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Biomonitoring of the Urban Environment of Kielce and Olsztyn (Poland) Based on Studies of Total and Bioavailable Lead Content in Soils and Common Dandelion (*Taraxacum officinale* agg.)

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Abstract: Kielce and Olsztyn are two different urban ecosystems. They differ from each other in terms of geological and climatic conditions, as well as spatial development and industrial past. The aim of this article is to assess and compare the degree of lead contamination of the natural environment in both cities based on the conducted tests of soils, as well as a common dandelion's roots and leaves. For this study's purpose, 60 samples of soils and common dandelion's roots and leaves were collected in each city, according to four land-use types, namely industrial areas, urban green areas, urban allotment gardens, and urban forests. Basic physico-chemical properties and concentrations of lead, i.e., total content and bioavailable content were determined in the soils, using speciation analysis. Lead concentrations in the roots and leaves of common dandelion were, in turn, determined using the ICP-OES method. By using kriging models, spots with excessive lead concentrations differing from the geochemical background were identified in each city. The number of spots was comparable for both cities; however, the values for this metal differed significantly. No relationship has been found between land-use types and concentrations of lead in soils and common dandelions. The results of the study, as well as statistical and spatial analyses show that this species may be recommended as an indicator for biomonitoring of urban environments.

Keywords: urban soils; bioindicators; contamination assessment; spatial distribution

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1. Introduction

Soils, along with development of cities and progressive urbanisation, have become strongly transformed anthropogenically, which resulted in changes in their morphological and physico-chemical properties. The concentration of potentially toxic metals in the soil surface levels, resulting from the parent rock chemistry, anthropogenic deposit and different soil properties, including sorption capacity and buffering capacity, poses a great threat to the environment [1–3]. Lead is a metal with proven toxicity to living organisms. Therefore, the issues related to concentrations of this element in urban soils is a popular topic in the scientific literature [4–6]. Excessive accumulation of lead in the surface levels of urban soils may pose a threat to their ecological safety [7,8]. This is of particular importance for amateur vegetable and fruit cultivation in urban allotment gardens [4]. However, the overall content of trace metals does not provide an answer the question of the real level of toxicity. Therefore, in order to interpret the results of soil contamination tests in a correct way, it is necessary to perform sequential extraction (determination of bioavailable fractions) which indicates a given metal's mobility, toxicity and ways of behaviour in the environment, i.e., a real threat to the ecosystem [9].

The quality of urban soils has a direct impact on the state of vegetation. However, the level of change and damage caused by contaminants is extremely difficult to be assessed.

That is the reason, while assessing the state of the environment in cities, bioindication is used, which provides information about changes taking place in the ecosystem [10–12]. Many species of plants and animals are used for bioindication, which are able to respond to differences in the quality of the environment through physiological, anatomical and morphological changes occurring under the influence of contaminants. The accumulation of contaminants by the bioindicator is, thus, the result of factors affecting homeostasis. However, using plant organisms for biomonitoring in urban areas is of greater importance than using animal ones [13,14]. The advantage is an inexpensive and simple method of conducting tests, limited to the set of a given bioindicator. When interpreting the results of tests, a problem with determining the real causes of the changes observed may occur, because there are also such changes in ecosystems which are purely natural. Hence, in order to make an assessment of ecosystem quality reliable, a given bioindicator must be characterised by common occurrence and availability, as well as easy identification and high tolerance to factors being measured [15].

One of the species used in biomonitoring is *Taraxacum officinale* belonging to the *Asteraceae* family with a well-known common biologic name: Common dandelion. Studies using common dandelion as an indicator of the state of the environment are widely conducted around the world [16–18]. Common dandelion has a proven ability to accumulate high concentrations of contaminants present in the soil and in the air in its tissues. Nevertheless, as shown by the available study results, there are no clear conclusions regarding the relationship between environmental pressure, content of heavy metals in the soil or PM10 dust precipitation, and accumulation of increased amounts of heavy metals by common dandelion's tissues [16,19]. At the same time, some of the studies conducted indicate that the process of heavy metals' uptake by common dandelion is complex and selective, and depends on many factors. That is why, this species cannot be treated as a sensitive and universal bioindicator for all types of heavy metals [16,20].

Bearing in mind the recognition of the soils of Kielce and Olsztyn in terms of lead content and comparison of the results with the usefulness of common dandelion as a bioindicator, this article attempts to: (a) Determine the usefulness of common dandelion in biomonitoring of cities; (b) determine differences in the level of lead content in soils collected in two cities with different natural characteristics and spatial development; (c) determine the actual environmental risk based on the analysis of lead bioavailable fraction in a soil sample; (d) verify the relationship between land-use types and lead concentrations in soils.

Shaping soil features depends on a number of anthropogenic factors (industrial plants, railways, roads) is the natural feature of cities. The industrial traditions of Kielce date back to the 15th century when the exploitation and processing of mineral resources, such as iron, lead and copper ores, developed, and that subsequently led to the creation of the Old-Polish Industrial District. Currently, the metal ore mining traditions in Kielce are not continued, but the metallurgical industry is still a leading sector. Certainly, traces of this activity may be found in the soil cover, among others, in the form of accumulation of trace metals, including lead. On the other hand, Olsztyn is one of the least affected cities by the metallurgical industry, and that led to a decision to make an attempt to compare the soil environment of these both cities.

2. Materials and Methods

2.1. Study Area

Soil and common dandelion samples were collected in two Polish cities, namely Kielce and Olsztyn. The samples were collected in areas classified into four type of land use: A–urban allotment gardens, B–urban forests, C–urban green areas, and D–industrial areas (Figures 1 and 2). The comparison of selected features of the cities is presented in Table 1.

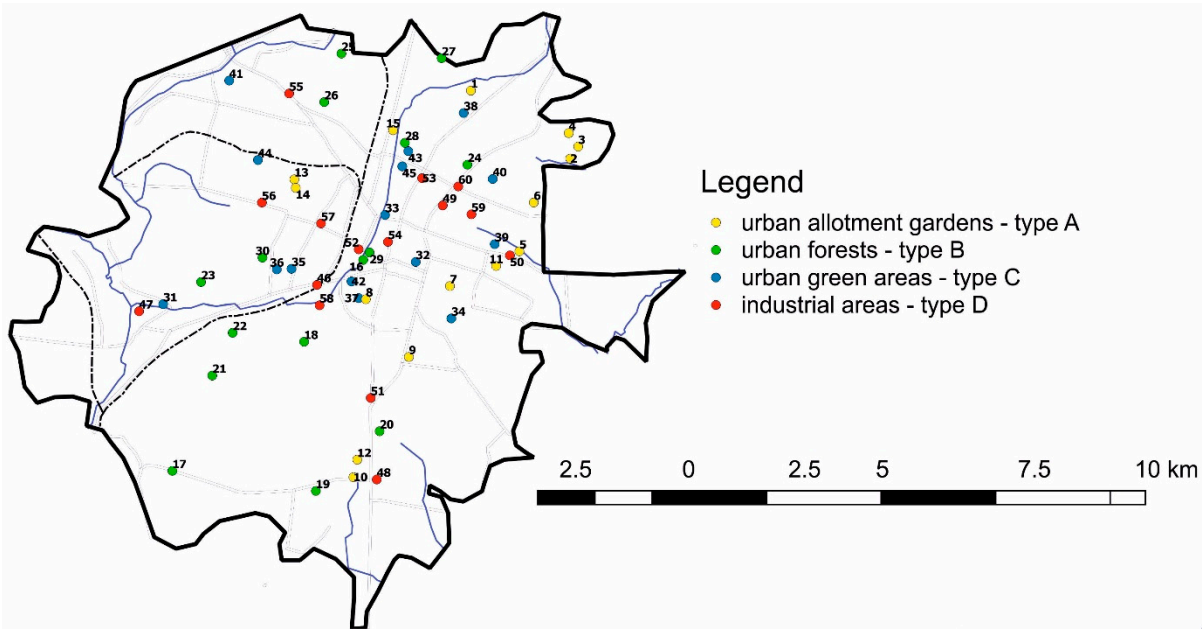


Figure 1. Location of soil and common dandelion sampling points in Kielce, including land-use types.

