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Relationships Between Heavy Metal Concentrations in Japanese Knotweed (*Reynoutria Japonica* Houtt.) Tissues and Soil in Urban Parks in Southern Poland

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Abstract. This study focuses on the concentrations of trace elements and macroelements in soils, leaves, stems, rhizome and seed of *Reynoutria japonica* in 5 urban parks with different levels of disturbance (high, medium, low). The sampling locations within each park were chosen along river banks or forest edges. The soil samples were taken only in the humus horizon which averaged about 15 cm in thickness. Concentrations of Ca, Mg, K, Na, Fe, Al, Zn, Cd, Pb, P, S, Cr, Cu and Ni in plant material and soil were analyzed. The orders of average heavy-metal abundances found are Zn>Cu>Pb>Cr>Ni>Cd in leaves and Zn>Cu>Pb>Ni>Cr>Cd in a park soils showing a high levels of disturbance. In cases of low disturbance levels, the orders of average abundances for leaves are Zn>Cu>Cd>Ni>Pb>Cr and, for soil, Zn>Cr>Ni>Pb>Cu>Cd. The highest enrichments noted for Zn in topsoil was about 581.2 mg/kg in soil and, in leaves, 594 mg/kg. On all of the sites, both in the case of soil and plant materials, Zn was a dominant element and its concentration ranged from 44.6 to 581.2 mg/kg in soils and from 38.6 to 541.7, leafs (38-594 mg/kg), stems (115.8 -178.4mg/kg). The lowest concentrations of Cd (0.14-0.21 mg/kg, Cu (5.9-6.9 mg/kg) and Ni (4.6-14.5 mg/kg) in soil were observed in a parks with low levels of disturbance. Similar patterns of regularity were also observed in leaves, stems and rhizome. Different concentrations of metals in each park result from the degree of diversity of the parent rocks on which soil was formed. In the case of soil material transported from elsewhere, the concentrations of heavy metals are higher than in soils formed from local rocks. In a park located near a road, the concentrations of metals found also reflect traffic emissions and other sources of pollution. The results showed that *R. japonica* has a high capability to accumulate heavy metals. The stems contain more accumulated Zn than leaves, seed and rhizome.

1. Introduction

Rapid economic growth and a large expansion in urban population may lead to changes in arable land, meadows, forest surfaces and the emergence of an expanding urban area. Rapid urbanization is usually accompanied by undesirable environmental problems, such as a drastic reduction in greenery and deterioration of the environment. Every year, the number of people living in urban areas increases by about 1.96%, compared to 0.11% in rural areas [1]. Urban parks are often created in areas changed by human activity, and on artificial (anthropogenic) substrates formed from rocks of various origins, from different geological periods and of diversified chemical composition [2]. Such are often colonized by



Reynoutria japonica, an alien species in Europe. This species can colonize any area with sufficient light availability and displaces native species [3]. In this way, it can affect soil features and distort the biogeochemical cycles of elements [4,5] including heavy metals. In this way, this species takes part in the distribution of metals. In recently times, special attention has been focused on the role of alien species with high biological production and vigorous growth [6,7] which have ability to change soil fertility and has influence soil-biotic functioning during the succession of ecosystems. Invasion of geographically-alien plant species may not only have an impact on the chemical properties of soils but also on the different processes that take place in an ecosystem. One of the alien plant species which may lead to significant changes in bioceonoses and the pedosphere is *Reynoutria japonica* [7].

Soils forming and developing in urban areas are anthropogenic soils that have been produced because of intense economic activity of humans. Their development is related, *inter alia*, to geo-mechanical, municipal- and chemical transformations which lead, to various degrees, to the destruction of the primary soil horizons and profile [8,9,10,11,12]. Despite their non-natural character, these are substrates for the encroaching or incoming species. Only a limited number of publications have dealt with the relation of metal concentrations in the plant-soil system of anthropogenic soils and the participation of Japanese knotweed. This study focuses on the concentrations of trace elements and macroelements in soils, leaves, stems, rhizome and seeds of *Reynoutria japonica* growing in urban parks differing significantly in the level of their anthropogenic transformation

2. Material and methods

2.1. Study areas

The research was carried out in 5 city parks, in southern Poland as outlined in table 1. These parks differ in terms of their degree of disturbance which is related, in part, to their place of origin. Parks such as the Zielona Park (PZiel-4) and the Góra Zamkowa Park (GZamk-5) are distinguished by their low level of disturbance, having been created in areas where the soil cover was not significantly changed; they were formed on natural ground.

