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A STUDY OF SOIL POLLUTION BY HEAVY METALS IN THE CITY OF POZNAŃ (Poland) USING DANDELION (*Taraxacum officinale* WEB) AS A BIOINDICATOR

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ABSTRACT

Monitoring the pollution status of the environment by using plants is one of the main topics of environmental biogeochemistry. The bioavailability and mobility of heavy metals (Zn, Cu, Pb, Cd and Ni) in urban soil of Poznań (Poland) were assessed on the basis of upper parts of dandelion (*Taraxacum officinale* WEB) and soil samples collected in May and July 1998. Sampling points were located along 2 roads crossing the town along West-East and North-South directions. All soils were characterized by a negligible share of clay particles, high content of organic carbon (about 1.5 g kg^{-1}) and pH above 7.0.

Soils adjacent to studied roads were mostly contaminated with zinc, lead and cadmium, but the level of contamination assessed by means of the soil pollution index *SPI* was low. The pattern of spatial distribution of *SPI* indices could be used to delineate areas of soil contamination by heavy metals. Dandelion used as a test plant could provide an alternative method for monitoring urban soils contamination, especially when sampled in May. Total plant pollution indices *PPI* depended mostly on individual indices calculated for cadmium and lead.

Key words: urban soils, heavy metals, Soil and plant pollution indices (SPI and PPI), *Taraxacum officinale*.

INTRODUCTION

Cities under various geographical, geological, climatic and sociological conditions are usually considered as big sources of pollutants, including heavy metals, irrespective of specific types of men activities [10, 17]. From an environmental point of view, all heavy metals are very important because they cannot be biodegraded in soils, so they tend to accumulate and persist in urban soils for a very long time [7]. Lead, cadmium, copper, zinc and nickel are metals frequently reported to have the highest impact on organisms. Forms and amounts of a given metal that can be absorbed by an organism can be defined as bioavailable. Therefore, bioavailability is one of the keys to understanding chemistry of heavy metals in soils [4, 6].

Sound environmental management of urban soils contaminated with heavy metals requires a wide knowledge on their spatial distribution and mobility. Plants due to their high sensitivity to heavy metals seem to provide good indicators of environmental pollution. Hence, plants could be used as an alternative method for assessing a relative pollution level in soils threatened with heavy metals contamination [2, 15, 16, 18].

The objectives of the study were to (i) investigate the spatial distribution of five metals, namely Zn, Cu, Pb, Cd and Ni in urban soils adjacent to the main roads crossing the city of Poznań, (ii) assess metals bioavailability using dandelion (*Taraxacum officinale* WEB),(iii) evaluate this plant as a potential bioindicator for urban soils.

MATERIALS AND METHODS

Soil and plant samples were collected in 1998 from sites located along two major roads carrying traffic flow from W-E and N-S directions of Poznań, Poland. Soil samples were taken in May. Roots and aboveground organs of dandelion (*Traxacum officinale* WEB) were sampled twice, in May and in July. At each sampling site along both roads, 20 subsamples to 10 cm of depth were collected from 4 m^2 area with a core sampler and combined.

The soil samples were air-dried, crushed to pass through a 1 mm sieve and stored in plastic bags until being analysed. Basic soil parameters were measured by common methods: a particle size distribution by the Casagrande-Proszynski aerometer method [11], soil pH was determined using a 1:5 soil/water ratio in 0.01M $CaCl_2$ [13]; organic carbon was determined with a Tiurin method [11]. Soluble forms of Zn, Cu, Pb, Cu and Ni were extracted by 2 M HNO_3 [1].

Plant samples (not rinsed) were previously air-dried at 105°C. For analyses, 1.0 g (duplicated) was incinerated at 540°C. The residue was dissolved in hot 10 ml of diluted *aqua regia* (1:3, *v*/*v*) and filtered subsequently. The filtrates were made up to 20 ml by adding bidistilled water. All metals in soil extracts and plant digests were analysed by FAAS (Flame Atomic Absorption Spectrometer, Varian 250) method. The concentration of metals is given as mg/kg dry weight (DW).

