Influence of diversified anthropogenic pressure on heavy metals contents in soils and plants of garden allotments

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Abstract. The presented research aimed at assessing the impact of anthropogenic pressure of varying intensity on the heavy metals content in the soils of garden allotments and in the biomass of plants grown there. In order to achieve the study purpose, the contents of Pb, Zn, Cu, Cd were determined in the soil samples of three allotments located in Silesia (strong industrial and urban pressure), Lublin (moderate industrial and urban pressure) and Biała Podlaska (weak urban pressure). The same elements were analysed in leaves and roots of red beets grown on the soils in urban areas mentioned above. It was found that the soils derived from Silesia were the most polluted, less polluted were the soils from Lublin, and the least polluted were the soils from Biała Podlaska. The content of Pb, Cu, and Cd in the leaves and roots of red beet harvested on the examined soils was dependent on the concentrations of these elements in soils. The obtained results indicated that the contamination of soils and plants with heavy metals should be included into the comprehensive assessment of the human impact on the environment, especially in industrial and urbanised areas, and suggested the need for further, widely spread studies of soils in such areas.

1. Introduction
Small, family or company gardens (in Poland called allotments garden) are often used by hobbyists to grow vegetables and fruit and as recreational areas for city residents [1]. They are popular in many countries and due to their functions, should be located in the areas free from air, soil and groundwater pollution. However, in most Polish agglomerations, allotment gardens are located in the vicinity of industrial plants, communication routes and in reclaimed areas, where the contamination with heavy metals and other substances is often observed [2]. A similar unfavourable location of city gardens can be noticed in several European [3] or American and Asian metropolises [4].

Heavy metals and other types of pollutants, such as sulphur, carbon or nitrogen compounds, are among the main city's impact risks on green areas, and in particular, on allotment gardens, which in most cases are used for the production of consumable biomass [5,6]. Heavy metals and metalloids are released into the soil from the bedrock (lithogenic source) and from various anthropogenic sources. The natural factors influencing the occurrence and distribution of heavy metals in soils include the composition of the bedrock, the weathering degree, physical, chemical and biological properties of the soil, as well as climatic conditions [7]. The main anthropogenic sources of heavy metals include industrial emissions and agricultural activities, combustion of fossil fuels and traffic pollution. In
urban areas, soils can be contaminated with heavy metals as a result of intense car traffic [8]. The content of heavy metals in soils varies, and their concentration increases with the intensity of anthropogenic pressure [9]. Even a slight increase in the concentration of heavy metals in the soil may pose a threat to the environment and human health [10]. The uptake of heavy metals by plants from the soil is a very important stage in their trophic transport in food chains. Metals are taken up from contaminated soil by plants and then transferred through the food chain [11]. Considering contamination of the human food chain, crops pollution such as grains and vegetables is a very serious problem. The consumption of plants contaminated with toxic heavy metals may pose a threat to the human health [12]. Thus, the aim of the presented studies was to assess the impact of anthropogenic pressure of varying intensity on the heavy metals content (Pb, Zn, Cu, Cd) in the allotments soils and in the biomass of plants grown there.

2. Materials and methods
The studies on the influence of differentiated anthropogenic pressure on the heavy metals content in soils and plants of allotment gardens were carried out in the areas with a diversified impact of anthropogenic pressures (mainly with varied influence of urban and industrial pollution). They were urbanised areas: Silesia (Zabrze and Miasteczko Śląskie, strong industrial and urban anthropogenic pressure), Lublin (moderate industrial and urban anthropogenic pressure), and Biała Podlaska (weak urban anthropogenic pressure – Table 1).