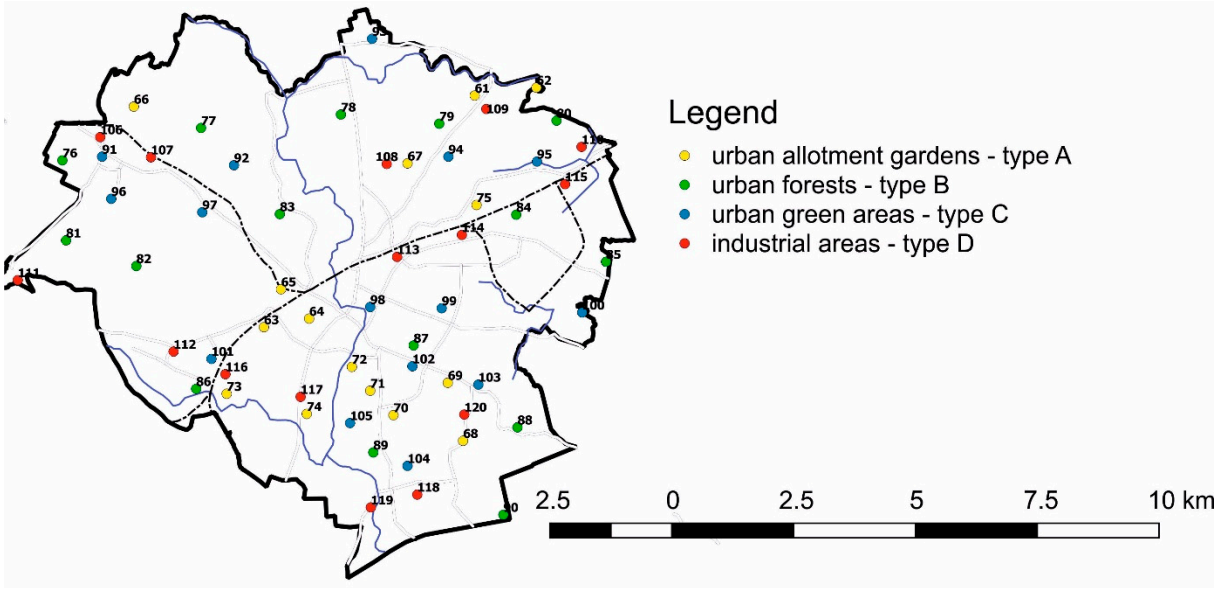


Figure 2. Location of soil and common dandelion sampling points in Olsztyn, including land-use types.

Table 1. Cities selected for the study along with comparative analysis.

Characteristics	Kielce 50°53′ N and 20°37′ E	Olsztyn 53°47′ N and 20°29′ E
Similarities		
Area (ha) [1]	10,965 ha	8833 ha
Demographic conditions [population] [1]	197,704	172,993
Current spatial development [% area] [1]	industrial areas–5.8 urban green areas–23.06	industrial areas–4.1 urban green areas–23.82
Differences		
Atmospheric air quality [2]	heavy metal concentrations in PM10 and PM2.5 dusts as well as benzo(a)pyrene exceeded the allowable values	heavy metal concentrations in PM10 and PM2.5 dusts as well as benzo(a)pyrene did not exceed the allowable values or exceeded them sporadically
Geological structure [3]	Middle and Upper Devonian limestones and marls (in the past: processing of iron, copper and lead ores).	peats and silts as well as river sands and deluvia.
Historical or present activity of metal processing plants	Yes	No

[1] Based on 2018 Central Statistical Office's studies; [2] Based on 2016-2018 Provincial Environmental Protection Inspectorate's studies; [3] Based on Geological Map of Poland.

2.2. Soil Collection and Analysis

In each city, 60 soil samples were collected at the level of 0–20 cm. Each sample was collected in a 3 m × 3 m plot and weighed about 1 kg, which corresponded to 10–11 punctures made with Egner's sampling stick. Before collection, non-humic organic matter was removed. The soil was dried at a constant room temperature not exceeding 40 °C, ground in an agate mill and sieved through a 1 cm sieve. Each soil sample was thoroughly mixed. The following determinations were made: particle-size distribution by the sieve-hydrometer method according to the PN-R-04032:1998 standard [21]; soil reaction (pH in 1 mol/dm^3 KCl solution) by the potentiometric method according to the PN-EN 15933:2013-02E standard [22], using an Elmetron pH meter with a pH-EPS-1 electrode; total organic carbon (TOC) by the Tiurin's method, using $K_2Cr_2O_7$ + H_2SO_4 oxidant in the presence of a catalyst (silver sulphate)-0.1 mol/dm^3 Mohr's salt solution was used as a reducer of excess oxidant [23].

The content of lead in soil was determined in accordance with the applicable methodology [24,25]. Before making measurements, the soil had been mineralised in the MARS 6 microwave acid digestion system (CEM Corporation, Matthews, NC, US) mineraliser in specially prepared vessels in order to determine the total content of lead. Then, 0.500 g of soil was weighed for mineralisation, and 7.5 cm^3 of hydrochloric acid ACS as well as 2.5 cm^3 of nitric acid ACS were added. The weighed amount of soil with *aqua regia* was set aside for a minimum of 30 min in order to degas it. After mineralisation was completed, a 15 min cooling phase took place. Before making measurements, the soil was treated with acetic acid at a concentration of 0.11 mol/dm^3 in a volume of 20 cm^3 per 1.000 g of soil in order to determine the bioavailable content of lead. The soil was being shaken for 16 hours at a room temperature (22 °C) using the CENTRIFUGE MPW-210 shaker (MPW Med. instruments Spółdzielnia Pracy, Warsaw, Poland) [24,25]. The extract was separated from the soil by centrifugation (4000 rpm) and the solution was transferred into a volumetric flask closed with a stopper. Determination of lead in the soil was performed by the inductively coupled plasma optical emission spectrometry (ICP-OES) technique, using the Agilent Atomic Spectrometer 5100 SVDV (Agilent Technologies, Inc., Santa Clara, CA, USA). Calibration curve was made by preparing a series of solutions at a concentration from 0.040 mg/L to 2.00 mg/L made out of the 1000 µg/mL standard lead solution

produced by Chem-Lab (cat. no. CL01.1226.0250). The calibration curve was checked at two points laying on it, i.e., 0.070 mg/L and 1.50 mg/L, with test solutions made out of the 1000 mg/L standard solution produced by Merck (cat. no. 1.19776.0100).

