FACTORS INFLUENCING THE CONCENTRATION OF HEAVY METALS IN SOILS OF ALLOTMENT GARDENS IN THE CITY OF WROCLAW, POLAND

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ABSTRACT

Small, family gardens, in Poland usually called allotment gardens, are a popular recreation place for town residents. Their additional function is cultivating vegetables and fruit. This paper analyses the total concentration of Cu, Pb and Zn in the soil of 180 allotment gardens in Wroclaw, one of the 5 biggest towns in Poland. The concentration of metals (12.5-659 mg Pb $\cdot$ kg^{-1}, 38.1-2103 mg Zn $\cdot$ kg^{-1} and 12.9-595 mg Cu $\cdot$ kg^{-1}) depends mainly on the nearby location of industrial pollution sources, but also varies with the amount of organic matter, pH and the content of plant-available macronutrients, suggesting a relationship between metal contamination and the intensity of organic or mineral fertilization and liming. Significantly higher metal concentrations have been measured in soils of allotment gardens arranged on formerly housing or industrial areas, as compared to gardens set up on arable land. Up to 35% of soils in the city zone are excessively contaminated, unsuitable for vegetable and fruit production, and require reclamation.

KEYWORDS: allotment gardens, heavy metals, soil contamination, organic matter, soil pH.

INTRODUCTION

Small, family or company-owned gardens, in Poland referred to as allotment gardens, are often used for amateur planting of vegetables and fruit, serving as recreation grounds for town residents, popular in several countries [1, 2]. Such gardens are widespread in all Polish towns, where individual allotments of 0.03-0.05 ha are grouped together into complexes of up to several dozens hectares of land. The overall number of allotment gardens in Poland is roughly estimated at 1 million, with the cumulative acreage of approx. 45 thousands hectares. The first allotment gardens in Poland were established over 100 years ago on arable land on the outskirts of towns. After World War 2, many new allotment gardens were set up on reclaimed industrial and mining land and on the grounds of destroyed town-centre housing areas, or closed-down parks and cemeteries [3]. Many of these were situated in the vicinity of principal communication lines, industrial facilities and power stations, in zones prone to air, soil and groundwater contamination. Similarly unfavourable location of in-town gardens can be seen in several European [4, 5] or American and Asian [6-9] metropolitan areas. Because of their function, gardens should be located in contamination-free areas. However, there have been repeated reports that heavy metal concentration levels in soils in these gardens are high enough to compromise the quality of vegetables and fruit being grown [10-12]. For the most part, reports from urbanized areas all over the world point out the elevated concentration of lead from traffic pollution [4], although there are also other contaminants like zinc and cadmium, and in a lesser degree copper, nickel and chromium from industrial sources [13, 14]. Unambiguous identification of the principal soil contaminant is often difficult as in urbanized areas emissions from several point, linear and areal pollution sources may overlap [6, 7].

In a number of allotment gardens in Poland soil contamination exceed the limits set out by the Polish Ministry of Environment [15]. Such gardens should be instantly excluded from use and soils should be reclaimed. Due to the risk of transfer of toxic substances to the food chain, in several Polish towns measurements are being carried out to monitor the heavy metal and PAH contamination of soils [16, 17, 8, 19]. The monitoring of soil contamination in allotment gardens in Wroclaw has been put in place since the 1970s [20]. To date, most of the bigger allotment complexes have already been analysed in terms of soil properties and contamination. This paper seeks to characterise the scope and the spatial distribution of soil contamination with selected trace elements (Pb, Zn and Cu), and to study the relationship between metal concentration and the fundamental properties of soils in selected allotment gardens in Wroclaw.

MATERIALS AND METHODS

Wroclaw is the capital of the Lower Silesia region in the south-west of Poland, and has a population of approx.

640 thousands on the area of 293 km^2. The town is located on Holocene alluvial sediments of the Odra river and its tributaries (the Bystrzyca, Ślęza, Oława and Widawa), and on moraine tills of the Vistula glaciation. In the soil cover of the town Cambisols, Gleysols and Fluvisols [21] prevail in river valleys and Cambisols, Luvisols and Phaeozems on moraine uplands surrounding the Odra River valley (Fig. 1). Wroclaw is located in the temperate climate zone, with mean annual temperature of 8.4^{o}C, mean sum of precipitation of 588 mm and the vegetation period lasting, on average, 234 days. Winds from the west directions (N, WNW, NWW) occur, on average, on 51% days in the year.