Table 1. Features of parks studied

Site Name	Disturbance Level	Types of park and site attributes			Site coordinates
		habitat	soil	Vegetation	
PGrab-1	high	Heavy artificial surface formed with ground material of variable grain size, with a high proportion of fine-grained material	Technic Regosol, Technic Anthrosol	Dense single-species patches of <i>Reynoutria japonica</i> , and vigorous specimens	50°18'41.08"N 19°04'00.55"E
PSro-2	high	Garden plot the edge of the park comprising dumped organic topsoil material	Hortic Anthrosol Technic Anthrosol		50°17'54.32"N 19°08'45.67"E
PSiel-3	medium	Zone adjoining a regulated river flowing through the park, with concreted river bank	Fluvic Cambisol Cambisol	Forming a hedge along the river	50°17'01.29"N 19°08'25.89"E
PZiel-4	low	Zone adjoining the river bed and the edge of a hornbeam forest. Both areas protected by law	Fluvic Endogleic Cambisol	<i>R. japonica</i> with a high proportion of ruderal- and nitrophilous plants forming dense patches	50°20'36.36"N 19°11'07.27"E
GZamk-5	low	Edge of a mixed forest with domination of hornbeam, linden, maple, creat broad-leaved forest	Haplic Cambisol Brown Rendzinas		50°19'42.10"N 19°08'02.49"E

In contrast, Park Grabek (PGrab-1) was established on grassland, and the whole area of the park was thoroughly rebuilt using, in part, transferred soil-like material and decorated; for this reason, it is deemed here to be a park characterized by a high level of disturbance. Another with a high level of disturbance is Środula Park (PSro-2) established as part of the revitalization of post-mining sites through the liquidation of slag heaps. About a million cubic meters of material was used in its construction. A medium level of disturbance is exemplified by Park Sielecki (PSiel-4; table 1) where natural ecological processes are observed, e.g., the return of typical forest species, commonly in river valleys.

2.2. Soil and plant sampling

Soil samples for chemical analyses were taken only in the humus horizon (A) which averaged ca 15 cm in thickness and represents the main rooting zone of *R. japonica*.

In the laboratory, air-dried samples were sieved (<2 mm) and analyzed, following the standard procedures of Bednarek et al. [13], namely, pH measured potentiometrically in H₂O and in 1N KCl using a glass electrode, total organic C (%) according to Tiurin's method, total N content (%) using the Kjeldahl method, CaCO₃ using the Scheibler method and hydrolithic acidity (H_h) according to the Kappen method [13].

Leaves, stems, seeds and rhizome of *F. japonica* were sampled at the end of the vegetation season in late September and early October. Latex gloves were used to allow for isolation of the sampled plant material from human skin. The preliminary preparation of the samples for analyses involved washing of the plant material with distilled water, drying at room temperature and at 105°C followed by homogenization. Sampling and preparation procedures followed the instructions given by MacNaeidhe [14] and Markert [15]. Concentrations of Ca, Mg, K, Na, Fe, Al, Zn, Cd, Pb, P, S, Cr, Cu and Ni in plant material and soil were measured using ICP-OES – Inductively Coupled Plasma Optical Emission Spectrometry after a wet mineralization in nitrohydrochloric acid (3HCl+HNO₃).

All plant and soil samples were analysed in triplicate for all the properties being investigated. The Spearman correlation rank was applied to check whether there is any relationship between the concentrations of heavy metals in the *R. japonica* plant tissues and in the soil samples.

3. Results and discussion

3.1. Chemical properties of soils in the parks and level of disturbance

The thickness of the humus horizons ranged from 7-15 cm. These horizons were generally characterized by medium- and fine-grained fractions commonly mixed with clay-silty materials. The highest concentration of organic carbon (C_{org}) was recorded on the site with a high degree of disturbance (PGrab-1; 8.18%) and the lowest at the PZiel-4 site (0.53%) with a low level of disturbance (table 2). A similar pattern is seen in the case of total nitrogen (N_t); the correlation coefficient between C_{org} and N_t is 0.58. The narrow ratio of C/N of anthropogenic systems does not reflect the modification of biological processes related to organic carbon transformation or their rates but may reflect previously transformed river-transported organic material of external origin (ex situ).

