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Accumulation of selected trace elements in soil and roadside trees – case study

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Abstract

The aim of the study was (1) the assessment of soil pollution with trace elements along a high-traffic transport route, (2) determination of the content of trace elements in leaves of roadside trees, and (3) comparison of the usefulness of aqua regia with 1 mol dm^{-3} HCl and 0.01 mol dm^{-3} $CaCl_2$ for extraction of phytoavailable forms of Cd, Cu, Cr, Ni, Pb, and Zn from urban soil. The analysis covered contents of trace elements in soil and tree leaves along one of the main transport routes in Warsaw. The analysis of total contents of the studied metals (Cd, Cu, Cr, Ni, Pb, Zn) showed no exceedance of values acceptable for these elements in soil. The analysed tree species were characterised by variable ability to absorb trace elements. Usually White birch (*Betula pendula* Roth) accumulated the highest amounts of the studied elements (especially Zn), and Swedish whitebeam (*Sorbus intermedia*) the lowest. The correlation between analysed trace elements concentration in tree leaves and soil suggests that the assessment of these metals pollution of soils is more efficient by means of 1 mol dm^{-3} HCl than determination of total forms. It was also evidenced that trees can be used for the assessment of the state of pollution of the environment with trace elements.

1. Introduction

As a result of rapidly developing urbanisation and industrialisation, the urban environment is often characterised by elevated levels of organic (e.g. PAHs – polycyclic aromatic hydrocarbon, polychlorinated biphenyls) and mineral pollutants, including trace elements or heavy metals (As, Cd, Cu, Cr, Hg, Ni, Pb, Zn) originating from various sources such as transportation, municipal facilities – boiler stations, heat and power plants, or industrial plants (Li, 2018; Romanowa and Lovell, 2021). Such pollutants can accumulate in soils constituting a threat for ecological safety in cities (Dmochowski and Dmochowska, 2011; Cheng et al., 2014). One of the primary sources of emission of trace elements in the urban environment is road transport. In the process of fuel combustion in car engines, the atmosphere is supplied with 0.12 up to 1.23 mg kg^{-1} of fuel consumed different elements, such as Fe, Zn, Cu, Mn, Ni, Cr, Ba, V, Ce, Pb, Cd. The content of metals in emissions is also higher in the case of diesel engines (Zn – 320, Cu – 300, Ni – 13.9, Cr – 10.7, Pb – 8.6, Cd – 0.28 μg kg of fuel consumed) than spark ignition (Zn – 13.1, Cu – 11.9, Ni – 1.52, Cr – 1.76, Pb – 1.27, Cd – 0.05 μg kg of fuel consumed) engines. Both in the case of diesel oil and gas, the highest concentrations of these elements in exhaust fumes concern Zn, and Cu (Wang et al., 2003; Cheung et al., 2010; Nwaedozie and Nyan, 2018; Coufalík et al., 2019). Road transport is also a source of so-called non-exhaust emissions, resulting from shearing of particular elements of a vehicle, e.g. brakes, clutch, tyres, and wearing off the road surface, often carrying various trace metals (Cu, Zn, Ba, Sb, Mn). In Poland, transport emits Pb – 9.07, Cd – 0.04, Hg – 0.12, Cr – 3.42, Cu – 71.89, Ni – 0.54, Zn – 26.75 Mg per year. This represents from 0.4% of the total emission to the atmosphere for Cd to 38% for Cu (Poland's National Inventory Report 2022). Such pollutants are subject to wet and dry deposition by falling to the surface, and accumulate in soil. They can be a direct and indirect threat to living organisms, including human health, and even life (Ferreira et al., 2016; Li, 2018; Romanowa and Lovell, 2021).