| Garden allotment | City                                      | N       | S       |
|------------------|------------------------------------------|---------|---------|
| S1               | Zabrze, Silesia – Kończyce gardens       | 50° 16’ 67” | 18° 47’ 83” |
| S2               | Zabrze, Silesia – Mikulezyce gardens     | 50° 19’ 55” | 18° 47’ 02” |
| S3               | Miasteczko Śląskie, Silesia – Żyglin gardens | 50° 16’ 09” | 18° 44’ 09” |
| L1               | Lublin – Mickiewicz’s gardens            | 51° 13’ 35” | 22° 34’ 92” |
| L2               | Lublin – Al. Piłsudski’s gardens         | 51° 14’ 47” | 22° 33’ 52” |
| B1               | Biała Podlaska – Szarotka gardens        | 52° 01’ 92” | 23° 07’ 92” |
| B2               | Biała Podlaska – Kraszewski’s garden     | 52° 01’ 96” | 23° 07’ 76” |

The soil samples of the studied gardens were taken for the tests at depth of the 0-20 cm. At the same time, the samples of red beet grown on the test soils were taken. Three samples of soil, leaves and roots of red beets were collected from each garden. The results presented in the paper are the mean values obtained from three analysed samples which were collected at a given facility.

The following chemical properties of the collected soil samples were determined: pH in H2Odist and 1M KCl, (the potentiometric method), hydrolytic acidity -Hh (the Palman method in 1 M CH3COONa), alkaline cations – S (in the extract of 0.5 M chloride ammonium at pH = 8.2), the sorption capacity – T and the saturation degree of the sorption complex with alkaline cations – V (parameters calculated using the appropriate formulas), total organic carbon content (by combustion with a TOC-VCSH apparatus with SSM-5000A module – Shimadzu), total nitrogen content (the modified Kjeldahl method using the Kjeltech TM 8100 distillation unit). In the soil and plant samples, the total content of heavy metals (Pb, Zn, Cu and Cd) was determined by applying inductively coupled plasma optical emission spectrometry using ICP - AES model PS 950 (Leeman). The analysed samples were previously mineralised using a mixture of concentrated HCl and HNO3 acids (2:1 ratio) with addition of 30% H2O2. During the analysis different emission wavelength was used. For the elements assessed, it was as follows: Pb – 220.353 nm, Zn – 213.856 nm, Cu – 224.700 nm, Cd – 214.438 nm.
The obtained results were subjected to a statistical analysis (correlation coefficients, analysis of variance) using the STATISTICA 5: Anova/Manova Version, '97 Edition software. These calculations were performed mainly to compare the state of environmental pollution between objects (Silesia-Lublin-Biała Podlaska), as well as to assess the soil impact on plants.

3. Results and discussion

The basic properties of the soils for garden allotments are presented in Table 2. The soils of the gardens in Silesia and Biała Podlaska were characterised by a lighter grain size composition (loamy sand). The soils from allotment gardens in Lublin (silt clay loam and loam) had a more favourable granulometric composition, which classifies them as medium soils. The garden soils of Silesia and Lublin were characterised by near neutral pH, while those of Biała Podlaska showed slight acidification. The soils from Lublin were characterized by the highest sorption capacity, which resulted from their finer granulometric composition. The soils from Silesia had slightly lower sorption capacity, while the soils from Biała Podlaska were characterised by the lowest sorption capacity. The described dependencies were also observed for the saturation degree with alkaline cations (V).

Table 2. Basic properties of the test soils.

| Garden allotment | Textural groups | pH | S  | T  | V  | C  | N  |
|------------------|----------------|----|----|----|----|----|----|
|                  | in H₂O dist.   | 1 M KCl | cmol(+) kg⁻¹ | %  | %  | %  |
| S1               | ls             | 6.9 | 6.8 | 22.3 | 24.7 | 90.3 | 2.34 | 0.24 |
| S2               | ls             | 7.1 | 7.1 | 24.7 | 25.5 | 96.7 | 1.48 | 0.21 |
| S3               | ls             | 7.0 | 6.9 | 36.7 | 38.3 | 95.8 | 3.42 | 0.29 |
| L1               | sc-l           | 7.4 | 7.3 | 39.3 | 40.4 | 97.3 | 1.92 | 0.16 |
| L2               | l              | 7.4 | 7.1 | 33.9 | 35.1 | 96.6 | 1.64 | 0.14 |
| B1               | ls             | 6.0 | 5.5 | 15.1 | 19.0 | 79.5 | 1.42 | 0.12 |
| B2               | ls             | 6.5 | 6.3 | 18.1 | 20.6 | 87.8 | 1.38 | 0.11 |
| Silesia (mean value) | -             | -   | -   | 27.0 | 29.5 | 94.3 | 2.41 | 0.25 |
| Lublin (mean value)   | -             | -   | -   | 36.6 | 37.8 | 97.0 | 1.78 | 0.15 |
| Biała Podlaska (mean value) | -          | -   | -   | 16.6 | 19.8 | 83.6 | 1.40 | 0.12 |