Elements confirming the validity of results used in the discussed method: preparation of a calibration curve at every 30 measurements; checking all calibration curves with independent standard solutions at two points on each of them; blank samples in a series of tests with the addition of a standard solution (certified reference material produced by Sigma-Aldrich TraceCERT, cat. no. 16595); recovery tests. Parameters characterising the method:

- Limits of quantification-0.536 mg/kg (determined on the basis of blank samples)
- Accuracy (shown as % of recovery) = 91%
- Relative standard deviation of correctness-0.070
- Relative standard deviation of repeatability-0.032

2.3. Common Dandelion Collection and Analysis

In each city, 60 samples of common dandelion's roots and leaves were collected. The plant was harvested with a ripper in plots where the soil samples were afterwards collected. One sample was made of 20 specimens of common dandelion. After the plants were washed with tap and distilled water, they were allowed to dry at a room temperature and then homogenised (leaves and roots separately) using the PULVERISETTE 14 Premium Linea variable speed motor mill (FRITSCH GmbH–milling and Sizing, Idar-Oberstein, Germany). Then, the content of lead was determined by the inductively coupled plasma optical emission spectrometry (ICP OES) technique after mineralisation in a mixture of concentrated hydrochloric and nitric acids in a volume ratio of 3:1. The measurements were made in accordance with the methodology discussed in the Section 2.2. [24,25]. The determinations were made in triplicates, and then the mean value was specified.

2.4. Statistical and Spatial Analysis

The data was statistically elaborated using the Statistica (Version 15) software. Classical statistical measures were determined, such as: arithmetic mean, median, standard deviation, as well as minimum and maximum values. Regarding statistical analysis, non-parametric tests were used–the adopted significance level was $p < 0.05$. Spearman's rank correlation analysis was performed. The analysis of variance was performed using the Mann-Whitney U and Kruskal-Wallis tests. When analysing the results, the following geo-environmental indicators were used [26,27],

$$\text{geoaccumulation index Igeo} = \log 2[\text{Cn}/1.5\ \text{Bn}] \quad (1)$$

where: Cn–content of lead in soil, Bn–lead geochemical background (9.8 mg/kg d.m.; [28], 1996), 1.5–natural lead fluctuations in the environment resulting from slight differences in geological structure,

$$\text{phytoaccumulation factor PF} = C_{Me^{+}plant}/C_{Me^{+}soil} \quad (2)$$

where: CMe_{+plant}–content of lead in common dandelion's roots or leaves, CMe_{+soil}–content of lead in soils,

$$\text{translocation factor TF} = \text{Cx leaves}/\text{Cx roots} \quad (3)$$

where: Cx leaves–content of lead in common dandelion's leaves, Cx roots–content of lead in common dandelion's roots.

Lead spatial variability was analysed using the Surfer v. 15 program. The results have been shown on maps in a scale of 1:25,000. Isolines were conditioned by the most common histogram classes. Kriging method was used–one of the most common interpolation techniques used in recent years [29,30].

3. Results and Discussion

The grain-size distribution of the studied urban soils in Kielce showed a dominant share of sandy loam (Table 2). Sporadically there are: loam, sand and silt loam. The soils of Olsztyn showed the same grain-size trend as the soils of Kielce. The smallest differentiation was noted for the type of industrial areas (type D) where clayey sand dominated. Great differentiation was noted for the soils of urban allotment gardens (type A). Under natural conditions, grain-size distribution is considered to be one of the most durable soil features. However, in cities there is a problem of transformed soil profiles as indicated, among others, by studies conducted on the soils of such cities as Szczecin and Bratislava [31,32]. This has also been confirmed by the studies on the soils of Kielce and Olsztyn. The anthropogenic factor is the main cause of changes in soil profiles [13,33].

Table 2. List of grain-size groups or texture classes of the studied soils in Kielce and Olsztyn with regard to land-use types distinguished in soil texture classifications (acc. to USDA and PTG 2008).

Land-Use Type/Study Area	Grain-Size Group [% of Share]				
	Sandy Loam SL (gp)	Sandy Loam SL (gl)	Loam L (gz)	Sand L (pl, ps)	Silt Loam SiL (pyg, pyi)
In total/Kielce	63	22	12	0	3
In total/Olsztyn	68	18	3	9	2
urban allotment gardens–type A/Kielce	33	40	20	0	7
urban allotment gardens–type A/Olsztyn	47	40	13	0	0
urban forests–type B/Kielce	73	20	0	0	7
urban forests–type B/Olsztyn	80	0	0	20	0
urban green areas–type C/Kielce	53	27	20	0	0
urban green areas–type C/Olsztyn	53	33	0	7	7
industrial areas–type D/Kielce	93	0	7	0	0
industrial areas–type D/Olsztyn	93	0	0	7	0

The mean pH value for Kielce was 6.86; while, it was 6.64 for Olsztyn (Table 3). The tested soils were slightly acidic and slightly alkaline, which is in accordance with the trends in pH distribution of urban soils [34]. Low pH values were sporadically recorded, mainly in the soils of urban forests (type B). In cities, a clear shift in the reaction towards alkalisation is the result of alkaline dust precipitation, use of street snow removal agents, and high concentrations of calcium carbonate of anthropogenic origins [35]. A pH value is crucial for the bioavailability of heavy metals to plants, i.e., the increased pH values reduce the risk of entering the food chain by heavy metals [5].

For the soils, statistically significant differences were found between the types of land use and the values of pH. The lowest median and the minimum values for Kielce and Olsztyn were observed in the soils belonging to the type B (urban forests). It is conditioned by the type of plant community and the distance from direct contaminants, mainly transportation routes. Acidification of soils under forest communities is the result of decomposition of organic matter.

Table 3. Statistics concerning the physico-chemical properties of the studied soils in Kielce and Olsztyn with regard to land-use types.

Land-Use Type		pHKCl		Organic Carbon [%]	
		Kielce	Olsztyn	Kielce	Olsztyn
in total	minimum value	4.50	3.92	0.40	0.29
	maximum value	7.67	7.58	2.21	2.21
	mean value	6.86	6.64	1.63	1.66
	median value	7.03	6.86	1.80	1.84
	SD	0.69	0.71	0.50	0.56
urban allotment gardens –type A	minimum value	5.37	5.31	1.07	0.41
	maximum value	7.40	7.51	2.18	2.21
	mean value	6.83	6.75	1.71	1.88
	median value	6.85	6.75	1.75	2.00
	SD	0.50	0.51	0.362	0.469
urban forests –type B	minimum value	4.50	3.92	0.49	0.29
	maximum value	7.53	7.45	2.14	2.21
	mean value	6.29	6.15	1.57	1.43
	median value	6.27	6.32	1.57	1.28
	SD	0.98	1.02	0.542	0.731
urban green areas –type C	minimum value	6.02	5.80	0.40	0.46
	maximum value	7.61	7.58	2.17	2.21
	mean value	7.14	6.75	1.58	1.71
	median value	7.21	6.85	1.81	1.95
	SD	0.39	0.46	0.616	0.528
Industrial areas –type D	minimum value	6.37	5.64	0.87	0.86
	maximum value	7.67	7.49	2.21	2.21
	mean value	7.17	6.92	1.66	1.63
	median value	7.25	7.06	1.83	1.72
	SD	0.35	0.48	0.473	0.416

The mean content of organic carbon at the level of 1.63 for Kielce and 1.66 for Olsztyn proved the lack of differentiation of soils in terms of organic matter concentrations between these two cities (Table 3). Similar results were recorded for all types of land use. Organic matter in urban soils is very diverse, depends on plant communities and advancement of urbanisation processes. However, its content in urban soils often do not differ significantly from that recorded for arable soils [33,34,36].

The recorded values for Kielce and Olsztyn are considered high, which is beneficial in terms of soil fertility, biogeochemical cycle, as well as climate change mitigation [33]. High concentrations of organic carbon in anthropogenic soils may be related to the admixture of organic waste materials to soil profiles [36]. Accumulation of organic matter in soils is also conditioned by thermal, air and water parameters of ground. They determine directions and rates of mineralisation and humification of organic matter. In urbanised areas, the content of organic matter in soils is related to their grain-size distribution, showing a negative correlation between sand fraction and organic matter content, which was confirmed in this study. A significant negative correlation was found at the level of -0.36 ($p < 0.05$) for organic carbon and sand fraction (soils of Kielce and Olsztyn altogether). This indicates a significant role of organic matter in the soil environment of urban areas.