Today, the principal source of air contamination in the city is the municipal heat and power station (located in the town centre) and the traffic network, but still recently there have been significant emissions from several metal plants, machine-building and chemical works located in all districts. Among those, the non-ferrous metalworking plant in the south-west part of the town (Fig. 1) was a particularly massive emitter of dusts polluted with heavy metals (Cu, Zn, Pb, Cd and more).

Within the town limits there are over 21 thousands of allotment gardens grouped in several dozen complexes, with a total area of approx. 850 ha. For the purpose of the analysis, 180 soil samples have been used, collected from the depth of 0-20 cm in various locations all over the town, in numbers proportional to the number of allotment gardens in the area. Each analytic sample was made of three mixed primary samples from the same garden, collected from points spaced few meters apart.

As a standard, particle size distribution (by sieving and hydrometer method), organic carbon content (by oxidation with potassium dichromate), pH in distilled water (pH_{H2O}) and 1 $mol{\cdot}kg^{-1}$ KCl (pH_{KCl}) - potentiometrically, exchangeable basic cations (Ca, Mg, K, Na) – extracted with ammonium chloride at pH=8,2, and exchangeable acidity – extracted with 1 $mol{\cdot}kg^{-1}$ KCl were determined for each soil sample [22]. Based on the obtained results, the sum of basic cations (BC) and the base saturation (BS) were also calculated. Additionally, to characterise soil fertility, the content of plant-available forms of phosphorus (P_a), potassium (K_a) and magnesium (Mg_a) were analysed. Phos-

