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Heavy metals in soils and selected root vegetables from allotment gardens in Warsaw, Poland – health risk assessment

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Abstract

Introduction and Objective. Heavy metals are considered the main sources of pollution among various soil contaminants. Urban soils, acting as receptors for the considerable influx of heavy metals from various sources, experience accumulation from both natural and anthropogenic sources. Contamination of urban soils with heavy metals may create a potential risk for health, especially in cities where industrial activity is carried out, and there is a high volume of road transport traffic. The aim of the study was assessment of the content of heavy metals: manganese (Mn), zinc (Zn), copper (Cu), lead (Pb) and cadmium (Cd) in root vegetables grown in 16 allotment gardens in Warsaw, Poland, and evaluation of risk to health.

Materials and Method. The content of heavy metals (Mn, Zn, Cu, Pb, Cd) was investigated in soils (N = 196 samples) and vegetables (N = 94 samples).

Results. It was found that vegetables such as parsley, carrots, beetroots and celery grown in allotment gardens in Warsaw, Poland, accumulated an elevated content of the heavy metals Mn, Zn, Cu, Pb and Cd.

Conclusions. The health risk assessment carried out shows that consumption of root vegetables (parsley, carrots, beetroots and celery) from the examined allotment gardens showed an increased risk of the carcinogenic effects of cadmium and lead. For health reasons, the consumption of these vagtables should be very limited, or should be totally eliminated from the diet.

Key words

soil, heavy metals, vegetables, health risk, allotment gardens

INTRODUCTION

Soils in allotment gardens (AGs), due to the environmental and historical context, are complex environments which are still poorly recognized. Their functioning may be seriously disrupted due to physical, chemical, and biological degradation of soil. Contamination of soil in AGs may create health risk, especially in the case of intake of particles of soil consumed with vegetables, or vegetables.

Heavy metals are classified into the category of contaminants of the environment due to their toxic effect on plants, animals, and humans. Contamination of soil with heavy metals is the result of anthropogenic, as well as natural activity. While evaluating the nutritional value of vegetables, contamination of the natural environment with heavy metals should be taken into consideration. Today, the presence of excessive amounts of heavy metals in the human environment is associated with the etiology of many diseases, especially of the cardiovascular, renal, nervous and skeletal systems, abnormal development of children, mutagenic and teratogenic changes, as well as the development of cancerous diseases [1]. Natural sources of heavy metals in soil include the atmosphere, irrigation, plant protection products (PPPs, including pesticides, phosphorus fertilizers), animal manure and sewage sludge, and particulate emissions from road transport. Other anthropogenic pollutants from plants may unfavourably affect global food safety, creating a significant health risk for humans after consumption of root vegetables contaminated with heavy metals [2, 3].

Hence, in vegetables from AGs located in large cities, or in industrial districts it should be reasonable and purposeful to determine the amount of heavy metals in the soil. Therefore, it is necessary to control the content of metals harmful for health in vegetables, which is the purpose, among other things, of the assessment of health risk related with their consumption.

From the point of view of both public and environmental health it is important to assess and monitor the level of heavy metals in soil and vegetables designed for consumption, in order to prevent contamination and potential negative effects for the environment, and indirectly for human health. The study focuses on the transfer of toxic heavy metals from soil to vegetables because they are the most exposed to environmental pollution, while simultaneously being an important component of the human diet. The aim of the presented study is the examination and recognition of the

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degree of contamination with heavy metals (Mn, Zn, Cu, Pb, Cd) of soils, and the selected species of roots vegetables, as well as the assessment of health risk related with consumption of vegetables grown in AGs located in Warsaw, Poland.