Urban greenery, and particularly trees growing near high-traffic roads, are especially exposed to the harmful effect of transport pollutants (Tomašević et al., 2004, El-Amier and Alghanem, 2012; Ferreira et al., 2016; Li 2018; Greksa et al., 2019; Romanowa and Lovell, 2021). Trees in the urban environment fulfil an important function due to their ability to regulate temperature, release oxygen, and absorb pollutants (Tomašević et al., 2004; Greksa et al., 2019; Pataki et al., 2021). Due to the ability of trees to uptake trace elements, they are useful in phytoremediation of the environment in urban areas (Dadea et al., 2017; Greksa et al., 2019; Rahman et al., 2022), and in monitoring of urban environment pollution with toxic metals (Sawidis et al., 2011; Dadea et al., 2017; Yang et al., 2022). The concentration of trace elements in a plant frequently exceeds their content in soil, therefore the determination of their concentration in tree leaves can't be sole indicator of soil pollution by these elements. Uptake of toxic metals depends on the plant species and its ability to accumulate these elements from soil and air, but also on the content of the elements in soil, and soil properties determining the transformation of metals into mobile forms (Alahabadi et al., 2017). Therefore, the assessment of the state of the environment in urbanised areas also requires the determination of the content of toxic metals in soils. Many methods of determination of the state of soil pollution with trace elements are applied in practice. Depending on the applied method, soil is subject to the determination of total content of trace elements (X-ray fluorescence spectrometry method – XRF), content approximate to total – "pseudototal" (digestion with aqua regia), as well as content of forms with various mobility, i.e. availability for plants, determined by means of different extraction solutions, e.g. 0.1 mol dm^{-3} $NaNO_3$, 0.01 mol dm^{-3} $CaCl_2$), buffer ammonium acetate CH_3COONH_4 (pH 7 and 4.8), diluted acids (2.5% CH_3COOH, 1 mol dm^{-3} HCl), and complexing extractants (0.05 mol dm^{-3} EDTA and 0.005 mol dm^{-3} DTPA) (Sabienë and Brazauskienë 2004, Soriano-Disla et al. 2010, Ivezić et al. 2013, Lima et al. 2016). Assessments of the state of soil pollution with toxic metals are frequently based on their total or pseudototal content. Such forms of metals, however, show a weak correlation with plant indices, eg. content in plant biomass or uptake by plants. Therefore, the assessment of the ecological safety of areas should employ methods permitting the extraction of mobile forms of trace elements from soil (Kashem et al., 2007; Rutkowska et al., 2010; Dmochowski and Dmochowska, 2011; Korzeniowska and Stanisławska-Glubiak, 2017; van der Ent et al., 2019).

In recent years, many studies have been conducted on the impact of transport on the content of toxic metals in soils and roadside plants in Poland. However, there is a little information on the impact of transport on the environment in large cities such as Warsaw (Dzikuć et al, 2017; Komorowski and Szulc, 2017; Popek et al., 2017; Różański et al., 2017; Kajka and Rutkowska, 2018; Wieczorek et al., 2020; Korzeniowska, 2022).

In this paper, we tested three hypotheses on how transport affects environmental pollution with trace elements in urban areas. First, we hypothesize that transport is a source of soil contamination with trace elements in urban areas. Second, we hypothesize that the content of trace elements in the leaves of roadside trees can be useful in assessing the impact of pollution from transport on the environment. Third, we hypothesize that the assessment of toxic metals pollution of soils is more efficient by means of 1 mol dm^{-3} HCl than determination of total forms.

To test this hypotheses we have conducted research (1) to asses soil pollution with trace elements along a high-traffic transport route, (2) to determine of the content of trace elements in leaves of roadside trees and (3) to compare of the usefulness of aqua regia with 1 mol dm^{-3} HCl and 0.01 mol dm^{-3} $CaCl_2$ for extraction of phytoavailable forms of Cd, Cu, Cr, Ni, Pb, and Zn from urban soil.

2. Materials and methods

The study covered a selected section of the Aleja Komisji Edukacji Narodowej Street in Warsaw. Aleja KEN is the main street of Warsaw's Ursynów district. Its length is 5.5 km, and the average daily motor-vehicle traffic is 36 079 vehicles per day (Website 2).

Five measurement points were designated along the street (Fig. 1), subject to sampling of soil and tree leaves. Points P1 (52°09'06.0"N 21°02'29.9"E), P2 (N 52°08'59.5"; E 21°02'41.2"E), P3 (52°09'07.0"N 21°02'31.5"E) were located in the direct vicinity of the road, and points P4 (52°09'07.4"N 21°02'33.7"E) and P5 (N

Fig. 1. Distribution of measurement points (Website 1)

52°09’08.0”; E 21°02’32.2”) at a distance of approximately 50 m from the edge of the road. Measurement points were located in the zone where gas and dust pollutants originating from transport accumulate (Gupta, 2020; She et al., 2022). Trees growing in particular measurement points included: P1 – Norway maple (*Acer platanoides* L.), P2 – silver birch (*Betula pendula Roth*), P3 – small-leaved lime (*Tilia cordata Mill.*), P4 – English oak (*Quercus robur* L.) P5 – Swedish whitebeam (*Sorbus intermedia*). The soil and leaves samples were collected in mid-August 2022. Weather conditions are presented in Figure 2.