The soil pollution index (*SPI*) and plant pollution index (*PPI*) were calculated for each locality according to the following equations [14] and based on suggested limit values as reported in Table 1:

$$SPI = \frac{1}{n} \cdot \sum_{i=1}^{n} \cdot 100 \cdot \frac{VS_i}{LS} \qquad (1)$$

$$PPI = \frac{1}{n} \cdot \sum_{i=1}^{n} \cdot 100 \cdot \frac{VP_i}{LP} \qquad (2)$$

where:

n - number of elements
VS and *VP* - content of an element in the soil and plant, respectively, mg/kg.
LS and *LP* - limit values for an element in the soil and plant, respectively, mg/kg.

Single and multiple regression analyses and additional statistical methods were applied to evaluate spatial distribution of *SPI* and *PPI* indices and their intrinsic properties.

Table 1. Limit values of heavy metal contents in soils and plants

Object	Metals, mg/kg (DW)				
	Zn	Cu	Pb	Cd	Ni
Soil*	50.0	30.0	50.0	0.4	15.0
Plant**	100.0	50.0	10.0	0.5	50.0

* limits for 2M HNO_3 extract in light soils [14]
** limits for forage [7]

RESULTS AND DISCUSSION

Composition of the surface layer of a soil profile is important to evaluate mobility of heavy metals in the environment. Generally, it creates conditions for the maximal accumulation of pollutants that normally reside within the upper 10–15 cm of a soil profile. With respect to lead, its relative concentration in this layer is increased by one or two orders of magnitude [3].

Soil pollution

Surface soils adjacent to both studied roads in Poznań consisted mostly of sand material rich in organic carbon, of pH values above 7.0 (Table 2). Such characteristics of surface layers may provide pollutants with a physical opportunity to migrate into deeper horizons of the soil profile [9] on one hand, though the presence of organic material and high pH value may, on the other hand, significantly decrease heavy metals mobility, hence their availability to plants [12].

Table 2. Selected physical and chemical characteristics of urban soils, mean ± SD.

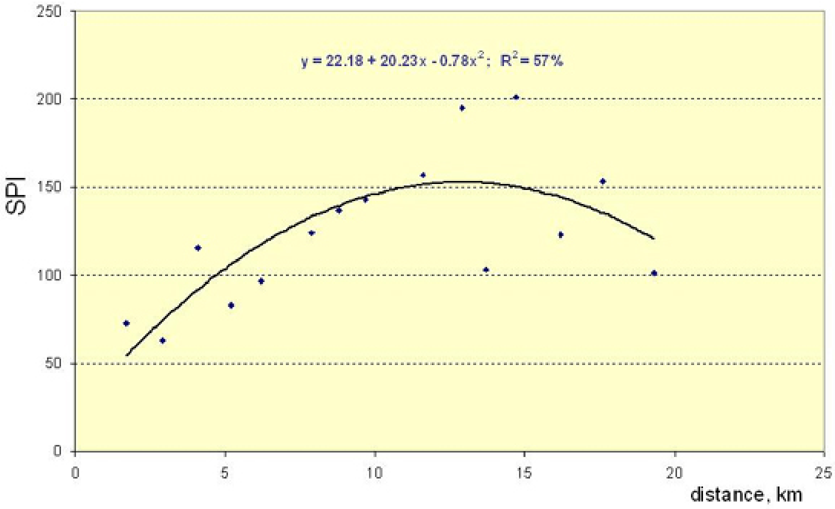
Soil characteristics	Road	
	WE n = 14	NS n = 15
Sand ($g \cdot kg^{-1}$)	843 ± 4.60	854 ± 8.00
Silt ($g \cdot kg^{-1}$)	157 ± 4.60	146 ± 8.00
Organic carbon ($g \cdot kg^{-1}$)	14.9 ± 0.28	14.8 ± 0.45
pH	7.40 – 7.90	7.20 – 8.20