MATERIALS AND METHOD

The study was conducted during 2022–2023, including 16 allotment gardens located in Warsaw. Precipitation in Warsaw in 2022 was 459.7 mm and the average temperature from June to August was 19.5°C. However, in 2023, the rainfall was 656.2 mm and the temperature in the same period – 20.5°C [4]. A total of 196 mixed soil samples were collected (5–6 samples from an individual garden) at the soil depth of 0–20 and 20–40 cm. A similar procedure was followed when collecting plant material. The aboveground and underground parts of the plants were analyzed separately. Vegetables for analysis were collected at the stage of full (consumption) maturity – 94 samples. The sample analysed was a mixed sample consisting of 6 individual samples. After being harvested from the allotment gardens, the vegetables were thoroughly washed in tap water, crushed, and dried at the temperature of 65°C. The soill samples were subjected to hot digestion in 20% HCl. Before digestion, the soil was ground in an agate mill, and the organic matter subsequently combusted at the temperature of 480°C. After grinding, the plant material was dry-ashed at the temperature of 480°C for 8 h. The ash was dissolved in hot concentrated HCl diluted with distilled water in a ratio of 1:1, and filtered.

Analyses were performed using the technique of atomic absorption spectrophotometry (AAS) [5]. The content of manganese (Mn), zinc (Zn), copper (Cu), and cobalt (Co) was determined directly in the solutions, whereas the content of lead (Pb) and cadmium (Cd) by complexation and transfer in the organic phase. In the study, the correlation coefficients were calculated between the content of individual heavy metals in the soil.

RESULTS AND DISCUSSION

The data obtained showed that the examined soil layers did not show enrichment in Mn and Cd (Tab. 1–3). For the purpose of the study, the depth of the soil sample collected in the surface layer was assumed to be within the range from 0–20 cm and deeper – 20–40 cm. In the surface layer, the content of Mn was significantly correlated with the amount of Co ($r^2 = 0.7055^{++}$). High correlation coefficients showed interactions between individual elements.

Table 1. Content [mg/kg d. m.] of heavy metals in soils (n = 196) in allotment gardens

Element	Depth [cm]	Scope	Mean±SD	Mean from control
Pb	0–20	16-84	32.0±19.02	10.3±3.1
	20–40	14-68	21.0±11.27	10.0±2.9
Cd	0–20	0.20-2.20	1.04±0.61	0.27±0.05
	20–40	0.20-1.80	0.81±0.57	0.20±0.04
Zn	0–20	82-364	175±72.06	32±7.2
	20–40	45-276	132±63.38	30±7.8
Cu	0–20	9.8-31.3	17.0±6.09	8.8±2.1
	20–40	8.5-23.6	13.0±4.99	6.4±1.8
Co	0–20	2.0-16.0	6.4±4.59	3.7±0.8
	20–40	2.0-15.0	5.4±4.09	3.0±0.6
Mn	0–20	162-520	334±92.63	329±68
	20–40	198-570	331±90.10	307±66

Table 2. Content of heavy metals in soils from allotment gardens along roads

Garden	Depth [cm]	[mg/kg d. m. soil]					
		Pb	Cd	Cu	Co	Zn	Mn
1	0–20	50±11	2.20±0,74	27.0±6.2	2±0.5	242±49	262±61
	20–40	34±9	1.60±0.36	25.0±6.8	3±0.7	222±56	300±70
2	0–20	44±11	1.40±0.29	25.0±7.2	4±0.8	122±43	260±64
	20–40	29±6	0.30±0.07	26.0±6.9	4±0.7	114±34	212±47
3	0–20	51±12	0.30±0.08	31.3±7.1	3±0.7	194±49	290±59
	20–40	22±5	0.20±0.05	12.3±3.9	4±0.9	128±31	229±44
4	0–20	60±13	0.60±0.14	14.6±3.1	4±0.7	334±68	234±49
	20–40	37±7	0.50±0.16	23.8±5.9	12±3.4	192±51	200±49
5	0–20	84±19	1.60±0.40	15.2±4.3	4±0.9	320±69	253±56
	20–40	22±5	1.3±0.29	12.5±3.9	2±0.4	237±51	267±49
6	0–20	40±9	1.00±0.24	29.9±7.8	4±0.9	194±31	285±61
	20–40	32±7	0.90±0.21	16.1±4.3	4±0.6	185±41	286±56
7	0–20	38±8	0.40±0.07	22.6±4.9	3±0.7	242±51	289±71
	20–40	37±9	0.30±0.06	23.6±5.6	4±0.8	176±42	301±68
8	0–20	39±10	1.60± 0.34	16.6±5.1	4±0.9	215±46	234±51
	20–40	26±6	1.70±0.41	15.7±3,7	3±0.7	200±58	256±53
9	0–20	68±14	2.20±0.51	11.2±3.6	16±4.2	184±49	520±99
	20–40	52±10	1.30±0.32	9.8±3.2	12±3.6	140±37	570±101
10	0–20	33±7	1.40±0.30	22.1±6.1	4±0.9	195±47	460±98
	20–40	30±8	1.20±0.31	16.8±4.6	3±0.7	168±41	470±104
11	0–20	26±6	1.20±0.29	13.8±3.7	4±3.1	140±32	20±4.9
	20–40	24±6	1.10±0.31	11.6±4.1	5±0.20	138±27	225±54