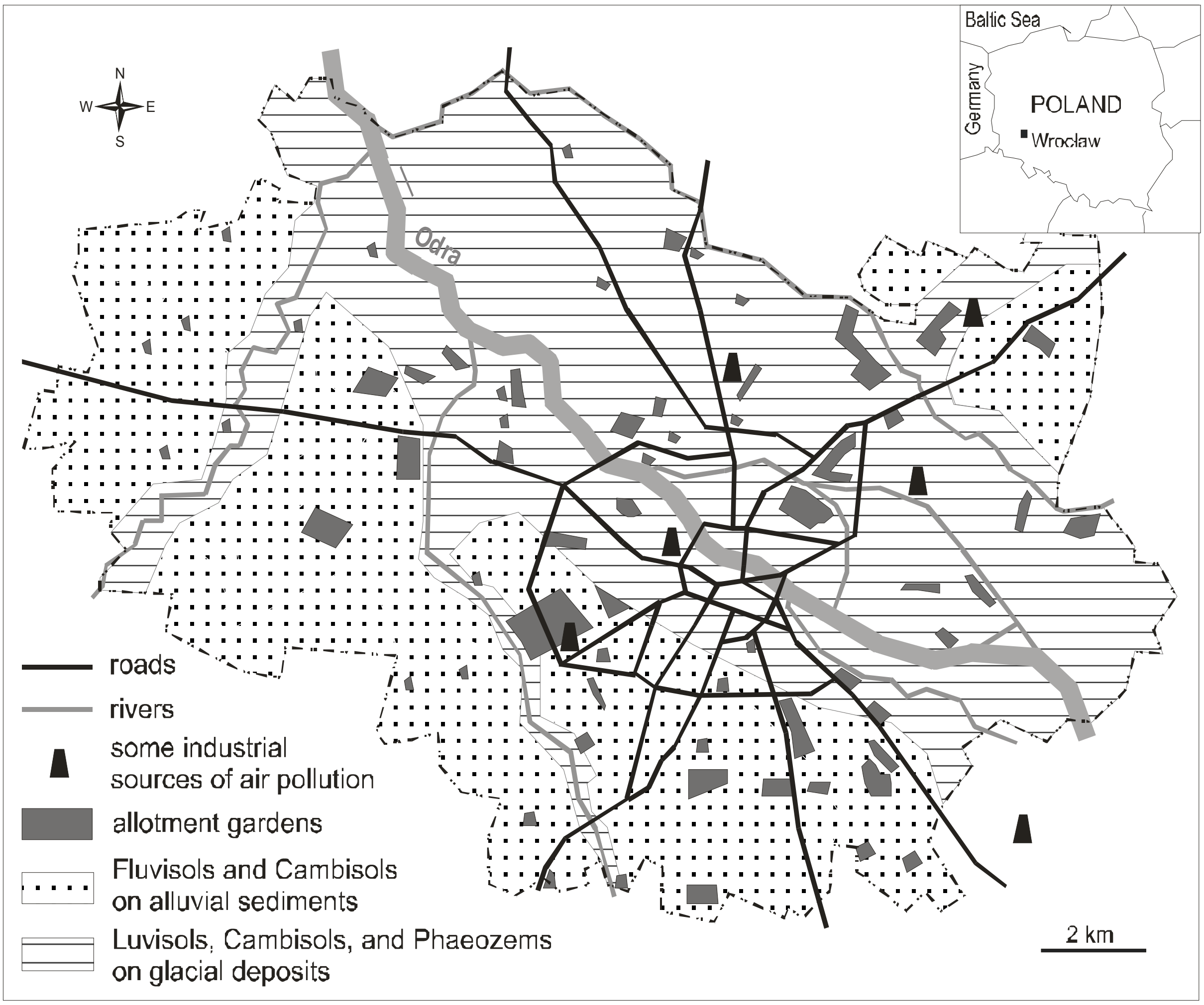

FIGURE 1 - Location of the allotment gardens in the Wroclaw city as related to kind of parent materials and soil typological units.

phorus and potassium were extracted using calcium lactate according to the Egner–Riehm method, while magnesium was extracted with calcium chloride, as per the method of Schatschabel [22].

The total contents of copper (Cu_t), zinc (Zn_t), and lead (Pb_t) were determined using the flame atomic absorption spectroscopy (FAAS), after the samples had been digested with 70% $HClO_4$. The quality of determination has been monitored using soil reference materials (SRM 2709, SRM 2711, RTH 912, RTH 953) with certified total ("aqua regia extractable") concentration of trace elements being analysed.

Statistical calculations (arithmetic and geometric mean, median, standard deviation, upper quartile, skewness, correlation coefficient and other) have been carried out using the Statistics 7 software (Stat Soft Inc., Tulsa, OK, USA).

RESULTS

The texture of soils in allotment gardens in Wroclaw is usually sandy loam (56% of samples), loam (10%), clay loam (3%) and loamy sand (31%), with the clay fraction content from 1 to 33% (5.5% on average). Soils with another texture (including sand, silty clay and silt) occur in less than 1% of samples. Soils with finer, loamy texture predominate in the southern part of the city, while in the northern and western part the prevailing soil texture is loamy sand. Soils from gardens display a relatively high content of organic matter – on average 2.4% of organic carbon (Table 1) and very high levels of plant-available macronutrients – phosphorus (665 mg $P_2O_5 \cdot kg^{-1}$ on average), magnesium (139 mg Mg $\cdot$ kg^{-1} on average) and potassium (276 mg $K_2O \cdot kg^{-1}$ on average), which proves that intensive mineral and organic fertilization is used. Due to regular and intensive liming, the reaction of most garden soils is between neutral and alkaline (mean pH_{H2O} 7.2, pH_{KCl} 6.8), while mean pH_{H2O} for arable land in Wroclaw area is approx. 5.8. As a consequence of loamy texture of soil, intensive liming and fertilization, garden soils in Wroclaw contain high amounts of exchangeable basic cations, on average 13.9 cmol(+) $\cdot$ kg^{-1} (the sum of exchangeable Ca, Mg, K, Na). The base saturation, often reaching 100%, is, on average, 93% (Table 1). The signs of intensive gardening use are displayed jointly, which is confirmed by statistically significant (Table 2) correlation coefficients between organic carbon content and pH_{H2O} (r=0.52 at p<0.001), plant-available phosphorus (r=0.46 at p<0.001), magnesium (r= 0.48 at p<0.001) and potassium (r=0.29 at p<0.01). Characteristically, the soil fertility indicators are not correlated with the loamy fraction or the soil texture class, which confirms the outstandingly anthropogenic character of fertility of most of the garden soils being analysed. Anthropogenic transformation of soils is further confirmed by substantial differences in soil reaction (pH_{H2O} 5.7-8.3, pH_{KCl} 5.0-8.1), the content of humus (0.71-6.19% of organic carbon) and the content of macronutrients (e.g. phosphorus: 136-2570 mg $P_2O_5 \cdot kg^{-1}$), even between neighbouring allotments in one allotment complex. These striking differences are not due to natural geological diversity of soil parent material but result from different cultivation methods and from the various intensity of fertilization. Similar observations are made by other researchers [6], who point out the necessity of careful preparation of composite soil samples for laboratory analyses.