The organic carbon content in the soils of the garden allotments under study was relatively high. In the soils of the Silesia area the content of organic carbon ranged from 3.42 to 1.48% (average 2.41%). The highest content of organic carbon was found in the soils from Miasteczko Śląskie (S3). In the soils of Lublin allotments, the content of organic carbon ranged from 1.92 to 1.64% (average value 1.78%). The organic carbon content in the soils of allotments in Biała Podlaska was the lowest among the assessed areas and amounted to 1.40% (on average). The differences in the content of organic carbon between the soils in the studied areas were the result of the impact of anthropogenic pressure as well as the typological differentiation of soils on which allotments were located.

Total nitrogen content in the soils of allotment gardens from Silesia ranged from 0.29 to 0.21%. These values are typical for the top levels of arable soils in Poland [13]. The content of total nitrogen in the soils of allotments in Lublin and Biała Podlaska was significantly lower and amounted to 0.15% and 0.12%, respectively.

Heavy metals belong to the most toxic soil pollutants [14]. The content of heavy metals in high concentrations in soil is particularly dangerous, and their increased content is one of the indicators of environmental pollution [15]. The content of the assessed heavy metals in the soils of allotment s varied from low to high and was related to the location, which determined the intensity of the anthropogenic pressures.

The average value of the natural concentration of lead in soils in Poland is 18 mg kg⁻¹ d.m., and the average concentration in arable soils is 14 mg kg⁻¹ d.m. [16].
The total content of lead in the soils of the allotments in Silesia ranged from 86.6 to 335.0 mg kg\(^{-1}\)-d.m (average 173.4 mg kg\(^{-1}\)-d.m) – Table 3. These contents correspond to the 1\(^{st}\) and 2\(^{nd}\) degree of their pollution [17]. The highest content of Pb was found in the soil of the S3 site (Miasteczko Śląskie). The metallurgical industry (zinc smelter) is the largest anthropogenic source of pollution in these areas. The analysis of variance showed that the Pb content was significantly higher in the soils of allotments in Lublin compared to its content in the soils from the areas with moderate and low human pressure (Table 4). The content of lead in the soils of allotments in Lublin was several times lower than in Silesia. The content of this element was diversified and ranged from 27.4 to 41.8 mg kg\(^{-1}\)-d.m (34.6 mg kg\(^{-1}\)-d.m on average), which qualifies these soils to the group with natural content of this metal [17]. The soil from the L1 area, which is located in the more industrialised district of Lublin compared to the L2 area, was characterised by a higher Pb content. This is also found in the studies by Kowalska-Pyłka et al. [18], who showed that the average lead content in soil samples from the allotments in Lublin ranged from 22.15 mg kg\(^{-1}\)-d.m up to 78.88 mg kg\(^{-1}\)-d.m, and it was increasing with the increase of traffic volume and the saturation of the area with the industrial facilities. Low lead content was found in the soils of allotments in Biała Podlaska.

The correlation coefficients showed that the total lead content in the studied soils significantly correlated with the content of organic carbon (Table 5).

The zinc content in soils in Poland is within the broad limits of 10-200 mg kg\(^{-1}\)-d.m and varies depending on the type, grain size distribution and the content of organic substances in the soil [16]. The zinc content (Table 3) in the soils of allotments S2 and S3 from Silesia ranged from 315 to 759 mg kg\(^{-1}\)-d.m, respectively, which qualifies these soils to the 2\(^{nd}\) and 4\(^{th}\) pollution degree class [17].