Table 3. Content of heavy metals in soils in gardens located in the central part of allotment gardens

Garden	Depth [cm]	[mg/kg d. m. soil]					
		Pb	Cd	Cu	Co	Zn	Mn
1	0–20	27±5	0.30±0.06	14.4±3,1	4±0.9	114±26	241±51
	20–40	14±4	0.30±0.05	12.4±2.9	3±0.7	82±21	234±49
2	0–20	18±6	0.30±0.05	21.0±4.9	4±0.8	120±27	278±63
	20–40	12±5	0.20±0.04	19.0±4.1	3±0.7	113±26	260±69
3	0–20	11±3	0.30±0.06	15.5±3.8	4±0.7	114±31	253±60
	20–40	15±4	0.30±0.05	11.4±2.4	4±0.6	105±24	296±71
4	0–20	22±5	0.40±0.09	13.3±2.9	4±0.7	144±31	415±96
	20–40	11±3	0.30±0.07	11.1±2.6	3±0.7	127±29	407±99
5	0–20	14±3	0.30±0.06	8.2±1.7	3±0.6	82±21	350±86
	20–40	9±2	0.20±0.04	9.6±2.1	4±0.9	60±19	330±75
6	0–20	16±3	0.20±0.05	14.2±3.0	6±1.9	109±31	340±87
	20–40	9±2	0.20±0.05	9.0±2.1	3±0.6	151±36	350±79
7	0–20	17±4	0.40±0.09	11.8±3.3	4±0.9	82±19	225±56
	20–40	10±3	0.30±0.07	10.6±2.6	4±0.8	45±11	260±61
8	0–20	19±6	0.40±0.09	13.4±2.9	13±2.5	94±26	390±81
	20–40	14±3	0.30±0.07	12.4±1.5	13±2.7	88±29	410±89
9	0–20	14±4	0.60±0.11	12.0±2.7	9±2.1	94±31	340±72
	20–40	12±5	0.30±0.07	8.0±1.9	11±3.1	83±27	320±78

Table 4. Content [mg/kg d. m.] of Pb, Cd, Cu, Mn, and Zn in roots of vegetables grown in allotment gardens

Plant	Statistics	Pb		Cd		Cu		Mn		Zn	
		L	R	L	R	L	R	L	R	L	R
Parsley n = 26	min.	1.0	1.0	1.0	1.10	5.6	7.7	17	12	37	27
	max.	43.0	46.0	2.50	1.70	20.3	21.6	63	48	85	89
	mean	11.6	9.1	1.24	0.73	11.1	13.2	38	32	62	52
	SD	7.7	8.8	0.45	0.43	5.0	4.4	14	12	14	14
Carrots n=27	min.	6.1	1.0	0.40	0.10	5.1	4.2	21	4	32	21
	max.	118.0	50.0	4.40	2.90	20.4	20.8	106	52	104	132
	mean	17.7	14.2	1.32	0.69	11.5	10.9	43	24	68	52
	SD	16.4	9.9	0.86	0.60	4.6	4.8	19	15	19	30
Beetroots n = 20	min.	1.0	1.0	0.40	0.10	6.6	2.4	18	14	43	28
	max.	72.0	79.0	6.70	6.50	37.2	44.7	160	43	233	168
	mean	22.1	17.8	1.88	1.24	16.9	18.2	46	25	94	80
	SD	21.1	16.1	1.26	1.10	8.2	11.4	34	10	50	43
Celery n= 21	min.	1.0	1.0	0.20	0.10	3.3	7.4	18	13	46	34
	max.	59.1	68.0	4.20	5.30	25.9	30.2	63	43	96	108
	mean	18.6	17.0	1.10	0.95	12.5	14.3	32	25	65	64
	SD	14.7	16.3	0.83	0.80	6.3	5.7	10	8	15	18
Control – scope		0.2–0.3		Traces		3.5–5.5		60–140		30–50	