Soil samples were collected from the 0–25 cm soil layer. The three soil samples were taken from each measurement point. Soil was sampled within the range of the tree crown, but at a distance of approximately 15 cm from the trunk. Then, the soil was air dried, ground in a porcelain mortar, and sieved through 2 mm mesh. The resulting soil samples were subject to the determination of the following: grain size composition by means of the laser diffraction method (ISO 13320:2020), pH in a solution of 1 mol dm^{-3} KCl by means of the potentiometric method (ISO 10390:2021), organic carbon content (Corg.) by means of the dry combustion method (ISO 10694:1995), content of trace elements (Cd, Cu, Cr, Ni, Pb, Zn) after extraction in aqua regia – HNO_3:HCl/1:3 (ISO 11466:1995), after extraction in a solution of 1 mol dm^{-3} HCl (Rinkis, 1963), and after extraction in 0.01 mol dm^{-3} $CaCl_2$ (Houba et al., 2000). Concentration of metals in the resulting extracts was determined by means of the Atomic Absorption Spectroscopy (AAS) method. The analysed soil have different texture (sandy clay loam to silt), on pH 6.25 to 7.11 and Corg. content from 18.5 to 41.5 g kg^{-1}. The basic soil properties are presented in Table 1.

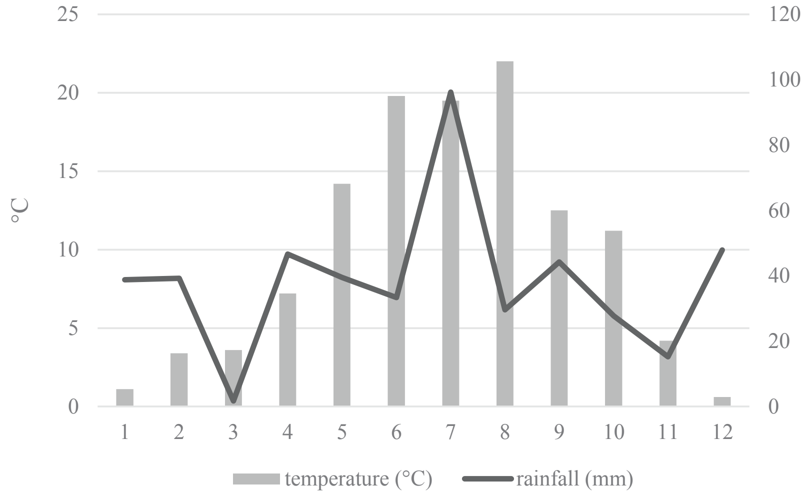


Fig. 2. Temperatures and rainfall in Warsaw at 2022

Samples of fully developed leaves were collected from a height of 1.5–2.0 m above ground. Leaf samples were collected from three trees of each species. Ten leaves were sampled for the analyses from each tree. All the trees were about 25–30 years old and 6–8 meters tall. The leaves were first washed with tap water, and then rinsed with deionised water, dried at a temperature of 60°C, ground, and again dried at a temperature of 105°C to solid mass. After wet mineralisation in a mixture of acids HNO_3 and $HClO_4$ (4:1), concentration of trace elements in plant material was determined by means of the AAS method. The

Table 1
Selected soil properties in measurement points

Tree/ measuerment point		sand (%)	silt	clay	soil texture	pH_{KCl}	Corg. (g kg^{-1})
Norway maple	P1	32	61	7	silt loam	6.85	21.6
	P1	66	13	21	sandy clay loam	6.79	27.9
	P1	72	5	23	sandy clay loam	6.43	24.2
Silver birch	P2	49	20	31	sandy clay loam	6.61	19.6
	P2	44	25	31	clay loam	6.25	22.5
	P2	32	60	8	silt loam	6.94	25.3
Small-Leaved Lime	P3	21	64	15	silt loam	7.11	41.5
	P3	28	66	6	silt loam	7.05	32.2
	P3	53	17	30	sandy clay loam	6.66	36.2
Pedunculate oak	P4	59	4	37	sandy clay	7.48	30.8
	P4	47	11	42	sandy clay	7.22	36.5
	P4	13	83	4	silt	7.04	40.2
Swedish whitebeam	P5	42	22	36	clay loam	6.29	22.6
	P5	34	57	9	silt loam	7.04	30.5
	P5	26	40	34	clay loam	6.27	18.5

detection limit of AAS method for trace elements content in soil and plants material is: Cd – 1.0; Cu – 1.0; Cr – 1.0; Ni – 2.0; Pb – 9.0; Zn – 1.0 µg dm^{-3}.

Results of chemical analyses were subject to statistical processing with the application of the analysis of variance (ANOVA) and simple linear regression analysis with Statistica 10 software. The assessment of differences between averages employed a Tukey test, at a significance level of $p < 0.05$.