### Table 3. Content of heavy metals in test soils (mg kg\(^{-1}\)-d.m).

| Garden allotment | Pb    | Zn     | Cu   | Cd   |
|------------------|-------|--------|------|------|
| S1               | 98.7  | 427.0  | 25.8 | 4.11 |
| S2               | 86.6  | 315.0  | 15.9 | 3.58 |
| S3               | 335.0 | 759.0  | 36.1 | 6.96 |
| L1               | 41.8  | 194.0  | 24.7 | 1.56 |
| L2               | 27.4  | 74.0   | 14.5 | 1.39 |
| B1               | 15.2  | 33.0   | 10.5 | 1.03 |
| B2               | 21.2  | 73.0   | 15.7 | 1.24 |
| Silesia (mean value) | 173.4 | 500.3  | 25.9 | 4.88 |
| Lublin (mean value) | 34.6  | 134.0  | 19.6 | 1.48 |
| Biała Podlaska (mean value) | 18.2 | 53.0 | 13.1 | 1.14 |

### Table 4. Analysis of the variance for heavy metals content in the soils of the studied objects.

| Objects          | Pb    | Zn     | Cu   | Cd   |
|------------------|-------|--------|------|------|
| Silesia-Lublin   | **    | **     | -    | **   |
| Silesia-Biała Podlaska | ** | ** | ** | ** |
| Lublin-Biała Podlaska | - | - | - | - |
| LSD              | 68.29 | 499.88 | 25.47 | 2.75 |

**- the significant difference at α=0.05

### Table 5. Correlation coefficients between the content of heavy metals and soil properties.

| Parameter | Pb       | Zn       | Cu       | Cd       |
|-----------|----------|----------|----------|----------|
| Corg.     | 0.5420** | 0.6862** | 0.2877   | 0.7279** |
| S         | 0.3994   | 0.3889   | 0.7081** | 0.3396   |
| T         | 0.3858   | 0.3723   | 0.7239** | 0.3196   |
| pH        | 0.3576   | 0.3563   | 0.3306   | 0.3448   |

**- the correlation coefficient significant at α=0.05, α_{0.10} = 0.4259; α_{0.05} = 0.4973.
In the humus horizons of the allotments of Lublin and Biała Podlaska, the zinc content was significantly lower (Table 4). It ranged from 74 mg kg\textsuperscript{-1} d.m. (site L2) to 194 mg kg\textsuperscript{-1} d.m. (site L1 located in the more industrialised part of the Lublin) and from 33 to 73 mg kg\textsuperscript{-1} d.m. in the case of the Biała Podlaska allotments, where the content of this element was typical for the soils with a natural content of this element. The zinc content was positively correlated with the organic carbon content in the test soils (Table 5).

Copper is an element necessary for plant growth in a small amount because it affects the photosynthesis process and is a component of many enzymes [18]. Both the lack and the excess of this element causes these processes to be disturbed and decrease the yield of plant biomass. The copper content in agricultural soils ranges from 0.2 mg kg\textsuperscript{-1} d.m. up to 725 mg kg\textsuperscript{-1} d.m. with an average content of 6.5 mg kg\textsuperscript{-1} d.m. [16]. In the soils of the Silesian allotments, the copper content was in the range of 15.9–36.1 mg kg\textsuperscript{-1} d.m., on average 25.9 mg kg\textsuperscript{-1} d.m. (Table 3), which qualified these soils to the groups from natural to the 2\textsuperscript{nd} class, according to the content of this element. The soils of the allotments in Biała Podlaska had a significantly lower Cu content than the soils from Silesia, ranging from 10.5–15.7 mg kg\textsuperscript{-1} d.m. The sum of alkaline cations and the sorption capacity (Table 5) was significantly correlated with the copper content in the studied soils.