In soils from allotment gardens in Wroclaw, trace elements occur in a very wide range: 12.5-659 mg Pb $\cdot$ kg^{-1}, 38.1-2103 mg Zn $\cdot$ kg^{-1} and 12.9-595 mg Cu $\cdot$ kg^{-1} (Tab. 1). The content of none of these has a typical normal distribution (Fig. 2), which is manifested, especially for copper, through high value of skewness, considerable disparities between the arithmetic mean and the median, high standard deviation and small difference between the arithmetic mean and the upper quartile (Tab. 1). Such population variability is generated by low number of soil samples with metal concentration levels several times higher than the median of whole sample (Fig. 2). For this reason, the geometric mean seems far more reliable for the assessment of trace elements content, as using it the result will be much closer to the median. The average concentrations of copper (arithmetic mean, AM 62.6 mg $\cdot$ kg^{-1}, geometric mean, GM 44.3 mg $\cdot$ kg^{-1}), lead (AM 91.7 mg $\cdot$ kg^{-1}, GM 72.6 mg $\cdot$ kg^{-1}) and zinc (AM 252 mg $\cdot$ kg^{-1}, GM 178 mg $\cdot$ kg^{-1}) exceed the levels accepted as geochemical background, which for the soils in the Wroclaw area are estimated as follows: Cu 25 mg $\cdot$ kg^{-1}, Pb 50 mg $\cdot$ kg^{-1} and Zn 70 mg $\cdot$ kg^{-1} [23].

TABLE 1 - Statistical characteristics of fertility and contamination of soils of allotment gardens in Wroclaw city.

Parameter	Minimum	Maximum	Arithmetic mean	Geometric mean	Median	Upper quatile	Standard deviation	Skewness
clay (<0,002 mm), %	1	33	7,5	5,5	6	10	5,9	1,8
organic carbon, %	0,71	6,19	2,57	2,36	2,42	3,04	1,07	1,0
pH_{H2O}	5,7	8,3	7,2	7,2	7,3	7,5	0,47	-0,9
pH_{KCl}	5,0	8,1	6,9	6,9	7,0	7,2	0,55	-1,0
BC, cmol(+) kg^{-1}	3,7	37,4	15,3	13,9	14,6	19,6	6,62	0,6
BS, %	41	100	93	93	95	98	8,22	-3,2
P_a, mg P_2O_5 kg^{-1}	136	2570	817	665	725	1200	500	0,9
K_a, mg K_2O kg^{-1}	50	880	326	276	290	425	183	1,0
Mg_a, mg Mg kg^{-1}	50	350	154	139	135	195	73,2	1,0
Pb_t, mg kg^{-1}	12,5	659	91,7	72,6	76,2	114	77,0	4,1
Zn_t, mg kg^{-1}	38,1	2103	252	178	184	274	280	3,8
Cu_t, mg kg^{-1}	12,9	595	62,6	44,3	38,5	63,0	77,1	4,3

TABLE 2 - Coefficients of correlation between concentration of heavy metals and properties of soils of allotment gardens in Wroclaw city.

	organic carbon	pH_{H2O}	pH_{KCl}	BC	BS	Mg_a	P_a	K_a	Pb_t	Zn_t	Cu_t
clay	0,03	-0,05	-0,07	0,19	0,10	-0,04	-0,14	-0,19	-0,02	-0,10	-0,05
org. carbon		0,52***	0,49***	0,27**	0,45***	0,48***	0,46***	0,29**	0,28**	0,21*	0,25**
pH_{H2O}			0,96***	0,33***	0,76***	0,42***	0,36***	0,26**	0,33***	0,29**	0,27**
pH_{KCl}				0,32***	0,78***	0,22*	0,13	0,11	0,31**	0,27**	0,26**
BC					0,52***	0,31**	0,26**	0,24	0,09	0,12	0,10
BS						0,28**	0,13	0,34***	0,23	0,19	0,19
Mg_a							0,44***	0,43***	0,54***	0,57***	0,54***
P_a								0,49***	0,33***	0,33***	0,26**
K_a									0,25*	0,31**	0,23*
Pb_t										0,91***	0,87***
Zn_t											0,89***

Correlation ratio significant at: * $p<0,05$, ** $p<0,01$, *** $p<0,001$.