In Kielce, the mean total content of lead was 43.60 mg/kg d.m. (SD = 54.12), which indicates a very large dispersion of the results (Table 4, Figure 5). In each land-use type, the values were very diverse. The most diverse values were recorded for the types B and D; while, the maximum values reaching 321.19 mg/kg d.m. (type D) were six times higher than the mean value calculated for this type of land use. For the soils of Olsztyn, the values were also different in all land-use types. Whereas, the concentrations of lead in the soils was definitely lower than that recorded in Kielce. The mean value (11.42 mg/kg d.m.) was almost four times lower and the maximum value (32.82 mg/kg d.m.) was ten times lower than those observed in Kielce. For the types A, C and D, high and comparable differentiation in lead concentrations was found.

Table 4. Statistics concerning the content of lead in the studied soils in Kielce and Olsztyn with regard to land-use types.

Land-Use Type		**Pb Total [mg/kg d.m.]**		**Pb Bioavailable [mg/kg d.m.]**	
		Kielce	Olsztyn	Kielce	Olsztyn
in total	minimum value	8.31	2.95	0.27	0.11
	maximum value	321.19	32.82	8.64	1.07
	mean value	43.60	11.42	1.87	0.35
	median value	26.90	8.40	1.41	0.33
	SD	54.12	8.07	1.43	0.17
urban allotment gardens –type A	minimum value	8.31	6.79	0.88	0.11
	maximum value	57.83	32.82	2.40	0.50
	mean value	28.28	14.55	1.50	0.29
	median value	27.66	12.64	1.32	0.28
	SD	11.24	8.03	0.52	0.12
urban forests –type B	minimum value	10.81	3.63	0.80	0.11
	maximum value	250.99	25.51	4.40	0.40
	mean value	60.35	7.49	1.95	0.26
	median value	37.98	5.53	1.40	0.29
	SD	70.14	5.70	1.21	0.09
urban green areas –type C	minimum value	8.85	2.95	0.27	0.18
	maximum value	102.28	31.60	6.13	0.62
	mean value	36.12	10.58	2.02	0.35
	median value	33.27	7.62	1.57	0.33
	SD	24.52	8.13	1.63	0.11
industrial areas –type D	minimum value	12.60	4.20	0.62	0.19
	maximum value	321.19	31.49	8.64	1.07
	mean value	49.65	13.08	2.00	0.50
	median value	24.70	8.88	1.42	0.47
	SD	77.75	8.99	2.01	0.23

Large deviations may be caused by a variety of metal origins [37]. Lead is one of the least mobile elements in soil. Lead is strongly bound by most of the soil components (mainly by Fe and Mn concretions), but it is also adsorbed by clay minerals, organic matter, as well as iron and aluminium hydroxides. Under natural conditions, concentrations of metal in a soil profile reflect its content in the parent rocks. However, the accumulation often results from anthropogenic activities when it comes to surface soil layers [38,39].

Concentrations of this element in soils do not show a homogeneous tendency, as evidenced by the results of soil studies conducted around the world (Table 5).

Table 5. Diversification of lead concentrations in the urban soils of the world.

City	Total Content–Value Range [mg/kg d.m.]/Mean Value	Author
Kielce, Poland	51–128	[40]
Olsztyn, Poland	9–51	
Warsaw, Poland	9–13	
Kielce, filling stations	10.4–156.8	[41]
Olsztyn, urban green areas	28.7–49.2	[42]
Hong Kong, China	7.53–496.0	[43]
Naples, Italy	4–3420	[44]
Fallujah, Iraq	2.62–5.30	[45]
Moscow, Russia	16.4–174	[46]
Novokuybyshevsk, Russia	6.0–27.4	[47]
Chittagong, Bangladesh	7.33	[1]
Belgrade, Serbia	55.5	[48]
Berlin, Germany	119	[49]
Stockholm, Sweden	101	[50]
World's mean value	27.0	[51]

Mobility of metals in soils is the subject of many studies which are to answer the question about phytoaccumulation of elements, among others [11]. Phytoaccumulation translates into a real threat to the ecosystem, posed by heavy metals. Hence, it is important to determine the mobile (bioavailable) fraction of a given element.

When it comes to Kielce, the mean content of the bioavailable fraction of lead was 1.87 mg/kg d.m. The greatest differentiation was noted for the urban green soils (type C) and industrial areas (type D) where the values of standard deviation exceeded the mean values. The values obtained for Olsztyn were lower than those in Kielce. The mean value at the level of 0.35 mg/kg d.m. and the values of standard deviation amounting to 0.17 mg/kg d.m. indicate several times lower values and their smaller dispersion than in the case of Kielce.

Papazotos et al. [52] showed in their study on the soils of Athens that the higher the total content of this metal in the soils, the lower the level of extraction of exchangeable forms. As far as the studied soils, the content of bioavailable forms of lead in the soils of Kielce was higher than in Olsztyn, comparing to the content of total forms. The analysis of the percentage share of bioavailable forms in the total content of lead did not clearly confirm the conclusions made by Papazotos et al. [52].

Bondar et al. [53] indicate that soil properties, i.e., clay content, pH and organic matter significantly affect the mobility of lead, when a strong and inverse correlation occurs. For the studied soils, such relationships were statistically insignificant. Only for pH, the correlation was significant but weak.

In the case of geoaccumulation index, the values for Kielce were at the level of Igeo $\leq$ 0–2, which indicates that soils ranged from practically uncontaminated to moderately contaminated. When it comes to Olsztyn, relatively lower Igeo values were recorded. Most of the soils, i.e., 75%, were classified as practically uncontaminated, and the other 25%–as slightly contaminated (Table 6). The soils of Kielce, based on the Igeo index value, are more contaminated than those of Olsztyn. However, Kielce is placed in the area of geochemical anomaly of lead [40,54]. In this case, the Igeo index allows for assessing the scale of soil

contamination, but it cannot be clearly stated whether this contamination is of natural or anthropogenic origins.

Table 6. Classification of soil quality according to the assumptions of geoaccumulation index for lead.

Class	Value	Soil Quality [Pb]	Percentage of Soil Samples (%)	
			Kielce	Olsztyn
0	Igeo $\leq$ 0	practically uncontaminated	5.0	75.0
1	0 < Igeo < 1	slightly contaminated	80.0	15.0
2	1 < Igeo < 2	moderately contaminated	15.0	0
3	2 < Igeo < 3	moderately heavily contaminated	0	0
4	3 < Igeo < 4	heavily contaminated	0	0
5	4 < Igeo < 5	moderately extremely contaminated	0	0
6	5 < Igeo	extremely contaminated	0	0

Literature data on the contamination of urban soils is significantly diversified and depends mainly on the value of the adopted geochemical background, as well as the source of emission of elements [26,55]. Igeo index analysis is a validated method of assessing metal contamination of sediments and soils in cities. It compares the current and pre-industrial concentrations of metals in soils [55]. It is very difficult to establish an appropriate reference level for the studied metal according to the geochemical background given for different areas. Homogeneous geochemical background allows for identification of differences in the accumulation of heavy metals in soils and a reliable assessment of contamination.