Table 3. Statistical description of heavy metal contents in urban soils

Statistical parameters	Heavy metals, $mg \cdot kg^{-1}$				
	Zn	Cu	Pb	Cd	Ni
W-E road, n = 14					
Arithmetic mean	85.7	25.9	104.0	0.29	3.8
Median	82.1	15.2	97.0	0.27	3.5
Standard deviation	38.1	23.9	29.8	0.19	1.4
Minimum	11.9	10.6	62.9	0.05	2.0
Maximum	149.1	95.9	168.0	0.76	6.5
Variation coefficient, %	44.5	92.3	28.7	69.0	35.6
N-S road , n = 15					
Arithmetic mean	87.0	15.0	110.9	0.57	5.1
Median	81.8	15.2	103.2	0.57	5.5
Standard deviation	27.4	6.2	32.0	0.46	1.7
Minimum	44.0	5.8	70.5	0.06	3.1
Maximum	145.2	28.3	198.7	1.82	9.0
Variation coefficient, %	31.6	41.2	28.9	80.0	33.4

The content of heavy metals in the surface soils of the two roads showed high variability (Table 3). Almost all of them fitted well to the log-normal distribution, except for nikiel (W-E road) and lead (both roads), which followed the pattern of normal distribution. Hence, distribution found in the soils around roads, indicates the occurrence of only one source of emission, namely combustion of leaded gasoline. The log-normal distribution of other metals suggests the presence of two or more heavy metal sources in the close vicinity of roads.

Figure 1. Soil pollution index (SPI) – the N–S road

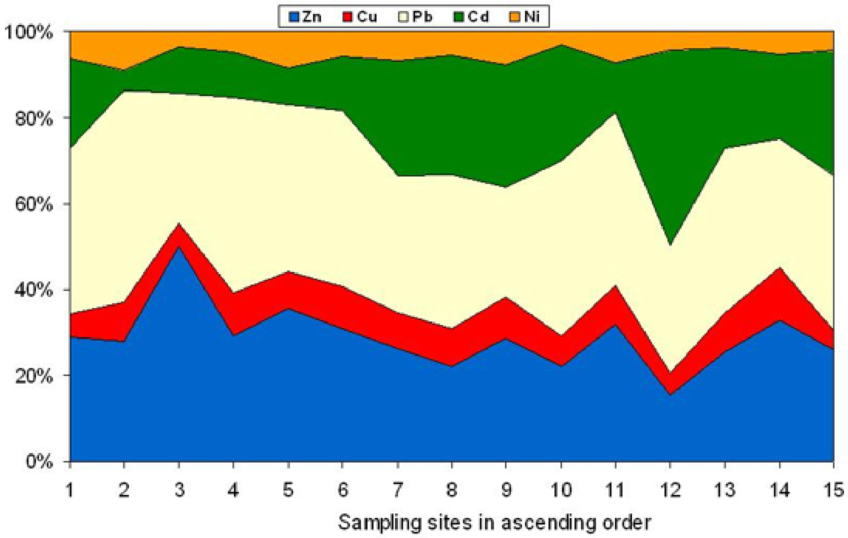


The calculated soil pollution indices (*SPI*) showed different levels of total soil pollution (Fig. 1) according to directions of traffic flow. Soils located along the W-E road were generally less polluted than those of the N-S one. However, the spatial distribution of SPI indices was much more regular for the N-S road and can be described by an equation:

$$\mathbf{\mathit{SPI} = 22.19 + 10.23x - 0.78x^2 \text{ for } R^2 = 57\%} \qquad (3)$$

where:
y – *SPI*
x – distance, km

Figure 2. Relative share of pollution indices for individual heavy metals – the N-S road



On the basis of the equation it is possible to delineate the area of the city with higher concentration of heavy metals. Fig. 1 makes it evident that the large emissions of heavy metals released in Poznań over years are clearly seen in the vicinity of the city-centre and in the areas to the south. The relative share of pollution indices for individual metals varied between localities (Fig. 2). For both roads zinc appeared to be the main pollutant.