The cadmium content in the soils of allotments in Silesia ranged from 3.58 to 6.96, on average 4.88 mg kg\textsuperscript{-1} d.m. (Table 3). These contents qualified the examined soils to the class from 3\textsuperscript{rd} to 5\textsuperscript{th}, according to the pollution degree [14]. The content of cadmium in the soils of Lublin gardens in the L1 area was typical for the slightly polluted soils, and the L2 site it corresponded to soils with a natural content of this element. In the soils of allotments of Biała Podlaska, the Cd content was typical for the soils with its natural content of this element [16] and amounted to (on average) 1.14 mg kg\textsuperscript{-1} d.m. The cadmium content was significantly and positively correlated with the content of organic carbon (Table 5).

Summing up, it should be stated that the degree of anthropogenic pressure has a significant impact on the contamination of the allotment soils with heavy metals, which was confirmed by the analysis of variance (Table 4). The soils of allotments from the areas under the strong anthropogenic pressure were characterised by a significantly higher content of Pb, Zn and Cd compared to the soils from the areas under the medium and low anthropogenic pressure, and significantly higher Cu content compared to the soils from the areas with low human impact. This indicates that the content of heavy metals may be one of the criteria for assessing the intensity of anthropogenic pressure. El Khalil et al. [19] showed that the concentrations of copper, lead and zinc in the soils from Marrakesh (Morocco) can be used as indicators of industrialization. The garden soils in Nantes, France, also revealed high lead concentrations, and indicated the human activity as the main source of this phenomenon [20]. The analysis of the soil samples from Madrid showed that the concentrations of Cd, Cu, Pb and Zn were inversely correlated with the distance from the city centre [21]. It should also be noted that the soils of allotments in Silesia do not meet the requirements of the Regulation of the Minister of the Environment of September 1, 2016 [22] on the method of assessing the soil surface pollution, specifying the permissible values of Pb concentrations per 100 mg kg\textsuperscript{-1} d.m., Zn per 300 mg kg\textsuperscript{-1} d.m., Cu per 100 mg kg\textsuperscript{-1} d.m., and Cd per 3 mg kg\textsuperscript{-1} d.m.

The soil, as a permanent element of the landscape, is the "recipient" of all pollutants, but at the same time it "distributes" them to the trophic chain, and directly to water and plants. Pollutants can also be transferred into the plants through their above-ground parts, which is observed in urbanised and industrialised areas [23]. The content of heavy metals in the red beet parts, which was used as a test plant in these studies, was diversified (Table 6), which resulted from the intensity of the impact of anthropogenic pressures (soil contamination), part of the plant, and the type of element. Referring the identified metal contents to the levels which determine the consumer usefulness of plants [17], it should be stated that Pb, Zn and Cd may pose a particular threat, which can adversely affect the ecological safety and health of the users of the allotments who are the consumers of the plant products harvested from the soils contaminated with heavy metals.

The content of heavy metals in parts of the plant depended on the localisation of allotments (intensity of pollution), as well as the type of the element. The content of lead, zinc and cadmium in
red beets from Silesia was 2-4 times higher in beet leaves than in roots, while the differences between the particular parts of the plants harvested from other areas were much smaller (Table 6). This can be explained by the fact that plants were additionally exposed to the deposition of atmospheric pollutants.

In the case of copper the lower mean contents of this metal were noted in roots than in leaves of beets grown on soil in studied areas.

Numerous studies have assessed the relationship between the heavy metal contamination (especially lead and cadmium) in urban garden soils and in the plant food products derived from these gardens [24, 25]. In the case of Pb, generally the greatest concentration in vegetables occurred where the soil Pb levels were the highest [26,27]. This was confirmed by the results of our research, which showed that the content of Pb, Cu and Cd in the leaves and roots of the red beet depended on the level of their concentrations in the soil (Table 7).