The mean content of lead in the roots of common dandelion collected in Kielce was 3.33 mg/kg d.m. and a large dispersion of values (SD-5.01) was noted (Table 7, Figure 5). The soils of urban forests (type B) and industrial areas (type D) showed the greatest diversification. The maximum values recorded for the soils of type B (urban forests), i.e., 31.50 mg/kg d.m. differed significantly from the mean value calculated for the sample. For Olsztyn, the mean content of lead in the roots was nearly three times lower and amounted to 1.24 mg/kg d.m. There was also smaller dispersion of the results in relation to those noted for Kielce (Figure 6). The maximum values (3.80 mg/kg d.m.) were recorded for the type D (industrial areas). Also in this type, the values showed the greatest diversification. The content of lead in the common dandelion's leaves had a mean level of 2.02 mg/kg d.m.; while, the greatest diversification of values was observed for the industrial areas (type D). Extremely high levels were recorded (maximum value amounting to 18.58 mg/kg d.m.) in this type of land use, as well. The common dandelion's leaves from Olsztyn contained less Pb than those from Kielce. The mean value was 0.85 mg/kg d.m., and the value of standard deviation amounted to 0.50. As in the case of roots, the maximum values and the greatest dispersion of values were recorded for plants collected in the industrial areas (type D). The minimum values were nearly 2.5 times lower for the roots and leaves, while the maximum values were 8 times lower for the roots and 7 times lower for the leaves (Table 7).

Table 7. Statistics concerning the content of lead in common dandelion in Kielce and Olsztyn with regard to land-use types.

Land-Use Type		Root [mg/kg d.m.]		Leaves [mg/kg d.m.]	
		Kielce	Olsztyn	Kielce	Olsztyn
in total	minimum value	0.71	0.29	0.51	0.20
	maximum value	31.50	3.80	18.58	2.27
	mean value	3.33	1.24	2.02	0.85
	median value	2.03	1.14	1.41	0.72
	SD	5.01	0.75	2.40	0.50
urban allotment gardens –type A	minimum value	0.83	0.40	0.51	0.35
	maximum value	3.17	3.39	2.86	2.27
	mean value	1.83	1.51	1.19	0.95
	median value	1.90	1.33	1.04	0.80
	SD	0.69	0.79	0.63	0.48
urban forests –type B	minimum value	1.06	0.29	0.68	0.30
	maximum value	31.50	1.50	6.35	1.60
	mean value	5.68	0.79	2.37	0.68
	median value	2.85	0.75	1.93	0.57
	SD	7.81	0.40	1.43	0.37
urban green areas –type C	minimum value	0.71	0.52	0.57	0.45
	maximum value	4.84	2.53	3.65	1.87
	mean value	2.26	1.34	1.31	0.77
	median value	1.81	1.41	1.12	0.61
	SD	1.04	0.55	0.75	0.36
industrial areas –type D	minimum value	1.03	0.50	1.42	0.20
	maximum value	24.15	3.80	18.58	2.20
	mean value	3.54	1.33	3.19	0.99
	median value	1.89	0.90	2.30	0.80
	SD	5.79	0.98	4.29	0.70

Studies on the content of lead in common dandelion's roots and leaves conducted around the world indicate a significant diversity of results (Table 8). Keane et al. [16] report that concentrations of lead in plants are proportional to those in soils. Taller plants take up lead from both soil and atmospheric air, while lead from precipitation may migrate not only to plants' leaves, but also to their roots [56]. Availability of lead for plants is determined by values of soil pH and availability of organic matter. However, no statistically significant relationships were found between soil properties and concentrations of lead in common dandelion's roots and leaves in this study. Kleckerová and Dočekalová [17] show significant positive correlations between roots and leaves of common dandelion, and that was also confirmed for Kielce and Olsztyn–the correlation coefficient amounted to 0.71. The results obtained for Kielce and Olsztyn show that in those areas where soils are more contaminated, the level of lead absorption is higher in both parts of common dandelion, i.e., roots and leaves. Similar observations have been made by Keane et al. [16] and Bini et al. [57].

Table 8. Diversification of lead content in the common dandelion's roots and leaves.

City	Total Content in Leaves [mg/kg d.m.]/ Mean Value	Total Content in Roots [mg/kg d.m.]/ Mean Value	Author
Geometric mean value for Poland	3.53	0.97	[58]
Szczecin, Poland	range of mean values: 0.173–0.241	range of mean values: 0.167–0.242	[59]
Warsaw, Poland	2.65–4.01	1.56–1.73	[60]
Biała Podlaska, Poland	0.45–7.2	0.22–5.4	[61]
Ruda Śląska and Bytom, Poland	2.14–165.0	3.7–699.7	[61]
Katowice, Poland	27.3	not known	[62]
Kielce, Poland	1.07–3.11	0.54–2.09	[63]
Large city's residential district	19 + 2	not known	[64]
Brno, Czech Republic	range of mean values: 2.13–9.06	range of mean values: 1.40–4.02	[17]
USA	0.5–48.5	not known	[16]
Plovdiv, Bulgaria	3.15 ± 0.7	3.46 ± 0.14	[14]
Peshawar, Pakistan	4.96 ± 0.006	4.71 ± 0.102	[65]
Belluno, Italy	120–193	99.8–142	[57]
Warsaw, Poland	0.09–0.36	0.15–0.53	[66]
Legnaro, Italy	1.56	21.6	[67]

In order to assess the degree of enrichment of common dandelion with lead in relation to its total content in the soil, the phytoaccumulation factor (PF) was calculated (Table 9). Phytoaccumulation factor describes plant's ability to uptake heavy metals from soils in relation to migration load. It is assumed that plants are able to accumulate heavy metals in their tissues. When PF = $\geq$0.1, such accumulation is assessed as poor. Moderate or intensive accumulation occurs when the values of WF are 0.1 - $\leq$1 or > 1, respectively [68].

Table 9. Phytoaccumulation factor and translocation factor of lead for the common dandelion's roots and leaves from Kielce and Olsztyn.

Pb		Kielce		Olsztyn	
		Root	Leaves	Root	Leaves
PF	mean value	0.09	0.07	0.13	0.09
	median value	0.07	0.05	0.11	0.08
	SD	0.09	0.07	0.07	0.05
TF	mean value	0.81		0.77	
	median value	0.77		0.69	
	SD	0.45		0.37	

The obtained PF values indicated weak accumulation of lead in the common dandelion's leaves from Kielce and Olsztyn (there was no excessive accumulation in the leaves). The values were comparable to each other and were characterised by great dispersion. In the case of common dandelion's roots, the higher PF values were recorded for the samples collected in Olsztyn, where the degree of accumulation may be described as moderate. Also for Olsztyn, smaller differences in the obtained values were recorded. With regard to Kielce, the obtained PF values were lower and indicated a weak level of lead accumulation.

These values were relatively low in relation to the studies conducted in, Brno where the mean values were 0.24 for leaves and 0.10 for roots [17].

Translocation factor is a measure of distribution of heavy metals taken up by plants and determines whether there is metal accumulation in the plant's underground parts or migration to its above-ground organs [68]. The TF values were comparable for both cities; but, slightly higher values were recorded for Kielce (Table 9). The obtained TF values ($\leq$1) indicated that lead is mainly accumulated in the above-ground parts of plants.

The bioindication sensitivity of common dandelion was tested using correlations among the shares of lead in the soil and the plant's roots and leaves. A significant correlation was found (Table 10), which indicates that common dandelion is a sensitive indicator of lead in the urban environment. It was statistically proved that there is a relationship between common dandelion's roots and leaves and the place (city) of their sampling (Figures 3 and 4). No statistical relationships were found between land-use types and concentrations of lead in the soils and common dandelion.

Table 10. Relationships between the content of lead in the soils and common dandelion.