3. Results and discussion

Content of trace elements in soil was variable depending on the applied extraction solution and place of soil sampling for analyses (Table 2). The highest amounts of the studied metals were determined after extraction with aqua regia, and the lowest after extraction with 0.01 mol dm^{-3} $CaCl_2$. Irrespective of the applied extraction solution, zinc showed the highest concentrations in soil, and cadmium the lowest (Table 2).

In terms of decreasing concentration of the studied elements in soil, they can be arranged as follows: Zn > Pb > Cu > Cr > Ni > Cd. Approximate amounts of total amounts of forms of trace elements in soils in the vicinity of transport routes in Warsaw and those extracted with 1 mol dm^{-3} HCl were obtained by Komorowski and Szulc (2017). Irrespective of the applied extraction method, the lowest amounts of trace elements were usually determined in measurement points 4 and 5. They were points at the greatest distance (approximately 50 m) from the edge of the road (Fig. 1). Kajka and Rutkowska (2018) investigating the content of trace elements in soil along the Jana Rodowicza "Anody" Street in Warsaw also evidenced that content of Zn Cu, Cd, Ni, and Pb at a distance of 60 m from the edge of the road was more than twice lower than at its edge, and at a distance of 300 m it was even seven times lower in the case of Pb. Accumulation of heavy metals in soils in the vicinity of roads is related to among others emission of pollutants from transport. Gas and dust pollutants originating from transport primarily accumulate in the zone of up to 50 m from the road, and their range usually ends at a distance of more than 150 m. Depending on the physiographic and meteorological conditions, however, the effect of such pollutants can reach even 500 m (Gupta, 2020; She et al., 2022).

The analysis of content of metals extracted by means of aqua regia showed no exceedance of the acceptable value for soils in urbanised areas in any of the measurement points (Regulation of the Minister of the Environment, 2016). Lack of pollution of soils with toxic metals in the vicinity of the main exit roads from Warsaw is suggested in research of Komorowski and Szulc (2017). Różański et al. (2018) investigating content of toxic metals in playgrounds in Warsaw also evidenced that total contents of Pb, Cu, Zn, Ni, Cd, and Co in soil did not exceed the acceptable values.

Among the analysed extraction solutions, aqua regia has the greatest extraction strength, and calcium chloride the lowest (van der Ent 2019). 1 mol dm^{-3} HCl was used to extract from 43

Table 2
Content of heavy metals in the soil in mg kg^{-1} DM depending on the extraction method

Meaurement point	Cd	Zn	Cu	Ni	Cr	Pb
aqua regia						
P1	0.16ab	148.11b	14.06c	6.74b	8.36ab	22.56b
P2	0.19b	150.49b	14.80c	4.63a	8.12ab	27.74b
P3	0.19b	117.26b	12.65c	4.98a	8.17ab	21.32b
P4	0.11a	173.15c	9.21b	6.83b	9.62b	21.25b
P5	0.17ab	41.46a	6.07a	4.39a	7.44a	12.41a
$^{x)}$permissible level	2	500	200	150	200	200
1 mol dm^{-3} HCl						
P1	0.14b	36.63c	7.07b	1.74b	0.74ab	19.98b
P2	0.13b	30.49bc	7.78b	1.14ab	0.73ab	23.36b
P3	0.12b	30.20b	6.55b	1.09ab	0.75ab	17.03ab
P4	0.07a	27.94b	2.92a	1.68ab	0.85b	15.49ab
P5	0.07a	9.35a	1.91a	0.73a	0.71a	8.97a
0.01 mol dm^{-3} $CaCl_2$						
P1	0.04b	0.14b	0.07ab	bd	0.02a	bd
P2	0.02ab	0.35c	0.09b	0.07b	0.02a	0.11c
P3	0.01a	0.07a	0.04ab	0.03ab	0.02a	0.07b
P4	0.01a	bd	0.04ab	0.01a	bd	0.10c
P5	0.01a	0.10ab	0.03a	0.06b	bd	0.02a

$^{X)}$ – permissible level according to Regulation of the Minister of the Environment (2016); bd – below limit of detection; a, b, c – different letters in columns indicate significant difference between means at $p < 0.05$