Table 6. Content of heavy metals in leaves and roots of red beet (mg kg\textsuperscript{-1} d.m\textsuperscript{-1}).

| Garden allotment | Plant part | Pb  | Zn  | Cu  | Cd  |
|------------------|------------|-----|-----|-----|-----|
|                  |            |     |     |     |     |
| S1               | leaves     | 8.19| 693 | 18.7| 9.94|
|                  | root       | 4.38| 275 | 18.7| 2.81|
| S2               | leaves     | 8.95| 184 | 14.1| 3.41|
|                  | root       | 3.04| 175 | 13.3| 1.00|
| S3               | leaves     | 93.80| 748 | 16.9| 8.12|
|                  | root       | 11.80| 199 | 15.2| 1.40|
| L1               | leaves     | 1.10| 187 | 8.8 | 0.37|
|                  | root       | 1.96| 97  | 10.5| 0.32|
| L2               | leaves     | 2.94| 126 | 12.9| 0.83|
|                  | root       | 1.48| 101 | 10.1| 0.66|
| B1               | leaves     | 2.16| 121 | 5.0 | 0.70|
|                  | root       | 1.95| 60  | 5.3 | 0.21|
| B2               | leaves     | 0.95| 152 | 9.7 | 0.77|
|                  | root       | 1.09| 102 | 8.3 | 0.59|
| Silesia (mean value) | leaves   | 37.0| 542 | 16.6| 7.16|
|                  | root       | 6.40| 216 | 15.7| 1.74|
| Lublin (mean value) | leaves | 2.02| 157 | 10.8| 0.60|
|                  | root       | 1.72| 99  | 10.3| 0.49|
| Biala Podlaska (mean value) | leaves | 1.55| 136 | 7.4 | 0.74|
|                  | root       | 1.52| 81  | 6.8 | 0.40|

Table 7. Correlation coefficients between the content of elements in the soil and their content in red beets.

| Soil | Leaves | Pb    | Zn    | Cu    | Cd    |
|------|--------|-------|-------|-------|-------|
|      |        | Pb    | Zn    | Cu    | Cd    |
| Pb   | 0.6844* | 0.4727| 0.8285** | 0.5945*|
| Zn   | 0.6712** | 0.4817| 0.8574** | 0.6289*|
| Cu   | 0.1161  | 0.0254| 0.6244*  | 0.1495|
| Cd   | 0.8455** | 0.5270| 0.7456** | 0.7519**|
| Pb   | 0.8963** | 0.3014| 0.4864 | 0.5910*|
| Zn   | 0.8176** | 0.3472| 0.5830* | 0.6376**|
| Cu   | 0.2684  | 0.0334| 0.6277*  | 0.2091|
| Cd   | 0.6750** | 0.3591| 0.4839 | 0.7538*|

* - the correlation coefficient significant at $\alpha=0.10$; ** - the correlation coefficient significant at $\alpha=0.05$, $\alpha_{0.10} = 0.5487$; $\alpha_{0.05} = 0.6347$.
4. Conclusions

The intensity of anthropogenic pressure on the environment had a significant impact on the content of lead, zinc, copper and cadmium in the soils of garden allotments. The soils derived from Silesia, where the strong human impact is observed, were the most polluted, less polluted were the soils from Lublin (under moderate human pressure), and the least polluted were the soils from Biała Podlaska (under low human pressure). Considering the level of pollution, the soils from Silesian allotments were classified to 1st or 2nd degree, regarding lead; 2nd to 4th degree, regarding zinc; 3rd to 5th degree, in the case of cadmium. The soils from the areas under the moderate (Lublin) and low (Biała Podlaska) anthropogenic pressure were characterised by a natural content of lead and cadmium, and an slight or increased contamination with zinc.

The content of Pb, Cu, and Cd in the leaves and roots of red beet harvested on the examined soils was dependent on the concentrations of these elements in soils.

The obtained results indicate that contamination of soils and plants with heavy metals should be included into the comprehensive assessment of the human impact on the environment, especially in the industrial and urbanised areas, and suggest the need for further, widely spread studies of soils in such areas. The results of the studies will make it possible to assess the level of ecological safety and enable the assessment of possible threats related to secondary contamination of the soil environment.

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