The C_{org} and N_t content in soils under a dense canopy of *R. japonica* is very uneven, mainly because of the deposition of external material of a mineral character in the case of sites located within town borders or of organic sediments from flooding waters or arable fields. The latter occurs on sites located on less disturbed land, outside urban areas [7].

There is a distinct similarity in CaCO₃ content between the one highly-disturbed site (PGrab-1; 1.45% CaCO₃) and GZamk-5 (1.60%) with low disturbance. In the former, this is related to the construction of cement pavements and, in the latter, to the geological structure. The carbonate determines the nature of the reaction (pH) and affects the biological processes that take place in the soil. These processes determine the course and rate of development of ecosystems in both anthropogenic systems and natural ecological systems.

The chemical properties of soils developing under *R. japonica* canopies are very diverse and their pH levels very wide; in the investigated sites, they range from 4.5-7.6 (in H₂O) to 4.9-7.1 (in KCl). Similar pH values (4.5-7.4) were recorded by Rahmonov et al. [7]. In a comparable case in Belgium, the soil pH under *R. japonica* varied from 4.4-7.3 [16].

Table 2. Some proprieties of soil under a canopy of *Reynoutria japonica*.

Site Name	Disturbance Level	Soil horizon	Corg	Nt	CaCO ₃	C/N	Hh	pH	
								H ₂ O	KCl
				[%]			[cmol(+)/kg]		
PGrab-1	high	OA (10 cm)	8.18	0.230	1.45	36	1.40	7.6	7.1
PSro-2	high	A (15 cm)	2.87	0.210	0.25	14	5.74	6.7	6.1
PSiel-3	medium	AC (13 cm)	1.38	0.140	0.34	10	1.29	6.8	6.1
PZiel-4	low	A (8 cm)	3.81	0.334	0.00	11	1.66	5.5	4.9
		AB (7 cm)	0.53	0.060	0.03	9	5.69	6.4	6.0
GZamk-5	low	OA (10 cm)	2.63	0.192	1.60	14	5.07	7.1	7.0

The total compositions of macroelements clearly differ between individual sites (table 3). The highest concentrations of Al (2210 mg/kg), Ca (20600 mg/kg), Mg (7100 mg/kg), K (2100 mg/kg), Na (445 mg/kg) and S (700 mg/kg) occur in the PGrab-1 site with high-level disturbance. On poorly developed humus horizons (AC), sodium (Na-50 mg/kg) levels are small. High concentrations of Fe (22000 mg/kg), Mg (2800 mg/kg) and K (2900 mg/kg) were recorded at the PZiel-4 site in a mixed horizon (AB) of brown soil (Cambisol).

The highest contents of phosphorus (700 mg/kg) and sulfur (300 mg/kg) are associated with high levels of disturbance at the PGrab-1 and PSro-2 sites. A positive correlation (0.664) between the concentrations of Corg and P is indicative of an organic phosphorus origin. On our study sites, the P contents are related to the anthropogenic character of the deposits. A similar explanation for observed P contents was given by Barney et al. [17]. Nitrogen and sulfur also show a correlation, but weaker (0.49).

Table 3. Total contents of some macroelements in the topsoil.

Site Name	Soil horizon	P	S	Na	Al	Ca	Fe	K	Mg
PGrab-1	OA (10 cm)	700	700	445	22100	20600	4590	2100	7100
PSro-2	A (15 cm)	700	300	63	4300	1800	6600	500	500
PSiel-3	AC (13 cm)	500	200	88	17000	500	20900	2800	2400
PZiel-4	A (8 cm)	400	300	58	14700	900	15400	2400	2300
	AB (7 cm)	200	100	60	19700	700	22000	2900	2800
GZamk-5	OA (10 cm)	400	200	50	6400	2400	7700	900	1200

The occurrence of the various elements discussed is not uncommon in anthropogenic soils. They can derive from the remains of organic matter of animal- or plant origin, and pollution from wet- and dry deposition.

The important source of pollution in city parks is water. Surface waters flowing from surrounding roads and arable areas also affect the composition of the river water through the transport of detergents and increases in phosphorus and other microelements. These, after periods of flooding, are deposited on the river banks. Thus, the banks constitute a very fertile habitat for the vigorous growth of *R. japonica* which may accumulate a variety of different metals originating from elsewhere.