to 90% of the total form of Cd and from 72 to 89% of Pb. In the case of copper, the value varied from 31 to 50% of total content, and for Zn and Ni from 16 to 25%. For Cr, 1 mol dm^{-3} HCl was used to extract only 9% of total content (Fig. 3). Komorowski and Szulc (2017) also extracted from 5% of Zn to 96% of total content of Cu in soils along transport routes in Warsaw. Wierzbowska et al. (2018) similarly used 1 mol dm^{-3} HCl to extract approximately 60% of Pb, 50% of Cu, and several to a dozen percent of Ni and Cr in comparison to the total content of these metals in soil. The lowest content of investigated elements in soil was determined after extraction in 0.01 mol dm^{-3} $CaCl_2$. The average content of Cd, Cu, Cr, Ni, and Pb for all measurement points did not exceed 0.1 mg kg^{-1}, and for Zn it equalled 0.17 mg kg^{-1} (Table 2). It should also be emphasised that in the case of Zn, in measurement point P4, Ni and Pb in measurement point P1, and Cr in measurement point P4 and P5, the extracted content of $CaCl_2$ was at a level below the limit of detection by means of the AAS method. The amount of the studied metals extracted with calcium chloride constituted from 6.5 to 28% of Cd in comparison to the form extracted with aqua regia. In the case of the remaining metals, the value was below 1% in comparison to total content (Table 3). Research by other authors also confirms the considerably greater strength of extraction with 1 mol dm^{-3} HCl in comparison to 0.01 mol dm^{-3} $CaCl_2$ (Kashem, et al. 2007; Rutkowska et al., 2010; Gediga et al., 2015;Korzeniowska and Stanisławska-Glubiak, 2017). Extraction solutions based on neutral salts, e.g. $CaCl_2$ release metals from exchangeable forms, i.e. those considered bioavailable, to the solution. Acid-based extracts, e.g. 1 mol dm^{-3} HCl, permit the determination of "pseudo-total" content of metals in soil through dissolution of oxides, hydroxides, carbonates, and organic matter (Kashem et al., 2007; Van der Ent et al., 2019). 1 mol dm^{-3} HCl solution is used for the determination of total non-residual and part of residual fraction of trace elements, resulting in the overestimation of their bioavailability, because the residual fraction is not available for plants (Kashem et al., 2007).

By accumulating trace elements both in leaves and bark, trees as perennial plants accurately reflect the effects of pollution of both soil and the atmosphere, and are used as bioindicators of environmental pollution in urban areas (Tomašević et al., 2004; Sawidis et al., 2011; Dadea et al., 2017; El-Amier and Alghanem, 2018; Greksa et al., 2019). The studied tree species accumulated zinc in the greatest amounts (from 18 to 138.5 mg kg^{-1} DM), and cadmium in the lowest (0.05–0.20 mg kg^{-1} DM) (Table 4). The content of particular metals in leaves of the studied tree species can be arranged in the following order: Zn > Cu > Cr > Pb > Ni > Cd. The comparison of the content of trace elements in leaves of particular tree species determined in the study showed no exceedance of contents considered critical for plant growth (Table 5).

Table 5
Normal and critical concentrations of trace elements (mg kg^{-1} DM) in plants (Kabata-Pendias, 2010)

Element	Normal	Critical for growth	Toxic concentration
Cd	<0.1–1	5–10	>10
Cu	3–15	15–20	>20
Pb	1–5	10–20	>20
Zn	15–150	150–200	>200
Ni	0.1–0.5	20–30	>30

Table 3
Share of extracted form of 0.01 mol dm^{-3} $CaCl_2$ to total content (extracted in aqua regia) of heavy metals in soil in particular measurement points

Measurement point	Cd	Zn	Cu	Ni	Cr	Pb
	%					
P1	27.96c	0.10a	0.48b	bd	0.24a	bd
P2	13.72b	0.24b	0.58c	1.56c	0.21a	0.41b
P3	6.43a	0.06a	0.34a	0.51b	0.18a	0.32a
P4	12.78b	bd	0.48b	0.17a	bd	0.49b
P5	7.75a	0.25b	0.52bc	1.52c	bd	0.17a

bd – below limit of detection; a, b, c – different letters in columns indicate significant difference between means at $p < 0.05$

Table 4
Content of trace elements in tree leaves in mg kg^{-1} DM

Measurement point – tree species	Cd	Zn	Cu	Ni	Cr	Pb
P1 Norway maple	0.16bc	22.50a	13.50b	2.01a	4.50ab	3.25ab
P2 Silver birch	0.17bc	138.50b	12.07ab	3.02b	3.05a	3.85b
P3 Small-Leaved Lime	0.20c	28.00a	10.67ab	2.00a	3.50ab	2.26a
P4 Pedunculate oak	0.15b	25.50a	12.00ab	2.99b	4.00ab	3.16ab
P5 Swedish whitebeam	0.05a	18.00a	9.00a	1.98a	5.03b	1.96a