L – leaves; R – root

In the examined soil samples, especially in the surface layer, an increase in the content of Pb, Cd, Cu and Zn was observed. This increase may be associated with atmospheric precipitation, and the use of PPPs containing Zn and Cu. A greater amount of Pb and Zn was found in the samples of soil collected from the gardens located along busy traffic routes (Tab. 2). In soils from these gardens, an increase was observed in the content of Cd, which indicates the contribution of road transport to contamination of soil with this metal, and a higher content of Cu (Tab. 2). In the surface layer, as well as in the deeper layer, the content of Zn was significantly correlated with the amount of Pb ($r^2 = 0.6091^{++}$ and $r^2 = 0.5911^{++}$), while the content of Cu with the amount of Pb, was found only in the deeper layer ($r^2 = 0.4067^{++}$).

In the surface layer, the indicator of accumulation of trace metals, calculated in relation to their content in control soils, was: Pb from 1.5 – 8.1, Cd from 0.7 – 8.4, Cu from 1.1 – 3.5, and Zn from 2.3 – 10.1. The content of Pb and Zn in soils of allotment gardens located in the vicinity of busy traffic routes indicated their increase. The results obtained (Tab. 3) allow the presumption that these soils should be classified as poorly contaminated with Pb and Zn (over 20–50 mg/kg soil, and 50–200 mg/kg soil, respectively), or as contaminated (containing Pb over 50 mg/kg soil, and Zn over 200 mg/kg soil) [6]. Soils from gardens located deep in the allotment gardens were poorly contaminated with Zn (Tab. 3).

In summing-up, it should be stated that soils in the examined AGs showed a considerably elevated content of Pb, Cd and Zn in surface layers. This demonstrates that soils located in the central part of allotment gardens may be designated for growing vegetables, whereas in the gardens located in the vicinity of communication routes, their cultivation should be limited or discontinued altogether.

An excessive content of trace metals in the area of AGs is the result of contamination of plants with dust containing heavy metals falling on plants grown near communication routes and industrial plants, as well as home boiler rooms [2, 7].

The above-ground parts of the examined vegetables contained less Mn than vegetables from the control garden (Tab. 5); however, a narrow Mn: Zn ratio in the investigated vegetables evidenced a deficiency of Mn [8]. The vegetables contained Zn from 21 – 233 mg/kg d. m. (dry mass), with the highest amount of Zn found both in the above-ground parts, and in the roots of beetroots, carrots and celery. A part of the vegetables contained excessive amounts of Zn, especially those grown in the gardens adjacent to busy communication routes. The content of Cu in the examined vegetables remained within the range 2.0–44.7 mg/kg d. m. A higher amount of Cu was found in vegetables from the AGs located in the vicinity of communication routes, this especially concerned beetroots and celery. The Cu: Zn ratio in vegetables from AGs in Warsaw was close or twice as big, compared to vegetables from the control garden.