3.2. Element concentration in *R. japonica* leaves, stems, seeds and rhizome

The highest concentration of Corg (49.1%) and Nt (1.356%) in leaves characterizes site PZiel-4, a site of low disturbance compared to the others (table 4). The high contents of organic carbon and total nitrogen are an indication of the high degree of viability of this species despite its development in areas commonly contaminated with heavy metals [18,7]. The ranked order of elements in terms of their concentration in leaves and stems of *R. japonica* is as follow:

Site name	Leaves	Stems
PGrab-1	Ca>K>Mg>S>P>Fe>Al>Na	Ca>Mg>K>Fe>Al>P>S>Na
PSro-2	K>Ca>Mg>S>P>Fe>Al>Na	K>Ca>S>Fe>P>Mg>Na>Al.
PSiel-3	K>Ca>Na>Mg>S.P>Fe>Al	K>Fe>Ca>Na>Al>Mg>S>P>Na
PZiel-4	Ca>K>Mg>S>P>Al>Fe>Na	K>Ca>Fe>P>Mg>S>Al>Na
GZamk-5	Ca>Mg>K>S>P>Al>Fe>Na	

The highest contents of Ca in the leaves of *R. japonica* were registered in PGrab-1 (19620 mg/kg) with a high level of disturbance and in PZiel-4 (14200 mg/kg) and GZamk-5 (18520 mg/kg) with a low level. In the former, the large Ca content is associated with the use of cement, in the latter with the local geological structure. Significant contents of K occur in the leaves of the Japanese knotweed, the maximum content observed in PGrab-1 (11830) and PSiel-3 (15460 mg/kg). In three habitats with various levels (high and medium) of disturbance, K contents in stems ranging from 5420-16150 mg/kg (table 4) are higher than the contents of all other elements. A significant proportion of phosphorus occurs in leaves (1240-1720 mg/kg) and, to a lesser extent, in stems (378-580 mg/kg). The seeds of *R. japonica* accumulate significant amounts of Ca (1900 mg/kg), K (11750 mg/kg), P (6100 mg/kg) and S (2370 mg/kg), all essential components during germination.

Table 4. Total content of macroelement in tissues of *R. japonica*.

Site Name	Types of vegetation materials	[mg/kg]										[%]	
		Al	Fe	Ca	K	Na	Mg	P	S	Corg	Nt	C/N	
PGrab-1	leaves	240	266	19620	9200	75	5960	1430	2300	47.5	1.953	24	
	stems	480	5280	9820	5420	218	8245	378	350	47.8	1.452	33	
PSrod-2	leaves	270	312	1800	11830	107	3890	1720	2380	47.6	2.167	22	
	stems	50	651	4200	16150	129	360	580	730	47.5	0.323	147	
	seeds	20	62	1900	11750	49	2650	6100	2370	46.9	3.134	15	
PSiel-3	leaves	140	191	14900	15460	2719	2670	2100	2570	48.8	2.787	18	
	stems	570	6268	3500	8790	2272	520	350	410	47.8	0.362	132	
PZiel-4	leaves	280	205	14200	11790	75	2950	1240	1570	49.1	1.545	32	
	stems	180	592	3300	5430	98	445	480	280	47	1.433	33	
GZamk-5	leaves	220	137	18520	6270	86	6350	1250	1340	47.7	1.356	35	
	rhizome	770	517	7570	5270	164	1250	1600	1180	47.7	0.851	56	

Commonly, *R. japonica* colonizes habitats that are poor in nutrients. Thus, the decaying remains enrich soils in macro and microelements, contributing indirectly to their fertilization.

In Europe, according to Dassonville et al. [19], a wide range of nutrient content under covers of alien species is strictly related to initial habitat conditions, i.e., soil conditions pertaining below the anthropogenic layer of sediments and deposits [7]. The rhizomes of *R. japonica* may grow deep into the natural mineral horizons where they reach the alkaline elements and, in such a way, accelerate the biological processes in soil. In rhizome of this species, the macroelement contents from the sites studied ranked as follows: Ca>K>P>Mg>S>Al.>Fe>Na. The contents of P (1600 mg/kg) and S (1180 mg/kg) in rhizome are much greater than in soil (100-700 mg/kg; table 4).

Elements such Ca, Mg, K, Na, P and S are very mobile in the soil-vegetation systems [4]. Most species, including alien species, impact on the biogeochemical cycles of many micro- and macro elements. Thus, as suggested by Ehrenfeld [5], alien species may directly modify the contents of many elements in the soils after the decaying their remnants.