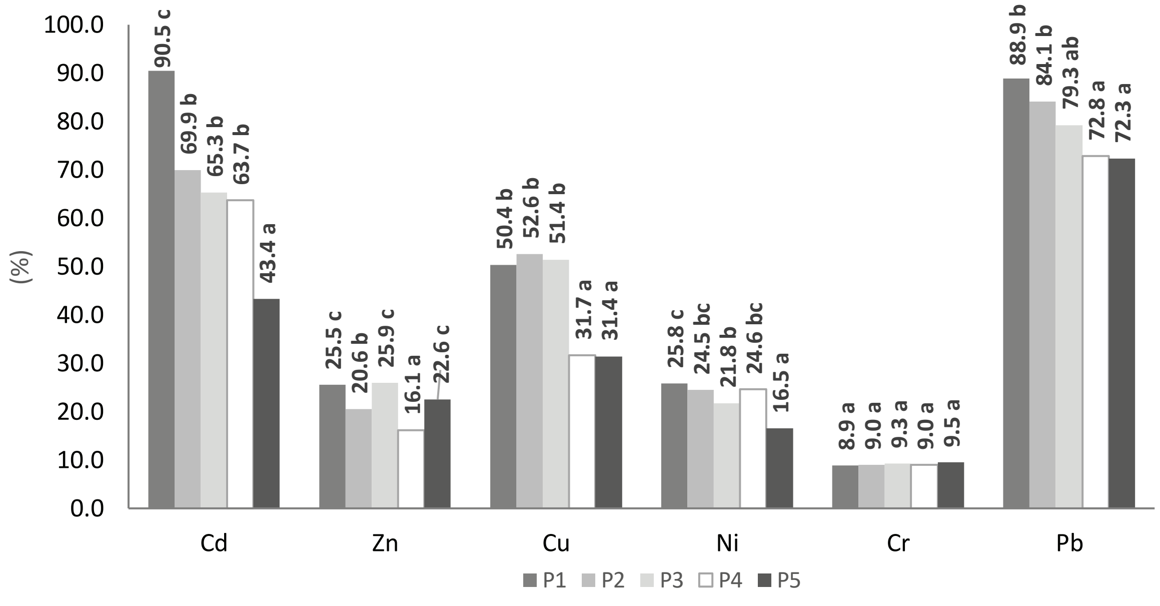
a, b, c – different letters in columns indicate significant difference between means at $p < 0.05$

Accumulation of trace elements by plants confirms their presence in mobile forms in the soil. Many plants, however, accumulate trace elements in their above-ground parts in amounts multiple times larger than those contained in the soil solution. It is therefore sometimes difficult to distinguish amounts of metals sampled from soil from the amount of metals deposited on leaves (Antoniadis et al., 2017).

In the study, the analysed leaves were washed with distilled water for the purpose of elimination of the effect of pollutants deposited on tree leaves. As evidenced in previous research (Fidos, 2022), dusts deposited on the surface of leaves can be an important source of toxic metals. The content of trace elements in leaves washed in distilled water was from several (for Zn and Cu) to more than 70% (Cd) lower than in leaves not subject to washing.