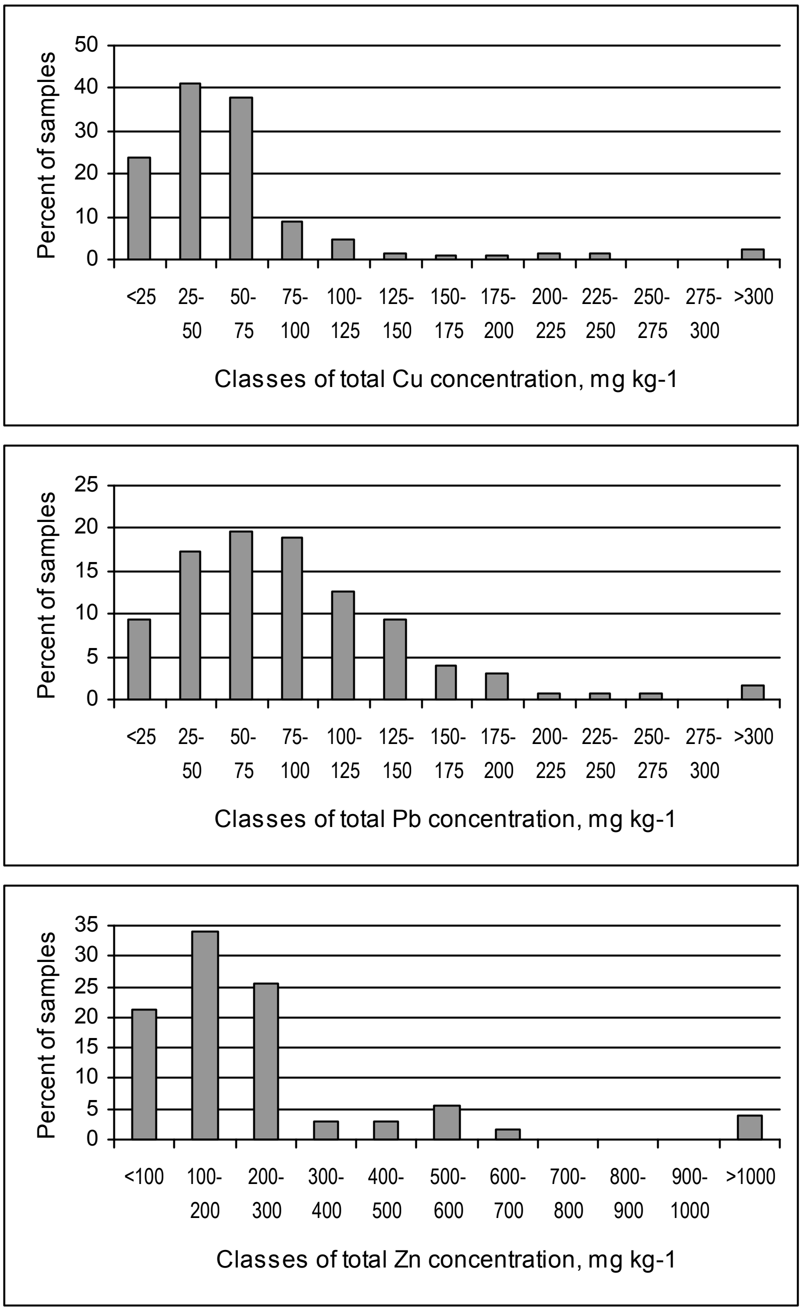

FIGURE 2 - Histograms of total concentrations of Cu, Pb, and Zn in soils of the allotment gardens of the Wroclaw city.