3.3. Comparison of heavy metal content in the soil-plant-soil system

The contents of heavy metals are diverse in the soils and in the plant tissues in the individual parks (table 5). Among the elements, Zn is clearly the most abundant (max. 581.2 mg/kg) in the soils everywhere except for the highly disturbed PSrod-2 site. Zn contents in leaves range from 38-594 mg/kg, and in stems from 115.8-178.4 mg/kg. Stems contain more Zn than leaves, seeds and rhizome. Zn contents in the soils vary with the lowest level recorded at the least disturbed site (GZamk-5; 44.6 mg/kg). The maximum Zn content recorded was 581.2 mg/kg (PSrod-2; table 4) is significantly lower than that (>2600 mg/kg) recorded in soils in, e.g., Wrocław [20]. The higher Zn content in the soil at the PSrod-2 site compared to the other sites may reflect metals from external materials and wastes dumped from a neighboring garden plot. The minimum Zn content (44.6 mg/kg; table 4) is higher than values (10.5 mg/kg) for Wrocław but lower than for Prague (min 54.7 mg/kg) given by Sołtysiak et al. [20].

Table 5. Contents of heavy metals in soil and in the leaves, stems, seeds and rhizome of *R. japonica*.

Site Name	Types of plant samples	Vegetation materials						Soil							
		Cd	Cr	Cu	Ni	Pb	Zn	Cd	Cr	Cu	Ni	Pb	Zn		
		[mg/kg]													
PGrab-1	leaves	0.33	1.06	7.41	0.79	4.9	55.2								
	stems	1.35	4.81	48.30	0.84	2.3	128	1.44	25.3	89.7	36.7	43.1	277.1		
PSrod-2	leaves	5.28	1.29	7.22	0.72	9.8	594								
	stems	2.34	0.47	11.03	0.66	0.8	178.4	6.75	8.7	25	5.4	178.1	581.2		
	seeds	0.38	0.35	11.07	1.58	0.7	70.2								
PSel-3	leaves	0.20	1.01	7.89	0.65	1.1	40.5	0.73	24.7	17.2	20.3	20.7	92.1		
	stems	1.24	5.40	56.38	4.19	13.2	115.8								
PZiel-4	leaves	2.17	1.56	5.15	1.64	2.1	75.8	0.21	25.6	6.9	14.5	12.3	51.4		
	stems	1.44	0.56	9.12	1.12	1.1	124								
GZamk-5	leaves	0.27	1.10	5.11	0.47	0.9	38.7	0.14	11.6	5.9	4.6	16.4	44.6		
	rhizome	0.40	1.72	8.58	1.21	3.3	37.6								

The Pb, Cu and Cr contents in the soils at the sites studied fall in the following ranges: Pb from 12.3 (PZiel-4) to 178.1 mg/kg (PSrod-2), Cr from 8.7 (PSrod-2) to 25.3 mg/kg (PGrab-1) and Cu from 6.9 (PZiel-4) to 89.7 mg/kg (PGrab-1). In most cases, the contents did not differ from the natural geochemical background and did not exceed the norms for Poland [21, 22, 23, 24].

Spearman's rank correlation coefficient relates the contents of heavy metals in vegetation material and soil. We found the following correlations: soil/leaves Cu (0.55), Ni (0.10), Cd (0.88), Pb (0.95) and Zn (0.88); soil/stems Ni (0.07), Cd (0.96), Pb (0.95) and Zn (0.91). Strong correlations characterize Zn, Cd and Pb. The plants have to uptake these metals because of their high concentrations in soil solutions. Considering its vigorous growth, these concentrations do not disturb the development of *Reynoutria japonica*.

4. Conclusions

The physical-chemical properties of soil under *Reynoutria japonica* were analyzed at sites that differed in their levels of disturbance. In the area with imported ground, the contents of heavy metal

are high because of the degree of human influence. In the park with low disturbance, the proportion of heavy metals is relatively low.

A positive relation between the concentrations of elements in the 'soil-plant' system is evident. The results of the work show that *R. japonica* can accumulate Zn, Cd and Pb – that it has a high capability to accumulate heavy metals. The stems contain more Zn than leaves, seeds and rhizome. This property of metal accumulation may be important in urban parks where many people spend time as *R. japonica* can potentially reduce any threat of contact with heavy metals. The degradation level of the environment does not impact on the colonization capacity of *R. japonica*. It can grow on sediments or soils with a wide pH range and can transform the physical-chemical conditions of soils.

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