However, the multiple regression used to evaluate heavy metals impact on the total SPI value revealed SPI patterns dependence on the soils spatial location, i.e. directions of the roads. With respect to the W-E road, SPI indices for lead alone and for zinc together with copper explained respectively about 83% and 97% of SPI indices variability:

$$\boldsymbol{SPI = 42.37 + 0.81\, SPI_{Pb} \text{ for } R^2 = 83\%} \qquad (4)$$

$$\boldsymbol{SPI = -1.75 + 0.31\, SPI_{Zn} + 0.34\, SPI_{Cu} \text{ for } R^2 = 97\%} \qquad (5)$$

Quite different patterns were found for the N-S road, where the SPI indices variability was attributed to cadmium in 78%, while to cadmium together with zinc in 93%:

$$\boldsymbol{SPI = 79.6 + 0.32\, SPI_{Cd} \text{ for } R^2 = 78\%} \qquad (6)$$

$$\boldsymbol{SPI = 32.3 + 0.29\, SPI_{Zn} + 0.29\, SPI_{Cd} \text{ for } R^2 = 93\%} \qquad (7)$$

Plant pollution

Concentration of metals in dandelion leaves varied with the date and site of sampling. For both sampling dates, May and July, the relation of metal contents was similar and followed the order: Zn > Cu > Pb > Ni > Cd. However, from May to July the level of all the elements increased significantly. Concentration of zinc and lead rose four and five times, respectively. A two-fold increase was reported for copper and nickel and 30% in the case of cadmium. Ranges of metal concentrations in dandelion leaves found in July are typical for urban soils [2] and higher than those reported for plants growing in uncontaminated areas [6].

Plant contamination can be assessed by means of threshold values for heavy metals content in forage plants [8] or by using the same data to calculate the total plant pollution index – *PPI* that is important only from an environmental point of view [14]. The first approach showed that dandelion leaves harvested in May could not be used as forage, because cadmium content significantly exceeded the threshold value of 0.5 mg/kg DM. In July the concentration of zinc, lead and cadmium also exceeded the respective threshold values (Tables 4, 5).

Table 4. Statistical description of heavy metal contents in Taraxacum officinale leaves, for the W-E road, n = 14

Statistical parameters	Heavy metals, mg·kg^{-1}				
	Zn	Cu	Pb	Cd	Ni
May					
Arithmetic mean	27.4	10.1	4.0	1.0	2.9
Median	26.7	9.6	3.7	1.1	2.5
Standard deviation	7.0	3.8	1.4	0.3	1.1
Minimum	18.5	5.7	1.7	0.6	1.5
Maximum	43.2	19.1	6.2	1.4	4.6
Variation coefficient, %	25.4	37.0	36.0	30.2	35.7
July					
Arithmetic mean	105.7	21.3	19.8	1.3	4.6
Median	111.0	18.7	18.9	1.2	4.6
Standard deviation	20.1	11.3	5.0	0.2	0.5
Minimum	60.5	9.9	12.4	1.0	3.6
Maximum	131.6	58.2	28.1	1.8	5.1
Variation coefficient, %	19.0	53.0	25.2	19.1	10.0

Table 5. Statistical description of heavy metal contents in Taraxacum officinale leaves, for the N–S road, n = 15