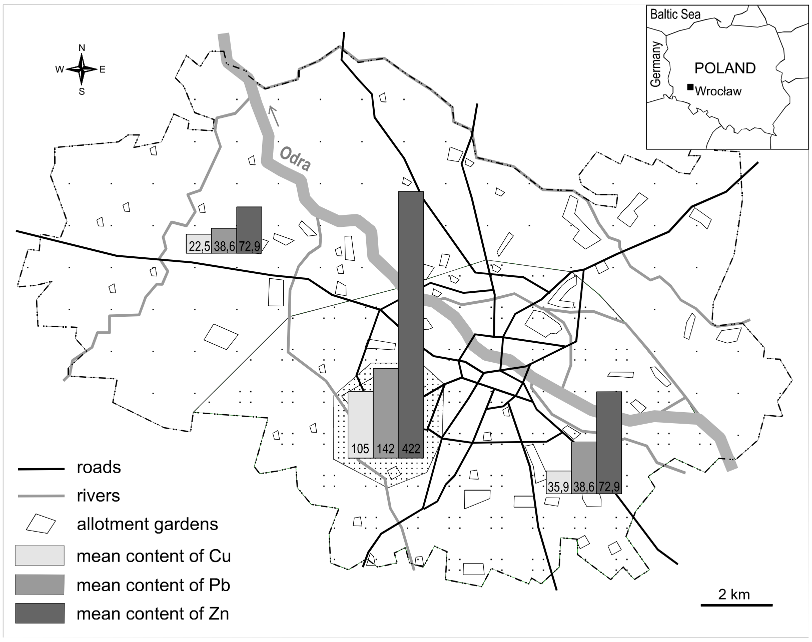

FIGURE 3 - Mean concentrations of Cu, Pb, and Zn in surface layer of soils of the allotment gardens as divided into three zones of different soil contamination in the Wroclaw city

The amount of elements in the surface soil layer does not depend on the soil texture class and is not correlated with clay content (Table 2). Statistically significant are, however, correlation coefficients between metal content and organic carbon content ($0.21<r<0.28$ at $p<0.05$) and pH ($0.27<r<0.33$ at $p<0.01$), with the highest values of coefficients for lead. Metal concentration distinctly correlates with the amount of plant-available macronutrients, in particular of magnesium. The metal concentrations being studied are also strongly correlated between each other ($0.89<r<0.91$ at $p<0.001$).

The concentrations of Cu, Pb and Zn are highly diversified spatially, even within the same allotment complex. Nevertheless, the town can be split into at least three distinct zones, differing by the range of content and average metal concentrations. The highest concentrations of all the elements are observed in the vicinity of the nonferrous metalwork plant in the south-west part of town (Fig. 3). Average (geometric mean) concentrations of metals on these allotments are as follows: 105.2 mg Cu $\cdot$ kg^{-1}, 142.2 mg Pb $\cdot$ kg^{-1} and 421.6 mg Zn $\cdot$ kg^{-1}. In the central and southern part of the town the average metal concentrations are significantly lower: approx. 35.9 mg Cu $\cdot$ kg^{-1}, 80.5 mg Pb $\cdot$ kg^{-1} and 160.9 mg Zn $\cdot$ kg^{-1}. The lowest concentrations, close to the geochemical background, have been observed in the northern part of the town and on its western outskirts, where the values measured were on average as follows: 22.5 mg Cu $\cdot$ kg^{-1}, 38.6 mg Pb $\cdot$ kg^{-1} and 72.9 mg Zn $\cdot$ kg^{-1}.

DISCUSSION

The average concentrations of Cu, Pb and Zn in soils sampled from allotment gardens in Wroclaw are higher than those reported in other big Polish cities [16-19]. Undoubtedly, this is due to the location of some of these gardens (which are among the oldest in the town) in the immediate vicinity of a non-ferrous metalwork plant, producing in the past considerable amounts of metal-bearing dusts. These concentrations (up to 595 mg Cu $\cdot$ kg^{-1}, up to 659 mg Pb $\cdot$ kg^{-1} and up to 2103 mg Zn $\cdot$ kg^{-1}) are similar to the levels observed in the surroundings of large copper smelters [24] and zinc smelters [25]. Nevertheless, in the whole Wroclaw area the concentration of metals being analysed correlates with the organic matter content, pH and the amount of plant-available macronutrients. These high values, being strongly interrelated, indicate intensive gardening use, including organic and mineral fertilization. Soil liming with waste lime (from non-ferrous metal smelting) containing excessive amounts of heavy metals is reported as a locally source of environmental pollution and potential health hazard [26]. Another factor that may contribute to heavy metal soil contamination is the use of composts made of contaminated vegetation and the reuse of discarded lime from the smelters, containing high concentrations of several trace elements. The widespread use of pesticides, the composition of which was generally based on salts of heavy metals, may neither be ignored.

