their tissues. Such organisms received the name of accumulative bioindicators [1, 2]. In most cases the amount of heavy metals in plants depends on their content in soil. However, these relationships are not simple and depend both on edaphic factors of substratum and on environmental pollution, including air pollution [3-5].

A common source of soil and plant contamination with heavy metals is traffic [6]. Most airborne heavy metals of anthropogenic origin accumulate in the smallest parts (<10 µm) of dust [6]. The amount of heavy metals in plants depends on the amount of their available form both in the soil and in the atmospheric fallout [7]. The aim of the research was to determine the utility of chosen plants as indicators of heavy metals contamination in the environment, depending on the distance from heavy traffic route and on the collection date of plant material samples.

Materials and Methods

The objects of the research were located within an open area along the heavily trafficed route out of Warszawa and placed 5-10 m, 2.0 km, 3.5 km, and 5 km from the roadway. The background object was the village, located 120 km from Warszawa (an area generally regarded to be unpolluted). Soil material consisted of medium coarse sand with C organic content of 1.23-1.72% and pH of 4.6-5.1.

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Table 1. Concentration of heavy metals in soil (mg·kg^{-1} d.m) and ± SD.

Location	Pb	Cd	Cu	Co	Zn	Ni	Sr	Cr
5-10 m from roadway	41.5±8.6	0.67±0.16	16.7±4. 8	3.85±0.84	137.0±24.8	12.6±2.6	28.3±6.1	19.4±3.9
2.0 km from roadway	13.6±4.1	0.18±0.07	5.5±2.0	2.93±0.51	42.2±9.1	6.1±1.4	11.4±3.4	9.5±1.7
3.5 km from roadway	2.3±0.6	0.82±0.21	18.0±4.4	8.02±1.52	85.1±14.3	24.9±5.9	30.1±5.7	35.8±7.8
5 km from roadway	10.3±4.7	0.51±0.16	20.3±6.1	7.94±1.20	54.1±12.1	24.8±6.2	27.9±6.7	36.1±8.4
Background	3.4±0.7	0.16±0.04	1.6±0.03	1.24±0.05	20.2±5.6	2.5±0.04	7.13±1.2	6.36±1.6

The literature provides data concerning the effect of traffic within 200 m up to 500 m from the roadway [1, 8]. Therefore, the research was designed to measure much bigger distances from it. Soil samples, were taken from the surface levels (0-20 cm) of mentioned research areas as well as plant samples, i.e. above-ground parts of dandelion, needles of *Pinus silvestris* and leaves of *Tilia cordata*. Samples of plant material were collected in two terms, May and September 2007. The research area consisted of 6 measurement stations. Each measurement station covered 10 m². The selection of plants was due to their occurrence in each sampling site. This allowed for proper comparison of analytical results. Representative samples of soil from the measurement station consisted of 8 individual samples. Dandelion was also collected from the measurement station. Representative tree sample included material from 6 trees. After processes of drying in air at 20ºC to constant weight and grinding, the material was mineralized. Concerning soil, only parts <1 mm were analyzed. Plants and soil were mineralized with microwave method in HNO_3 and HCL. The content of heavy metals (Pb, Cd, Cu, Co, Zn, Ni, Sr, Cr) in solution was examined using the ICP-AES technique.

The results were expressed as correlation and standard deviation (SD). Statistical analysis was performed in the Statistica program.

Results

The average concentration of measured metals in the surface levels of soil along a heavy traffic route (Table 1) depending on the distance from the roadway (Modlinska Street, Route No. 61, 52º19'19.055"N, 20º58'19.739"E) was set in the following order:

5-10 m from the roadway Zn>Pb>Sr>Cr>Cu >Ni>Co>Cd
2.0 km from the roadway Zn>Pb>Sr>Cr>Ni>Cu>Co>Cd
3.5 km from the roadway Zn>Cr>Sr>Ni>Cu>Co>Pb>Cd
5.0 km from the roadway Zn>Sr>Cr>Pb>Ni>Cu>Co>Cd
Background Zn>Sr>Cr>Pb>Ni>Cu>Co>Cd

Among measured elements, the smallest concentration was cadmium, which was in the range of 0.16-0.82 mg·kg^{-1} of dry matter, regardless of the distance from the roadway. The highest content was of Zn, whose most important source of contamination is traffic and was observed in the soil on measurement stations located in the closest vicinity to the roadway. However, based on the above order it can be observed that the heavy traffic could influence its content even at 5.0 km from the roadway. If the achieved results are compared to background findings, what must be observed is that content of Zn in examined soils is several times higher.