Statistical parameters	Heavy metals, mg·kg^{-1}				
	Zn	Cu	Pb	Cd	Ni
May					
Arithmetic mean	43.1	16.6	10.8	1.9	6.1
Median	44.2	17.4	10.3	2.1	5.9
Standard deviation	8.1	5.0	4.1	0.3	1.3
Minimum	29.2	9.5	5.4	1.3	4.3
Maximum	56.8	28.9	19.1	2.2	8.7
Variation coefficient, %	18.8	30.1	38.0	15.2	20.4
July					
Arithmetic mean	86.0	13.9	24.0	1.1	4.3
Median	82.6	12.1	23.9	1.1	4.6
Standard deviation	25.8	2.8	5.0	0.2	1.4
Minimum	51.3	11.3	16.2	0.8	2.0
Maximum	140.4	18.7	36.1	1.4	7.0
Variation coefficient, %	30.0	20.3	20.9	15.3	31.7

In the second approach it is assumed that some plants are very good metal accumulators when grown on areas threatened by heavy metal emissions. The calculated *PPI* indices depended on both site and sampling time. A doubled *PPI* average value, which rose from 59 in May to 121 in July, was found for the W-E road. At the date of first sampling *PPI* indices dropped significantly with the distance from West to East direction, as described by the equation:

$$PPI = 74.4 - 1.87\ d \text{ for } R^2 = 58\% \qquad (8)$$

d - distance from the west boundaries of the city, km

In July only the *PPI* indices for sites near the city centre tended to increase (Fig. 3b). The reason for lowering the regularity in spatial distribution of *PPI* indices in comparison to May can be explained by changes induced by the relative impact of individual metals on the total *PPI*. In May *PPI* indices were significantly affected by cadmium whose share ranged between 80% in the west, and 60% in the east part of the road. Hence, the regular decline of *PPI* indices resulted from the decreasing impact of cadmium. This statement takes the form of the following equation:

$$PPI = 20.3 + 0.192\ PPI_{Cd} \text{ for } R^2 = 86\% \qquad (9)$$

In July the effect of cadmium on the total plant pollution index slightly decreased due to significantly increased impact of lead, especially in the central part of the road. It was confirmed by the multiple regression analysis:

$$PPI = 5.29 + 0.29\ PPI_{Pb} + 0.23\ PPI_{Cd} \text{ for } R^2 = 88\% \qquad (10)$$

The next question refers to *SPI* and *PPI* relationship. Significant correlations between both indices were found only for July sampling. The *SPI* explained 44% of *PPI* indices variability:

$$PPI = 98.3 + 0.28\ SPI \text{ for } R^2 = 44\% \qquad (11)$$

Figure 3a. Plant pollution index (PPI) – the N-S road (May)

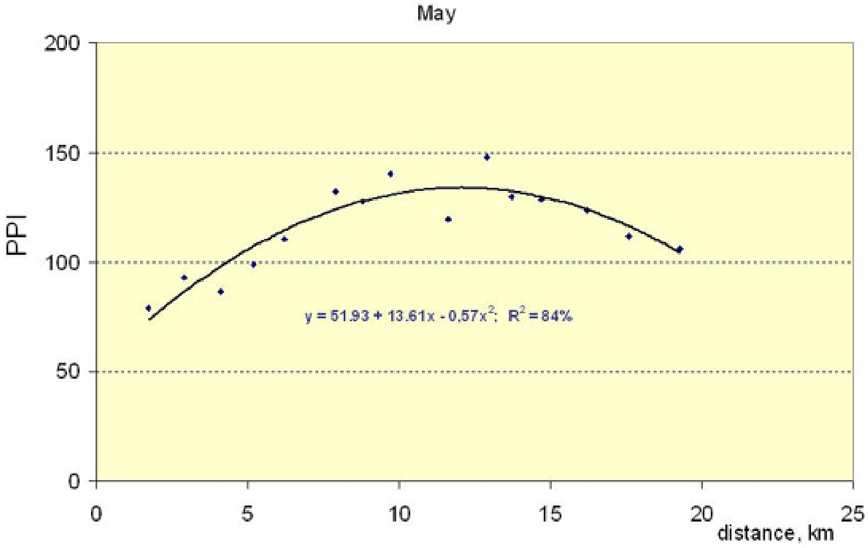
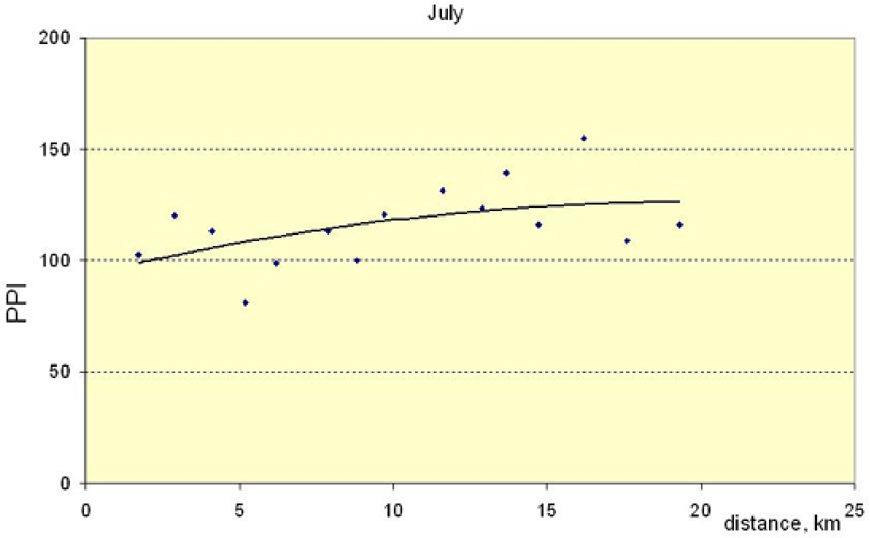