The contamination of garden soils in the central and southern part of the town is highly influenced by the prevailing direction and motion of contaminated air masses (western winds) and the fact that most gardens in this part of the town have been established on residential or industrial grounds, after those buildings were destroyed during World War 2. Closed-down parks and cemeteries were also used as grounds for allotment gardens. Brick and concrete debris and rubble, the remains of lime mortar as well as earth of unknown origin, used for reclamation, may still contribute to local soil contamination. Similar phenomena are observed in soils of allotment gardens in the city centre of Warsaw, a considerable part of which is set up on post-war rubble. Also here higher concentrations of several trace elements have been observed [27]. In the northern and western part of Wroclaw, where most allotment gardens were established after 1945 on arable land and where there are no big industrial plants to emit metal-bearing dusts, there is significantly less soil contamination than in the southern districts, and higher concentrations are observed only locally, without any clear explanation of their origin.

High content of organic matter and neutral reaction of soil also contribute to stabilizing of concentration of metals, by strong exchange sorption and decrease in metal salt solubility. At the same time the trace element availability for cultivated plants may be attenuated. According to Chodak et al. [20], after curbing industrial and traffic emissions, the heavy metal concentrations in vegetables cultivated on contaminated soil remain within admissible levels and often show no connection with the concentration of specific elements in soil. Nevertheless, irrespective of the actual metal uptake by plants, as much as 35% of examined gardens in Wroclaw do not meet the requirements set out by the Polish Ministry of Environment [15], which allow no more than 150 mg $Cu \cdot kg^{-1}$, 100 mg $Pb \cdot kg^{-1}$ and 300 mg $Zn \cdot kg^{-1}$ in the topsoil of arable land. Consequently, gardening on these allotments should be discontinued and gardens should be reclaimed so as to decrease metal content down to the legally admissible levels.

CONCLUSIONS

The concentration of heavy metals (Cu, Pb and Zn) in topsoil of allotment gardens in Wroclaw is highly spatially diversified and depends primarily on the location of industrial pollution sources, but also varies with the amount of organic matter, pH and the content of plant-available macronutrients, which suggests a relationship between metal contamination and the intensity of organic and mineral fertilization, and, in particular, liming of soil.

Compared to gardens set up on arable land in the north part of Wroclaw, metal concentrations measured in the central and southern parts of the town, on soils of allotment gardens established on former residential housing and municipal infrastructure grounds, are significantly higher. Approximately 35% of soils in the city zone are excessively contaminated, unsuitable for vegetable production and, according to the Polish law, require reclamation.

REFERENCES

[1] Crouch, D. and Ward, C. (2007) The allotment: its landscape and culture. Five Leaves Publications, Nottingham, GB, 126 p.

[2] Milligan, C., Gartrell, A. and Bingley, A. (2004) “Cultivating health”: therapeutic landscapes and older people in northern England. Social Science and Medicine, 58, 1781-1793.

[3] Kotus, J. (2006) Changes in the spatial structure of a large Polish city – the case of Poznan. Cities, 23, 364-381.

[4] Lin, Z., Harsbo, K., Ahlgren, M. and Qvarfort, U. (2007) The source and fate of Pb in contaminated soils at the urban area of Falun in central Sweden. Science of the Total Environment, 209, 47-58.

[5] Sanchez-Camazano, M., Sanchez-Martin, M. J. and Lorenzo, L. F. (1994) Lead and cadmium in soils and vegetables from urban gardens of Salamanca (Spain). Science of the Total Environment, 146-147, 163-168.

[6] Clark, H. F., Brabander, D. J. and Erdil, R. M. (2006) Sources, sinks, and exposure pathways of lead in urban garden soil. Journal of Environmental Quality, 35, 2066-2074.

[7] Duzgoren-Aydin, N. S. (2007) Sources and characteristics of lead pollution in the urban environment of Guangzhou. Science of the Total Environment, 385, 182-195.

[8] Finster, M. E., Gray, K. A. and Binns, H. J. (2004) Lead levels of edibles grown in contaminated residential soils: a field study. Science of the Total Environment, 320, 245-257.