Pb is another element, after Zn, which in terms of quantity had the highest content in soil. The influence of heavy traffic on its content in soil of the examined area was clearly observed. In comparison to the background, its content in soil of examined area was 1-12 times higher. The following positions in the mentioned order are occupied by Sr and Cr. The content of these elements in soils within 5 km of the roadway, in comparison to background findings, is elevated. The content of Sr was up to 4 times higher and of Cr up to 6 times higher 5 km from the roadway. Ni, Cu, and Pb in the mentioned order can be observed in the soils considered unpolluted, as well as in the research areas most distant from the roadway (3.5 and 5.0 km). Cu content was elevated in the areas closest to the roadway.

The content of heavy metals in above-ground parts of dandelion (spring term) from objects located closest to the roadway (Table 2) comes in the following discendentive order: Zn>Sr>Cu>Cr>Pb>Ni>Co>Cd. In the samples collected from an unpolluted area and from the object located 3.5 km away from the roadway there is more Zn than Sr. In the plant samples collected closest to the roadway in autumn, the quantitative order of analyzed elements is as follows: Zn>Sr>Cu>Cr>Pb>Ni>Co>Cd. Generally, the content of Zn, Cu, and Cd in above-ground parts of dandelion collected in autumn is higher than of those collected in spring. The content of other heavy metals is at a similar level. The content of Sr, Zn, Cu, Cd, and Pb in dandelion samples from research objects located along the heavy traffic route is elevated in comparison to their content in plant samples coming from an unpolluted area.

The content of measured heavy metals in needles of *Pinus silvestris* collected from objects closest to the roadway, both in spring and in autumn (Table 3), comes in analogical quantitive order as for the dandelion samples. Whereas for needles of *Pinus silvestris* collected from objects located further from the roadway, content of heavy metals comes in quantitive order similar to order for samples collected in the background object: Sr>Zn>Cu>Pb>Ni>Cr>Co>Cd. Results of research prove/show visible accumulation of Pb, Zn, Sr, Cr, and Cd in needles of *Pinus silvestris* growing in the

Table 2. Concentration of heavy metals in *Taraxacum officinale* (mg·kg^{-1} d.m) and ± SD.

Location	Pb	Cd	Cu	Co	Zn	Ni	Sr	Cr
	Spring							
5-10 m from roadway	3.3±0.6	0.20±0.04	11.8±2.7	0.39±0.08	45.1±9.3	2.8±0.7	43.5±8.6	3.9±0.8
2.0 km from roadway	2.9±0.5	0.16±0.03	10.4±2.3	0.40±0.08	34.0±7.6	1.6±0.3	36.4±7.3	3.4±0.7
3.5 km from roadway	3.3±0.5	0.16±0.04	11.2±2.4	0.38±0.09	36.0±7.0	1.9±0.3	34.0±6.9	2.8±0.5
5 km from roadway	3.7±0.7	0.19±0.04	11.2±2.5	0.37±0.09	35.5±7.3	2.0±0.4	38.3±4.1	2.1±0.4
Background	1.4±0.3	0.17±0.03	3.4±0.7	0.34±0.06	22.7±4.8	1.8±0.4	13.2±2.9	1.8±0.4
	Autumn							
5-10 m from roadway	3.1±0.6	0.41±0.08	14.3±2.9	0.61±0.14	75.6±15.3	2.2±0.4	44.9±9.1	4.7±0.9
2.0 km from roadway	2.3±0.5	0.21±0.04	12.6±2.7	0.21±0.04	62.8±13.4	1.1±0.2	37.2±7.3	1.3±0.3
3.5 km from roadway	3.5±0.7	0.35±0.07	20.8±4.2	0.69±0.15	76.3±15.1	2.4±0.5	38.1±8.2	2.1±0.4
5 km from roadway	2.4±0.5	0.48±0.09	14.4±2.9	0.48±0.09	72.1±14.3	1.9±0.3	31.3±6.7	3.4±0.7
Background	2.6±0.6	0.12±0.04	9.6±2.0	0.41±0.09	37.4±9.3	1.9±0.4	24.6±5.1	2.0±0.4

roadside regardless of the date of collection. Differences in content of Zn and Sr in dependence on distance are observed up to 2 km from the roadway. The observed dependency is related to spatial development of the area. The range of contamination is higher in non-built-up areas.