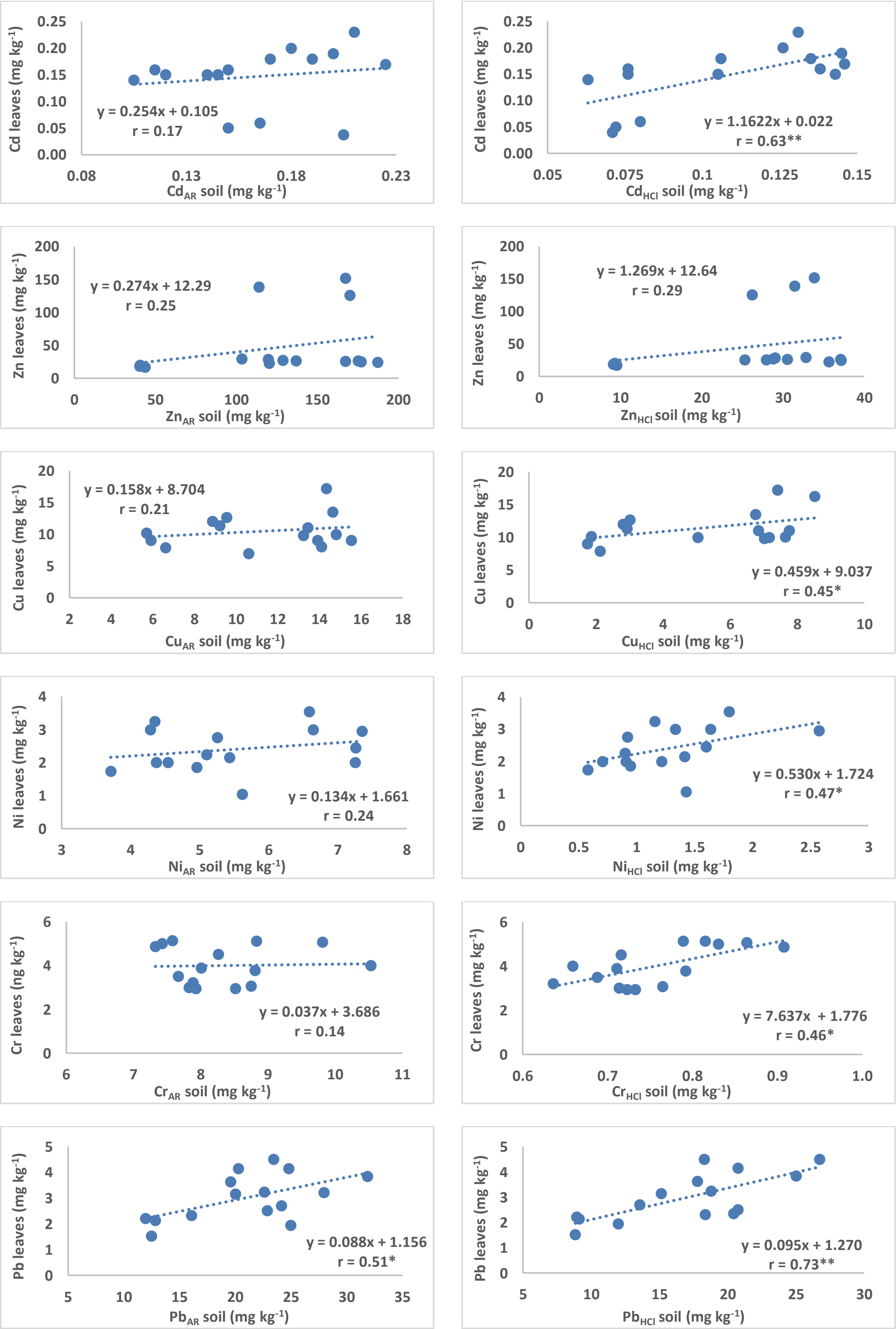
Content of trace elements in leaves was variable in particular tree species (Table 4). The greatest contents of the analysed elements were usually recorded in leaves of silver birch, and the lowest in leaves of Swedish whitebeam. Silver birch was characterised by the highest content of Zn (138.5 mg kg^{-1} DM) in leaves among all the analysed species. It was almost eight times higher than content of the element in leaves of Swedish whitebeam that accumulated the lowest amounts of the studied metals (Table 4) The reason for the low content of heavy metals in the leaves of Swedish whitebeam may be greater distance from the road (50 m). However, according to Gupta (2020) and She et al. (2022) this is the area affected by the greatest impact of traffic pollution. *Betula pendula* is not mentioned as a hyperaccumulator, although it shows exceptional affinity to Zn, considerably higher than other plant species. Higher than average Zn content in leaves and their usefulness for phytoremediation of polluted soils was observed in six analysed birch species (Dmuchowski et al., 2012, 2014). According to Greksa et al. (2019), English oak also shows high ability to uptake and accumulate Zn, and silver lime Pb.

Content of the analysed metals in tree leaves increased with their content in soil (Fig. 4). Content of metals in leaves was correlated stronger with content of metals extracted with 1 mol dm^{-3} HCl than with total (extracted with aqua regia) content of these elements in soil. The strongest correlation between content in leaves and content in soil was recorded for lead. Content of the element in leaves was significantly correlated both with the total form (r = 0.51) and that extracted with 1 mol dm^{-3} HCl (r = 0.73). Content of cadmium in tree leaves was also strongly positively correlated with Cd content extracted with 1 mol dm^{-3} HCl (r = 0.63). No significant correlation was detected between Zn content in tree leaves and soil, either in the case of total content (r = 0.25) or that extracted with 1 mol dm^{-3} HCl (r = 0.29) (Fig. 3). The study involved no analysis of the correlation between the content of the analysed metals in tree leaves and soil extracted by 0.01 mol dm^{-3} Ca Cl_2, because in many cases the content in soil was at a level below limit of detection by means of the AAS method (Table 2). Research by other authors also points to a stronger correlation between content of metals in soil and their amount extracted with extraction solutions weaker than aqua regia, e.g. 0.01 mol dm^{-3} $CaCl_2$ (Kashem et al. 2007; Menzies et al., 2007; Soriano-Disla et al.; 2010; Korzeniowska and Stanisławska-Glubiak, 2017; Kumar et al. 2022). In Poland, the assessment of soil pollution with toxic metals employs their total content (Regulation of the Minister of the Environment 2016). The total metal analysis (HNO_3:$HClO_4$) included all non-residual metals as well as metals present in the silicate mineral matrix. The latter fraction (silicate bound) is not considered bioavailable (Kashem et al., 2007). Therefore,



a, b, c – different letters in columns indicate significant difference between means at $p < 0.05$