The examined vegetables contained an alarmingly high amount of Pb (1–74 mg/kg d. m.) and Cd (0.10–6.7 mg/kg d.m.), despite a medium contamination of soils with these metals, which means they originated from dry and wet deposits. The highest content of Pb was found in beetroots, celery, and carrots. Considering the mean amounts

Table 5. Quantitative ration between heavy metals in vegetables

Plant		Cu : Zn	Zn : Cd	Mn : Zn
Parsley	L	0.13	53.40	0.61
	R	0.25	71.20	0.61
Carrots	L	0.16	51.51	0.61
	R	0.17	71.19	0.41
Beetroots	L	0.17	72.21	0.46
	R	0.22	103.84	0.30
Celery	L	0.22	58.18	0.50
	R	0.22	67.36	0.30
Control - scope		0.11	-	2.0-2.8

L - leaves, R – root

of Cd in the edible part of the examined vegetables, they can be ranked according to the content of this element as follows: beetroots > celery > parsley > carrots.

Based on the results of the study, it may be presumed that the content of Mn and Cu in the examined parts of vegetables remains within the ranges generally adopted for plants growing in conditions not much changed by humans. The examined plants growing in the vicinity of busy communication routes showed an excessive amount of Pb and Cd, compared to the plants from AGs on the outskirts of Warsaw. The majority of the examined vegetables contained from 9–17.8 times greater amount of Pb, and from 4.6–8.8 times more Cd. The reaction of plants to environmental contamination with heavy metals indicates the necessity for limitation in AGs of such vegetables as beetroots, parsley, celery, and carrots.

Assessment of exposure to Cd among inhabitants of the central part of the Silesian Province, south-west Poland, consuming roots of locally grown vegetables, included 54 soil samples and 70 samples of vegetables from 7 selected cities with county rights and 2 communes in the province. Among the vegetables, samples of carrots, parsley, and celery were examined, whereas samples of soil were collected from family allotment gardens, farmlands, and home gardens. The mean content of Cd in investigated soils was 4.8 mg/kg d.m., which is 160% of the maximum allowable value. The highest mean concentrations of this element were found in soil samples from family allotment gardens – 15.2 mg/kg d.m. It was found that in as many as 66 from among 70 samples of vegetables examined, the maximum allowable value of the concentration of Cd was exceeded [9].

A study conducted in 6 allotment gardens in Gorzów Wielkopolski included an analysis of heavy metals – microelements (Cu, Fe, Mn, Ni, Zn) and toxic heavy metals (Cd, Cr, Pb), in samples of soil, and 3 vegetable plants (carrots, lettuce, and tomatoes) cultivated in allotment gardens. The content of heavy metals in the surface layer of soil in allotment gardens varied and arranged in descending order Fe> Zn> Mn> Cu = Pb> Ni = Cr> Cd. Soil was not contaminated with heavy metals. The highest accumulation of microelements and toxic heavy metals was observed in lettuce leaves, while the lowest – in tomatoes. The values of hazard quotient (HQ) for Cd and Pb in carrots and lettuce grown in all AGs were higher than 1 and created risk for consumers' health. The HQ values for Cd, Pb, Ni and Cr in tomatoes grown in all AGs were lower than 1, which indicated the lack of risk for health and safe for consumption [10].

Investigations of the concentrations of heavy metals (Pb, Cu and Zn) in edible leafy vegetables among the Iranian population, and the assessment of carcinogenic and non-carcinogenic risks to consumer health, showed mean concentrations of Pb, Cu, and Zn – 5.56, 3.35, and 5.27 mg/kg, respectively. The concentration of Pb in the analyzed vegetables was higher than the maximum allowable value recommended by the World Health Organization (WHO)/Food and Agriculture Organization (FAO). In turn, the concentrations of all other heavy metals in the samples were lower than the maximum allowable values recommended by WHO/FAO. Hazard quotient (HQ) for all heavy metals was clearly lower than 1 and did not exceed 0.3 in any of the age groups. It was also confirmed that the consumption of vegetables is not associated with acute health risk related with heavy metals, long-term and regular consumption of vegetables probably increases the risk of developing cancer [11].

Health risk. Health problems related with environmental exposure to heavy metals may be the result of exposure to these elements not only via the respiratory route (dust), but primarily through the alimentary route. Among the natural sources of contamination of food are, among others, plants, and fish, on the basis of which food products are produced [12, 13].