[9] Ona, L. F., Alberto, A. M., Prudente, J. A. and Sigua, G. C. (2006) Levels of lead in urban soil from selected cities in a central region of the Philippines. Environ Science and Pollution Research, 13, 177-183.

[10] D’Elia, V., Lodi, V., Naldi, M., Gherardi, G., Violante, F. S., Bonparola, M., Badiello, R. and Raffi, G. B. (1999) Gardening work and heavy metals in urban environment. Arhiv za Higijenu Rada i Toksikologiju, 50, 163-170.

[11] Hough, R. L., Breward, N., Young, S. D., Crout, N. M., Tye, A. M., Moir, A. M. and Thornton, I. (2004) Assessing potential risk of heavy metal exposure from consumption of home-produced vegetables by urban populations. Environmental Health Perspectives, 112, 215-221.

[12] Imperato, M., Adamo, P., Naimo, D., Arienzo, M., Stanzione, D. and Violante, P. (2003) Spatial distribution of heavy metals in urban soils of Naples city (Italy). Environmental Pollution, 124, 247-256.

[13] Douay, F., Pruvot, C., Roussel, H., Ciesielski, H., Fourrier, H., Proix, N. and Waterlot, C. (2007) Contamination of urban soils in an area of northern France polluted by dust emissions of two smelters. Water Air and Soil Pollution, 188, 247-260.

[14] Kachenko, A. G. and Singh, B. (2006) Heavy metals contamination in vegetables grown in urban and metal smelter contaminated sites in Australia. Water Air and Soil Pollution, 169, 101-123.

[15] Ministry of Environment (2001). Quality standards of soil and earth. Dziennik Ustaw No 165, Act No 1359.

[16] Bozek, U. and Krolik, B. (2003) Heavy metals in the soil of allotment gardens in industrialized post-flooded areas in the Opole region. Roczniki Panstwowego Zakladu Higieny, 54, 137-144.

[17] Czarnowska, K. and Gworek, B. (1991) Contamination of soils in Warsaw with zinc, lead, and copper. Stan zanieczyszczenia cynkiem, ołowiem i miedzią gleb Warszawy. Roczniki Gleboznawcze, 42, 26-38.

[18] Czarnowska, K. and Walczak, J. (1988) Distribution of zinc, lead and manganese in soils of Lodz city. Roczniki Gleboznawcze, 39, 22-34.

[19] Gambus, F. and Wieczorek, J. (1995) Heavy metals in soils and vegetables of allotment gardens in Krakow. Metale ciężkie w glebach i warzywach z krakowskich ogrodów działkowych. Acta Agraria et Silvatica, 33, 12-24.

[20] Chodak, T., Szerszen, L. and Kabala, C. (1995) Heavy metals in soils and vegetables of allotment gardens in Wroclaw. Metale ciężkie w glebach i warzywach ogrodów działkowych Wroclawia. Zeszyty Problemowe Postepow Nauk Rolniczych, 418, 291-298.

[21] IUSS (2006) World Reference Base for Soil Resources 2006. 2nd edition, World Soil Resources Reports 103, FAO, Rome, 122 pp.

[22] Van Reeuwijk, L.P. (2006) Procedures for soil analysis. 7th edition. ISRIC – World Soil Information Centre. Wageningen, Netherlands, Technical Reports, 9, 150 pp.

[23] Kabata-Pendias, A. and Pendias, H. (2003) Geochemistry of trace elements (2nd Polish edition). PWN, Warszawa, Poland, 346 p.

[24] Karczewska, A. (1996) Metal species distribution in top- and sub-soil in an area affected by copper smelter emissions. Applied Geochemistry, 11, 35-42.

[25] Chlopecka, A., Bacon, J. R., Wilson, M. J. and Kay, J. (1996) Forms of cadmium, lead, and zinc in soils from Southwest Poland. Journal of Environmental Quality, 25, 69-79.

[26] Cieslinski, G., Merick, S. and Nielsen, G. (1994) Effects of soil application of cadmium contaminated lime on soil cadmium distribution and cadmium concentration in strawberry leaves and fruit. Journal of Plant Nutrition, 17, 1095-1110.

[27] Czarnowska, K. and Gworek, B. (1983) Spatial distribution of heavy metals in soils and soil pH in Warsaw area. Polish Ecological Studies, 9, 85-95

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