Fig. 3. Mean share of the extracted form of 1 mol dm^{-3} HCl in comparison to total content (extracted in aqua regia) of trace elements in soil in particular measurement points



* relationship significant at $p < 0.05$, **relationship significant at $p < 0.01$

Fig. 4. Correlation between content of trace elements in tree leaves and content of these elements in soil after extraction with aqua regia (AR) and 1 mol dm^{-3} HCl

total content of metals in soil is not a very useful indicator for the assessment of their phytoavailability in comparison with weaker extractants (Menzies et al., 2007). The application of the method employing 1 mol dm^{-3} HCl can also lead to the overestimation of the bioavailability of particular metals, because it is a strong extractant that dissolves all the non-residual and part of residual fraction (Kashem et al., 2007; Menzies et al., 2007; Kim et al., 2015;). According to analyses for the assessment of the state of pollution of soils with trace elements, it is better to use methods employing weaker extraction solutions that allow for the determination of forms of metals directly available for plants (Menzies et al., 2007; Kumar et al.. 2022; Kashem et al., 2007; Soriano-Disla, 2010).

4. Conclusions

Total content of analysed toxic metals in soil did not exceed values acceptable for urbanised areas. We can concluded that trees play an important role for the improvement of environmental quality in urban areas. They can absorb pollutants such as heavy metals from soil and air. Selected tree species can be used as an indicator for the state of the urban environment or to decrease the amount of specific pollutants. Content of trace elements in tree leaves points to variability between the ability of species to uptake these elements. In conducted research Silver birch is a species with the greatest ability to uptake trace elements, and Swedish whitebeam the smallest. Depending on the analysed element, the application of 1 mol dm^{-3} HCl permitted extraction of up to 90% of the total content from soil. A test employing 0.01 mol dm^{-3} $CaCl_2$ allowed for the determination of very small amounts of heavy metals in soils. Except for Cd and Ni, their share in total content was below 1%. This suggests that the assessment of the state of pollution of soils with trace elements should apply methods using weaker extraction solutions, because the amount of metals extracted by means of these methods correlates better with their content in plants than the amounts extracted with aqua regia.

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Akumulacja wybranych metali ciężkich w glebach i liściach drzew rosnących na terenach miejskich – studium przypadku

Słowa kluczowe

Metale ciężkie
Gleba
Drzewa
Środowisko miejskie

Streszczenie

Celem przeprowadzonych badań była (1) ocena zanieczyszczenia gleb metalami ciężkimi wzdłuż szlaku komunikacyjnego w jednej z dzielnic Warszawy (Ursynów) , (2) oznaczanie zawartości metali ciężkich w liściach drzew rosnących na poboczach wzdłuż Al. Komisji Edukacji Narodowej oraz (3) porównanie przydatności wody królewskiej z roztworem 1 mol dm^{-3} HCl i 0,01 mol dm^{-3} $CaCl_2$ do ekstrakcji fitodostępnych form Cd, Cu, Cr, Ni, Pb i Zn z miejskich próbek gleby. Analizie poddano zawartość metali ciężkich w glebie i liściach drzew rosnących wzdłuż jednego z głównych szlaków komunikacyjnych w Warszawie. Analiza sumarycznej zawartości badanych metali (Cd, Cu, Cd, Cr, Ni, Pb, Zn) nie wykazała przekroczeń wartości dopuszczalnych dla tych pierwiastków w glebie. Analizowane gatunki drzew charakteryzowały się zmienną zdolnością do wchłaniania metali ciężkich. Wykazano, że Brzoza brodawkowata (*Betula pendula* Roth) gromadzi zazwyczaj największe ilości badanych metali ciężkich, a w szczególności Zn. Najniższą zdolność akumulacji metali ciężkich w liściach wykazał Jarząb szwedzki (Sorbus intermedia). Korelacja między zawartością metali w liściach badanych gatunków drzew i próbkach gleb sugeruje, że ocena zanieczyszczenia środowiska metalami ciężkimi gleby jest wydajniejsza przy użyciu do oznaczeń roztworu 1 mol dm^{-3} HCl, niż oznaczanie form całkowitych. Wykazano także, że drzewa mogą służyć do oceny stanu zanieczyszczenia środowiska metalami ciężkimi.