Figure 3b. Plant pollution index (PPI) – the N-S road (July)



Detailed regression analyses performed for all the studied metals proved to find a significant correlation ($r = 0.72$; $P \leq 0.01$) between the content in soil and in the plant only for lead. For Thesaloniki urban soils, the relationship between soil and dandelion (leaves) Pb concentrations was slightly weaker [2]. The pattern of pollution indices found for the N-S road was different from the one observed for W-E road. Average PPI values for both sampling dates were above 100, reaching 119 in May and 116 in July. The spatial distribution of *PPI* indices, similarly to the case of the W-E road, was more regular in May than in July (Fig 3a). At the first sampling date the obtained relationship is described by the equation:

$$\boldsymbol{PPI = 51.9 + 13.6\, d - 0.57\, d^2 \text{ for } R^2 = 84\%} \qquad (12)$$

where:
d - distance from the N boundaries of the city, km

Figure 4a. Relative share of pollution indices for individual heavy metals – the N-S road (May)

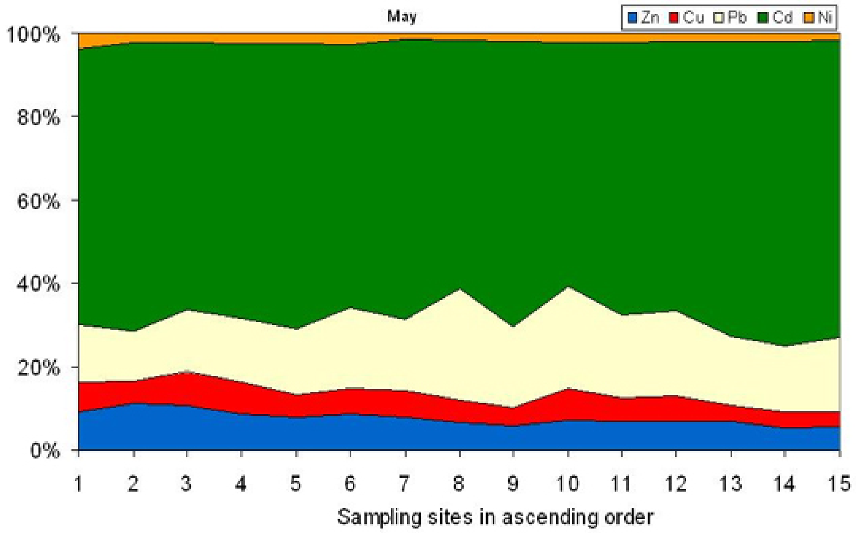
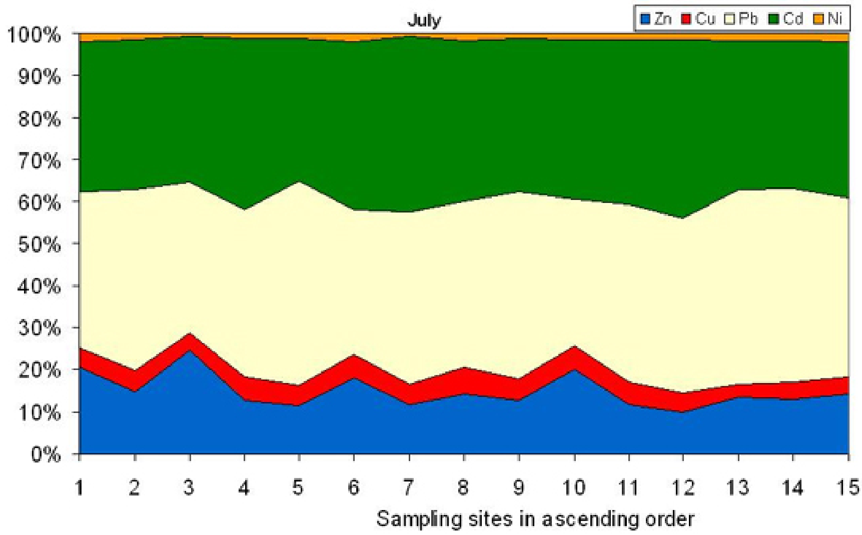


Figure 4b. Relative share of pollution indices for individual heavy metals – the N-S road (July)



A tendency towards a slight increase of *PPI* indices was observed in July for the North to South direction (Fig 3b). The relative share of individual metals in the total *PPI* was very similar to the one registered previously, but the impact of lead in July was much stronger than observed for the W-E road (Fig. 4a and Fig. 4b). In May the rule was confirmed by the multiple regression with both lead and cadmium introduced into the equation:

$$\boldsymbol{PPI = 66.7 + 0.46\ PPI_{Pb}\ \text{for}\ R^2 = 86\%} \qquad (13)$$