Variable	Spearman's $p < 0.5000$			
	Pb Bioavailable	**Pb Total**	**Pb Root**	**Pb Leaves**
Pb bioavailable	1.00	0.61	0.57	0.54
Pb total	0.61	1.00	0.77	0.60
Pb root	0.57	0.73	1.00	0.71
Pb leaves	0.54	0.60	0.71	1.00

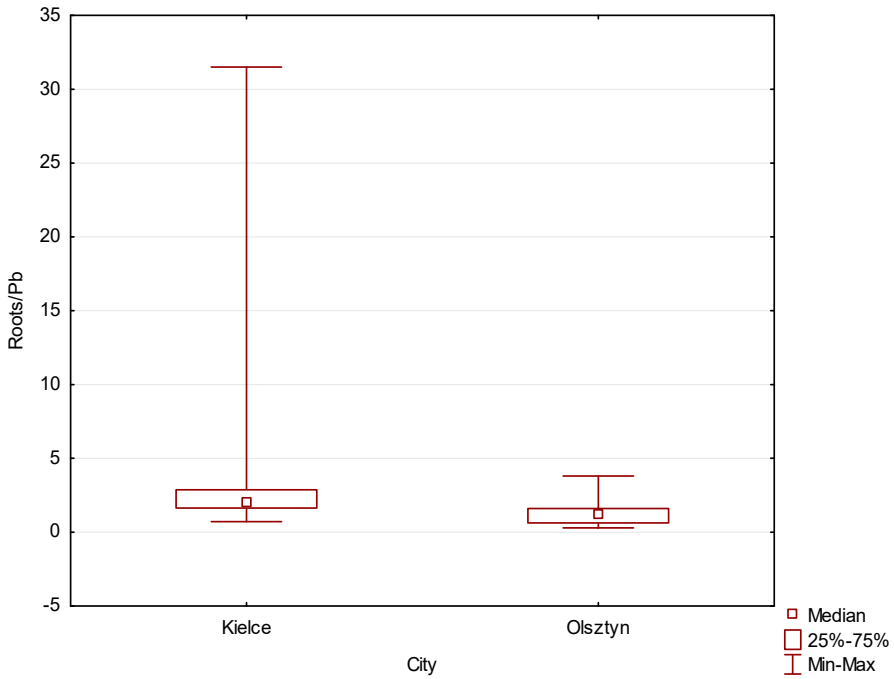


Figure 3. *Cont.*

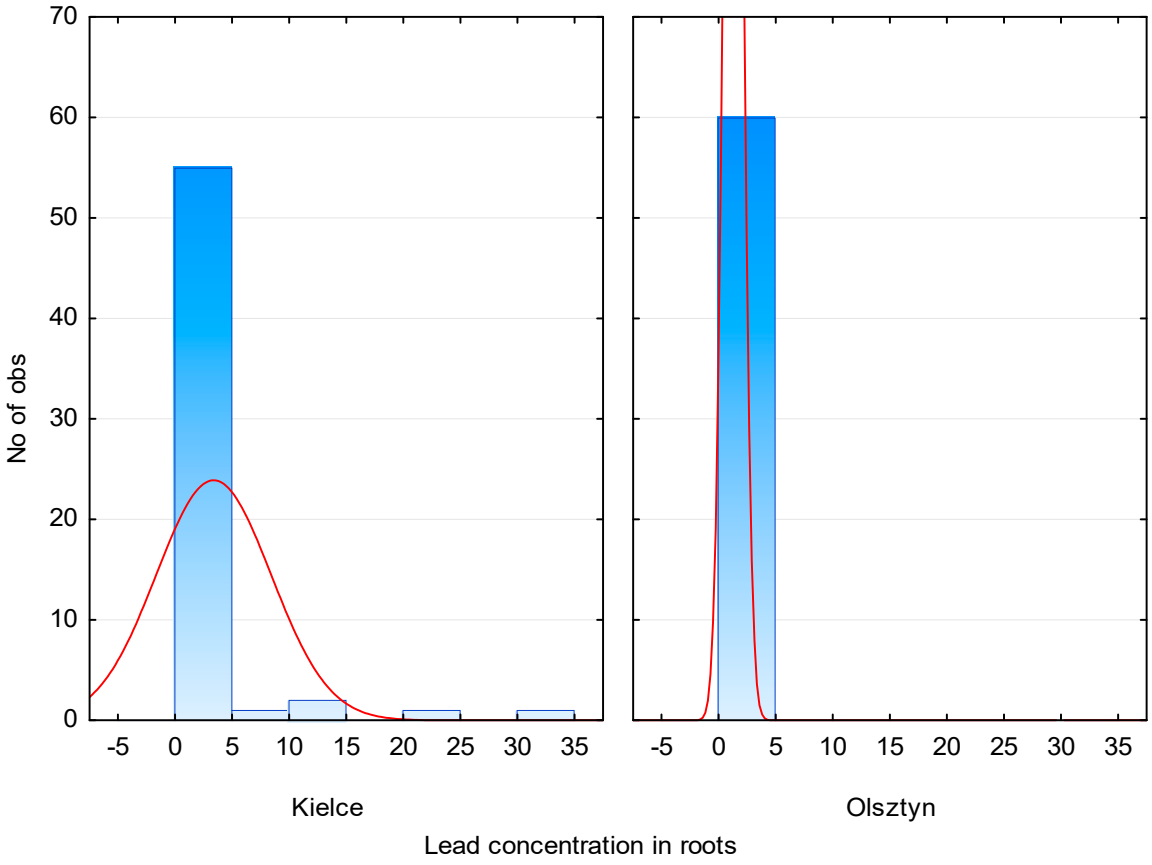


Figure 3. Diversification of lead content in the common dandelion's roots from Kielce and Olsztyn.