The content of Sr, Pb, Cd, Zn, and Cu in the needles of *Pinus silvestris* collected in the area closest to the roadway in autumn is visibly higher than in the analogical material collected in spring. Among tested heavy metals, the content of Sr in needles of *Pinus silvestris* exceeds background findings 11 times for spring term and 7 times for autumn term. From analyzed biological material, the highest content of Sr is measured in pine needles. Elevated contents of Sr were observed up to 2.0 km from the roadway.

The content of heavy metals in leaves of *Tilia cordata* collected in spring from the research object located closest to the roadway and from an unpolluted area comes in the following quantitive order: Zn>Sr>Cu>Pb>Ni>Cr>Co=Cd (Table 4). As for the objects located 2.0 km and 3.5 km from the roadway, the order is as follows: Zn>Cu>Sr>Pb>Ni=Cr>Co>Cd. In analogical material collected in autumn from by-roadway and unpolluted objects, Sr dominated in quan-

Table 3. Concentration of heavy metals in needles of *Pinus silvestris* (mg·kg^{-1} d.m) and ± SD.

Location	Pb	Cd	Cu	Co	Zn	Ni	Sr	Cr
	Spring							
5-10 m from roadway	5.16±1.4	0.20±0.04	10.5±2.4	0.70±0.15	94.9±20.3	2.1±0.4	112.0±24.7	6.2±1.4
2.0 km from roadway	3.14±0.7	0.10±0.02	8.4±1.9	0.60±0.13	78.1±17.2	1.4±0.3	84.0±19.3	3.7±0.6
3.5 km from roadway	3.0±0.6	0.10±0.02	8.7±2.0	0.40±0.09	60.4±14.1	1.9±0.5	10.0±3.2	4.6±0.7
5 km from roadway	3.16±0.7	0.20±0.05	7.91±1.7	0.40±0.08	59.3±11.8	1.6±0.3	9.9±2.1	4.2±0.7
Background	2.0±0.5	trace amounts	6.2±1.1	0.30±0.07	20.1±5.1	1.2±0.2	9.0±1.8	2.4±0.5
	Autumn							
5-10 m from roadway	7.6±1.1	0.62±1.2	18.2±3.4	0.63±1.2	89.9±20.4	3.9±0.8	143.2±29.3	4.0±0.8
2.0 km from roadway	5.6±1.22	0.32±0.06	6.1±1.4	0.32±0.07	0.76±12.4	3.1±0.8	70.4±14.2	3.9±0.8
3.5 km from roadway	3.6±0.8	0.10±0.02	5.9±1.3	0.40±0.07	53.5±11.8	3.2±0.8	45.8±9.4	2.6±0.5
5 km from roadway	3.6±0.7	0.10±0.03	4.8±1.1	0.40±0.08	48.3±10.3	3.0±0.36	28.3±6.1	1.6±0.3
Background	2.3±0.4	0.10±0.02	5.1±1.2	0.39±0.07	42.1±11.0	2.1±0.4	21.4±4.8	1.9±0.2

Table 4. Concentrations of heavy metals in leaves of *Tilia cordata* (mg·kg^{-1} d.m) and ± SD.