$$\boldsymbol{PPI = 19.0 + 0.27\ PPI_{Pb} + 0.51\ PPI_{Cd}\ \text{for}\ R^2 = 98\%} \qquad (14)$$

For all the studied metals the only significant correlation ($r = 0.81$; $P \leq 001$) between the content in soil and in plant was found for lead.

Soil total index of pollution affected significantly *PPI* only for plants sampled in July. The variability of *PPI* indices was found to be affected by *SPI* in 51% of cases only, as reported below:

$$\boldsymbol{PPI = 71.6 + 0.36\ SPI\ \text{for}\ R^2 = 51\%} \qquad (15)$$

In the light of the obtained results dandelion seems to provide a very responsive and reliable indicator capable of reporting current changes in the level of environmental metal pollution. Regular monitoring of heavy metal contents in dandelion leaves is of great interest for assessing the quality of urban environment in general. Its applicability was confirmed by a marked increase for most of the studied metals in plant leaves and by spatial variability that reflects the level of urban environment contamination with heavy metals.

CONCLUSIONS

1. Urban soils adjacent to the main roads crossing Poznań from West to East and from North to South were mostly contaminated by zinc, lead and cadmium.
2. Dandelion used as a test plant responded to heavy metals accumulation, and provides an alternative method for assessing urban soils contamination sampled in May.
3. The total *PPI* indices highly depended on the individual indices for cadmium and lead.
4. The pattern of spatial distribution of *SPI* and *PPI* indices could be used to determine the areas where environment is increasingly affected by heavy metals.

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