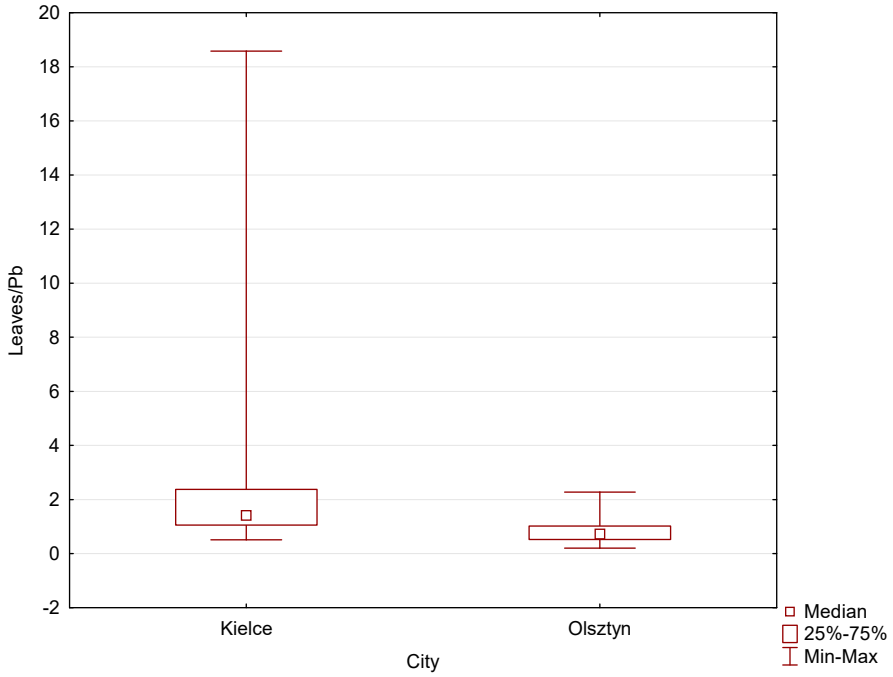


Figure 4. *Cont.*

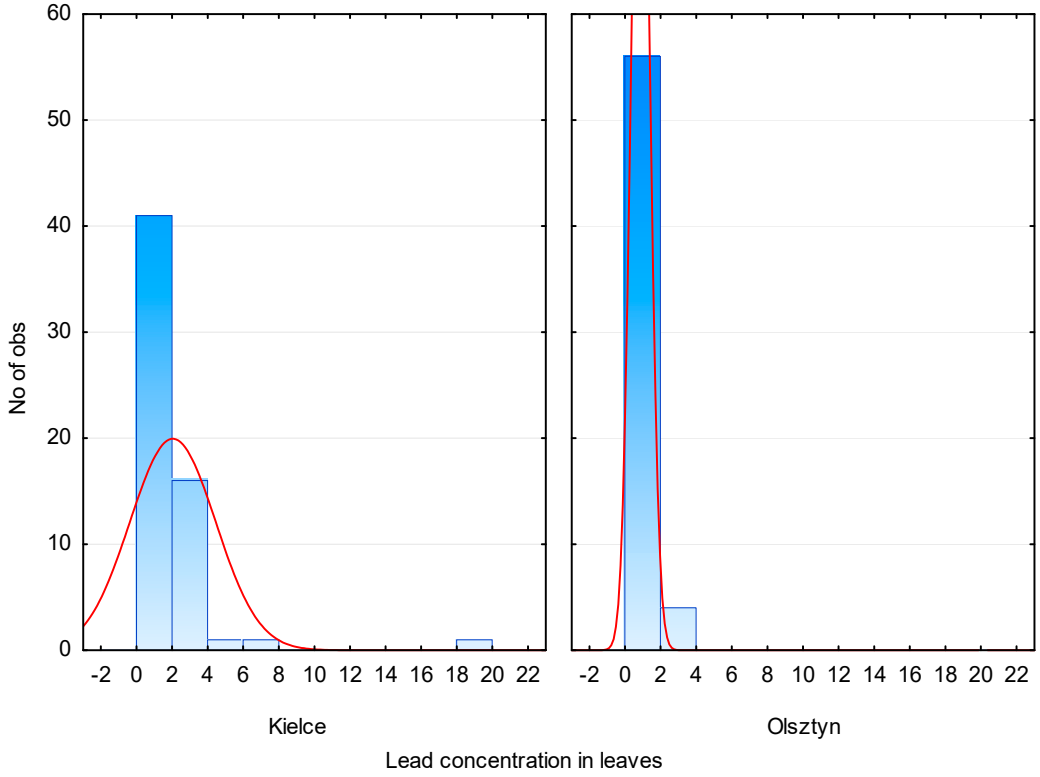


Figure 4. Diversification of lead content in the common dandelion's leaves from Kielce and Olsztyn.

The maps of lead concentrations in the soils and common dandelions show a large spatial variability of parameters in both Kielce and Olsztyn (Figures 5 and 6).

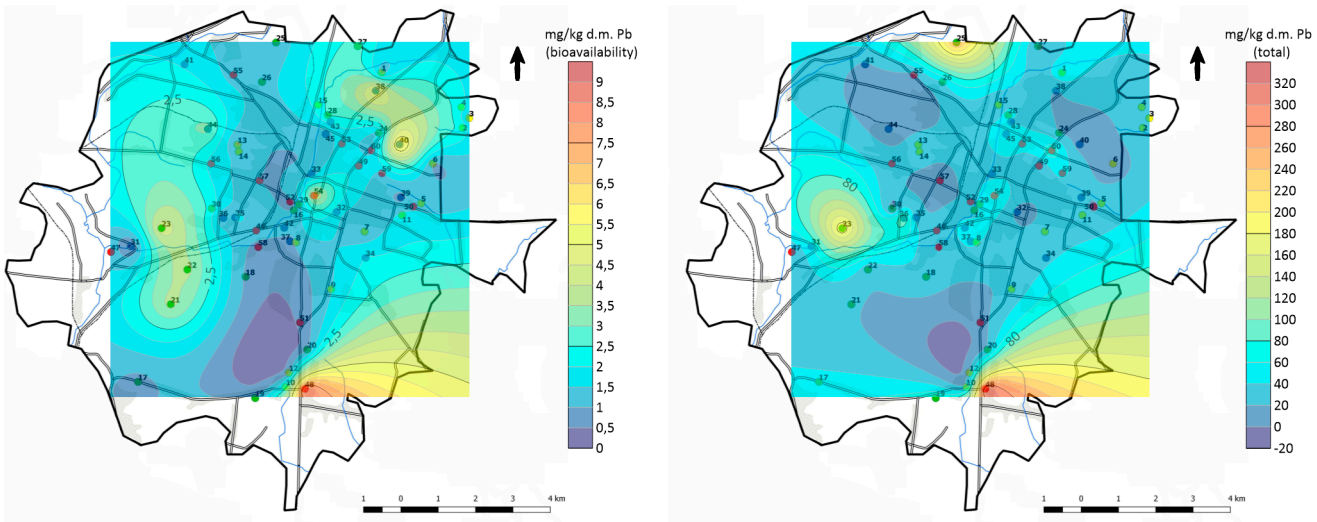


Figure 5. *Cont.*

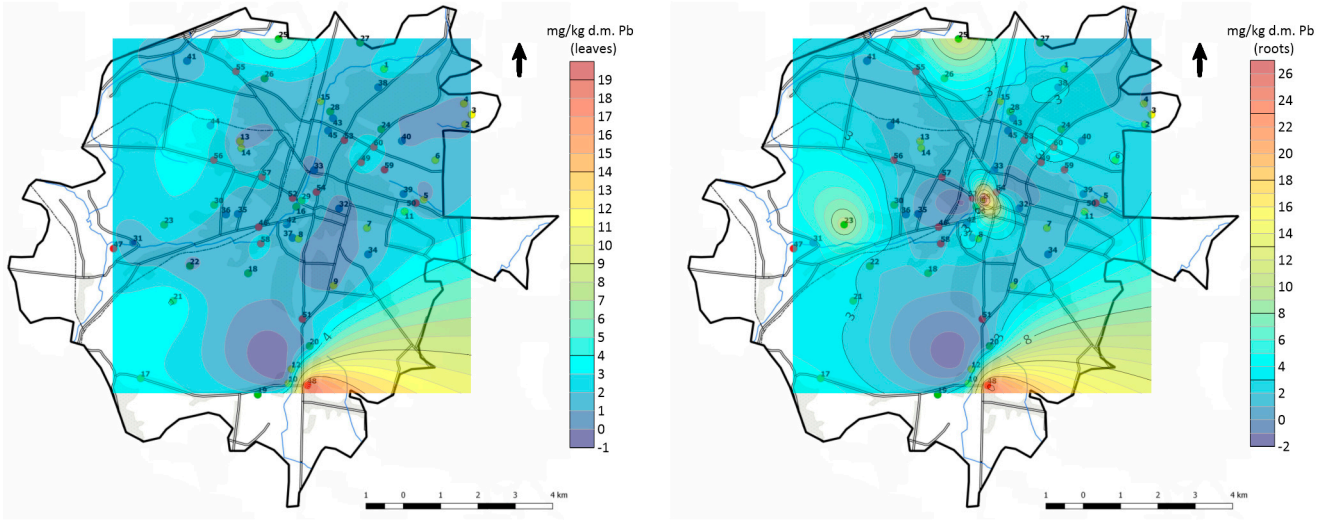


Figure 5. Lead content in the soils and common dandelions from Kielce (kriging method modelling).