Location	Pb	Cd	Cu	Co	Zn	Ni	Sr	Cr
	Spring							
5-10 m from roadway	7.1±1.5	0.35±0.07	17.4±4.1	0.35±0.07	136.0±27.8	4.9±0.9	19.9±4.8	2.6±0.5
2.0 km from roadway	5.8±1.2	0.21±0.04	18.2±3.6	0.40±0.08	120.0±26.2	2.4±0.5	17.2±3.6	1.4±0.3
3.5 km from roadway	3.6±0.8	0.11±0.02	13.4±2.7	0.30±0.07	64.2±13.4	1.4±0.3	12.4±2.6	1.4±0.4
5 km from roadway	1.6±0.2	0.10±0.02	12.6±2.5	0.40±0.09	62.0±14.1	1.6±0.3	12.5±2.7	1.6±0.4
Background	2.0±0.4	trace amounts	10.2±2.3	0.41±0.09	30.6±7.4	1.2±0.2	11.2±2.8	1.2±0.4
	Autumn							
5-10 m from roadway	7.5±1.6	0.39±0.08	9.8±2.1	0.39±0.08	79.5±16.4	1.3±0.3	91.8±20.4	2.6±0.6
2.0 km from roadway	1.9±0.4	0.18±0.03	8.0±1.7	0.18±0.03	67.9±14.2	1.1±0.2	24.1±4.7	1.6±0.3
3.5 km from roadway	2.9±0.5	0.14±0.03	8.0±1.8	0.30±0.06	65.1±13.6	1.1±0.2	26.0±6.1	1.6±0.4
5 km from roadway	1.8±0.2	0.10±0.02	5.3±1.1	0.35±0.08	40.8±9.4	3.9±0.8	64.7±13.6	3.2±0.7
Background	1.8±0.3	0.10±0.02	4.0±0.9	0.24±0.05	20.4±5.0	1.2±0.3	26.4±5.8	2.0±0.5

Table 5. Statistical relations between heavy metal content in *Taraxacum officinale* and their concentrations in soil.

Heavy metal	Autumn			Spring		
	r	r^2 [%]	linear regression	r	r^2 [%]	linear regression
Pb	-0.02	0.04	y = 2.82-0.0006x	-0.21	4.41	y = 3.20-0.01x
Cd	0.57*	32.49	y = 0.23+0.24x	0.85**	72.25	y = 0.10+0.23x
Cu	0.50*	25.00	y = 11.39+0.27x	0.35	12.25	y = 9.50+0.23x
Co	0.59*	34.81	y = 0.23+0.05x	-0.19	3.61	y = 0.60-0.009x
Zn	0.73**	53.29	y = 63.23+0.11x	-0.11	1.21	y = 49.3-0.03x
Ni	0.70 **	49.00	y = 1.12+0.46x	-0.34	11.56	y = 3.51-0.02x
Sr	0.88 **	77.44	y = 10.62+0.60x	0.23	5.29	y = 24.6+0.42x
Cr	0.20	4.00	y = 2.28+0.02x	-0.55	30.25	y = 8.56-0.06x

* P=0.05
**P=0.01

titive order. In leaves of *Tilia cordata* collected from remaining objects in autumn, quantitive order of heavy metal content is analogical to spring results.

Statistical Relations

The correlation factor (r) and linear regression (Table 5) was calculated to determine linear correlation between heavy metals content in dandelion and their content in soil. Moreover, determination factor (r^2) was calculated to provide information of regression force.

Statistical analysis shows highly significant relations between the content of Sr, Zn, and Ni, and significant relations between the content of Co, Cd, and Cu in soil and in dandelion collected in autumn. Calculations prove that there is no influence of Pb and Cr contents in soil on their contents in plant, while Pb shows a negative correlation, whereas statistical relations calculated for spring samples show highly significant correlation between Cd content in soil and in dandelion.

The content of examinated heavy metals in leaves of *Tilia cordata* collected in both terms and their content in soil show significant correlation. Such correlation is not observed only for Cu and Co. For Zn, Sr, and Cr the described significant correlation occurs regardless of the term of collection.

Discussion

This paper describes the use of *Pinus silvestris* bark as a passive bioindicator for environmental pollution monitoring. Positive results from the use of Scots Pine as heavy

Table 6. Correlation between heavy metal concentrations in leaves of *Tilia cordata* and needles of *Pinus silvestris* and their concentrations in soil.