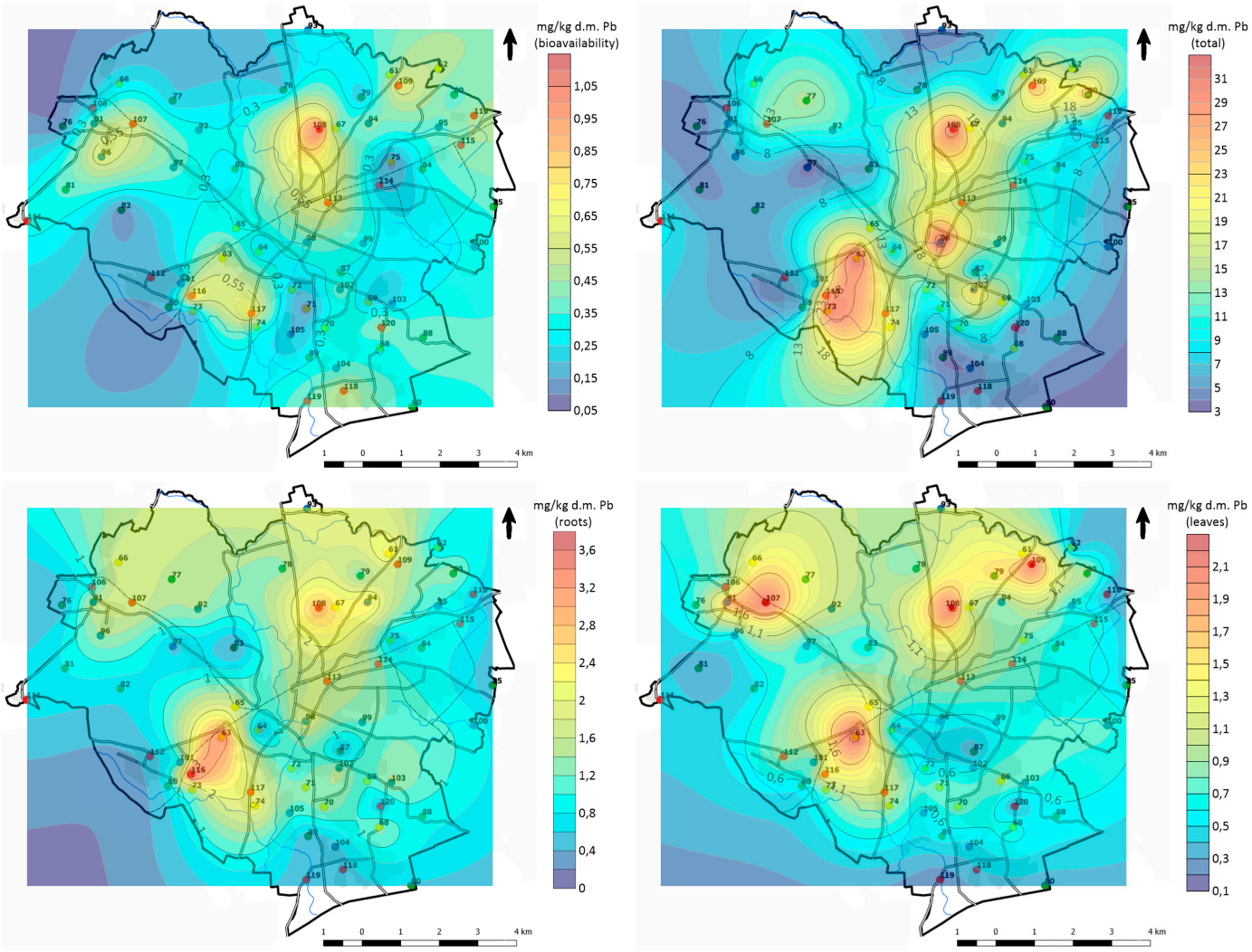


Figure 6. Lead content in the soils and common dandelions from Olsztyn (kriging method modelling).

In Kielce, areas with significantly higher lead concentrations in relation to the background values were identified. Such a situation was recorded for the sample (no. 48) collected at the filling station (type D). There, the extreme high values for the common

dandelion's roots and leaves were also found. Moreover, high lead concentrations in the soils were observed in the samples collected in the areas belonging to the type B–urban forests (no. 23 and 25) and type C–urban green areas (no. 36). The concentrations of lead in the soils correlated with those found in the common dandelion.

The range of variability for lead concentrations in Olsztyn was smaller than in Kielce; but, lead anomalies were found in this city, as well. The highest lead concentrations were observed in the samples collected from the areas belonging to the type A–urban allotment gardens (no. 63, 73), type C–urban green areas (no. 98), as well as type D–industrial areas (no. 108). As far as bioavailabilty is concerned, the maximum values were determined in such samples as no. 96 (type C) and 108, 109, 116, and 117 (type D). With regard to common dandelion's leaves, the maximum values were recorded in the samples no. 63 (type A), 107, 108, as well as 109 (type D); and when it comes to the roots–in the samples no. 63 (type A), 108, and 116 (type D). Like in Kielce, no significant relationships were found between the types of land use and high concentrations of lead in the soils and common dandelion. Similar spatial patterns are present on all maps of Kielce and Olsztyn, which indicates a strong spatial correlation between the total lead content and bioavailable fraction and the content of this metal in the common dandelion's roots and leaves.

In Kielce, the high lead load of the studied soils cannot be directly related to the existing metal processing plants, such as iron and cast steel foundries. Certainly, the historical exploitation and processing of metal ores in the city could have certainly had an impact on the increased lead content, especially in comparison with the studied soils of Olsztyn. However, there are more factors contributing to the increased accumulation of lead in the soils of Kielce. These include specific soil parent rocks shaping the geochemical background, defective buildings that do not take into account ventilation wedges, outdated heating systems, etc.

4. Conclusions

The analysis of the soils of Kielce and Olsztyn showed a slightly acidic, slightly alkaline pH, a dominant share of clayey sand and light clay, and high concentrations of organic matter.

The content of lead in the soils of Kielce was significantly higher than that in Olsztyn. This applies to both the total content and the bioavailable fraction of lead. It is influenced not only by the history of land use, which determines the anthropogenic factor, but also by the natural enrichment of the parent rock with lead. The share of bioavailable content of lead in relation to its total content was definitely much higher in the soils of Kielce. In the case of more contaminated ecosystem, a high spatial dispersion in the concentrations of bioavailable fraction was observed at the same time with a small range of lead concentrations. This may indicate a higher lability of the soil environment in Kielce with regard to the content of analysed metal.

The analysis of common dandelion in terms of lead concentrations showed that this metal is stabilised in the plant's root – the roots accumulated lead at a higher level than the leaves, and the translocation of this metal was low. The analysed levels of Pb, both total and bioavailable, in the field-collected soil samples were correlating significantly with the Pb levels reported for the corresponding common dandelion samples (roots and leaves).

The level of lead in biomass depends on its total and bioavailable concentrations in soils. And that was statistically confirmed. The morphological and physiological features of common dandelion, as well as its age and length of roots, combined with the good bioaccumulation of lead coming from soils, proven in different urban ecosystems, allow this plant (both roots and leaves) to be classified as plants recommended as bio-indicators for the monitoring of urban soils.

No significant relationships were found between the types of land use and the lead content in soils and common dandelions, which makes it risky to collect this herb in urban areas for consumption purposes, even when it grows in practically uncontaminated areas. The applied spatial modelling indicates the relationships between concentrations of lead

in soils and common dandelions, so that it is possible to determine the zones with high (deviating from the average values) lead concentrations. There are Pb anomalies in both cities, with the values recorded for Kielce being higher than those observed in Olsztyn.

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