Heavy metal	Leaves of *Tilia cordiale*		Needles of *Pinus silvestris*	
	Autumn	Spring	Autumn	Spring
	r	r	r	r
Pb	0.89**	0.81**	0.29	-0.34
Cd	0.54*	0.63*	0.07	0.21
Cu	-0.88**	0.26	-0.24	0.12
Co	0.49*	0.34	0.34	0.20
Zn	0.65*	0.71**	0.78**	0.92**
Ni	0.96**	0.84**	-0.12	0.26
Sr	0.93**	0.69*	0.90**	0.84**
Cr	0.96**	0.74**	0.62*	0.78**

* P=0.05
**P=0.01

metals bioindicator in the environment were obtained in studies by Pöykiö et al. [9].

The content of heavy metals in the leaves of *Tilia cordata* collected in spring and autumn, from a research object located closest to the roadway and the objects located 2 km and 3.5 km from the roadway, show only differences in the level of Sr and Cu. Therefore, the thesis that heavy metal accumulation is higher in the leaves collected in autumn than in spring has not been confirmed [7, 10].

Studies on the effects of heavy metals in leaves of *Hieracium pilosella* and soil were conducted by Krawczyk et al. [11]. For samples of the soil results are similar to those which have been obtained in a study for a distance of 5 meters from the road. Our results indicate that the zinc content is higher than copper and this relationship for Krawczyk is similar. As for the results obtained for leaves of bio-indicators collected during the summer, in both cases they appeared in the same relation: Zn> Cu>Pb>Ni>Cd. Such contents of cadmium are common for unpolluted soil.

For soil and dandelion samples collected in spring, statistically significant correlation was observed for their Cd content. Similar findings were achived by Królak [12].

Results of correlation analyses showed significant correlations among, e.g., Zn, Ni, Pb, Co, and Sr contents of roadside soil and leaf samples. Similar findings were acheived by Kazuyuki et al. [13], at the same time it was stated that Zn is emitted mainly from the abrasion of tires; Cr is emitted mainly from wear of the asphalt pavement.

The highest heavy metals concentration was found at a distance of 5-10 meters from the road and it exceeded the local background in the soils for all metals. The results showed that the soil near the highway had significant enrichment, particularly in Zn and Pb. As for the concentration of Pb, Cu, and Cd in soil samples, they were arranged in relation to each other as follows Pb>Cu>Cd. Analogous result for soil samples collected at a distance of 5 meters from the road were archived by Grigalavičienė et al. and Normandin et al. [8, 14].

Other examined heavy metals correlations, in general, are negative. It was positive, significant correlation is observed between content of Zn, Sr, and Cr in needles of *Pinus silvestris* and soil (Table 6). Molski and Dmuchowski [15] and Dmuchowski and Bytnerowicz [5] achieved similar correlation.

Concentrations of heavy metals were significantly higher at the polluted site. It was closer to the main road that concentrations are higher. The same conclusions reached Kurczyńska et al. [16].

It should be noted that there are no universal biomarkers for the determination of metal. Since effective biomarkers are not specific for a given metal, they should always be used in combination with biomarkers or tests of exposure. This occurs both in the determination of metals in the environment and in living organisms as confirmed by examination by Bernard [17].

Conclusions

The influence of heavy traffic on Pb, Cd, Cu, Co, Zn, Sr, and Cr contents in surface levels of soil in non built-up areas was observed up to 5.0 km from the roadway. It has been proved by the enhanced contents of examined heavy metals in *Taraxacum officinale*, needles of *Pinus silvestris,* and leaves of *Tilia cordata* collected up to 5.0 km from the roadway in comparison to these plants from unpolluted areas. Strontium demonstrates significant bioaccumalation affinity. The highest content of Sr is measured in needles of *Pinus silvestris* (11 times higher than in background material), followed by above-ground parts of *Taraxacum officinale* and leaves of *Tilia cordata*.

Significant correlations between Sr, Zn, Ni, Co, Cd, and Cu contents in soil and *Taraxacum officinale* collected in autumn have been found. Plants collected in autumn confirm this correlation only for Cd. The Pb, Cd, Zn, Ni, Sr, and Cr contents in leaves of *Tilia cordata* show positive correlation with their contents in soil, regardless of the term of collection. Calculations prove positive correlation between contents of Zn, Sr, and Cr in needles of *Pinus silvestris* and their contents in soil, regardless of term.

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