Toxic substances present in soil and dispersed with dust and settling in soil on which vegetables are grown create risk for human health worldwide. Heavy metals have the ability to accumulate in tissues and organs for many years. Pathologic symptoms may vary according to the degree of toxicity of the element, duration of exposure, and the size of the dose taken. While investigating their effect on health, chronic exposure to these elements should be considered in doses which, although not exceeding the specified allowable values, with time may cause health problems. Negative effects distant in time may occur even after discontinuation of exposure. An excess of heavy metals in vegetables, and their subsequent consumption by humans, may exert an effect on physiology and metabolism and is related with diseases such as cancer, mental retardation and immunosuppression [14, 15, 16]. Table 6 presents classification of heavy metals according to their toxicity [16].

Table 6. Classification of heavy metals according to their toxicity

No.	Metal	Level of toxicity
1.	Ag, Cd, Hg, Sb, Pb, U, As	High toxicity
2.	Ni, V, Co, W, Cu, Cr, Zn	Mediocre toxicity
3.	Mo, Mn, Fe	Low toxicity

Studies concerning food monitoring indicate that humans are constantly exposed to heavy metal residues occurring in food products available on the market. Hence, the assessment of the risk for consumers related with the consumption of products containing residues of heavy metals should be a permanent element of official food control, as well as of interest to public health [17].

Assessment of health risk due to HE is the process of estimating the probability of adverse health effects in persons who may be exposed to HE in the contaminated environment, at present or in the future. It is divided into 4 stages: 1) identification of risk, i.e. checking under what conditions HE is harmful to humans; 2) dose-response, i.e. finding the threshold value above which it poses a corresponding risk to humans; 3) exposure assessment, which is calculated using the exposure formula with exposure parameters; 4) characteristics of the risk which determines whether there is a health risk in the event of exposure to individual THQ values of metals – (<1) indicate a relative lack of health risk related with the intake of an individual heavy metal by consumption exclusively of contaminated vegetables. However, if vegetable consumption were to be associated with a potential health risk, especially for children, individual THQ for vegetables would add up to nearly 1. However, if we take into account the individual THQ resulting from the consumption of crops, the health risk would be higher for children, because the THQ values will always be >1 [18, 19].

Assessment of risk for human health. Analysis of risk for human health resulting from exposure to substances with a threshold effect, i.e. not having genotoxic or carcinogenic properties, is based on the model recdommended by the United States Environmental Protection Agency (US EPA) where, in order to estimate exposure to heavy metals, the hazard quotient (HQ) is calculated. The amount of a harmful substance taken daily by an adult person/child is calculated as the dose taken (US EPA) [20].

$$D = \frac{C \times DC}{BW}$$

where:
D – dose taken;
C – concentration of an element in a sampler of vegetable/fruit (mg/kg);
DC – dose consumed: mass of the vegetable/fruit consumed (kg/day);
BW – body weight of the exposed person, for an adult person 70 kg was adopted for calculations.

Health risk for an adult person was estimated by calculating hazard quotient according to the following formula:

$$HQ = \frac{D}{RfD}$$

where:
HQ – hazard quotient;
RfD – reference dose.

RfD is the estimated daily amount of a chemical which does not cause undesirable health effects throughout the person's life. In the case of the selected elements (Cd and Pb) the RfD value is set by various health safety organizations, such as the United States Environmental Protection Agency (EPA) [21].

The measure of the potential risk of the occurrence of adverse effects for health caused by a mixture of chemical components is the HI index, which is used in most risk assessment approaches for mixtures. The HI index for the mean daily consumption of vegetables was calculated as follows [22]:

$$HI = \sum_{i=1}^{n} HQ_i \qquad (3)$$

Table 7 demonstrates the hazard quotient (HQ) for an adult person for the selected heavy metals in the analyzed vegetables.

HQ and HI results are unitless values. In the case of HQ and HI a result less than or equal to 1 is considered as the safe level for the examined population. A result exceeding 1 is related with the possibility of occurrence of negative, non-cancerous health effects in the exposed population, where the amount of the products consumed and the degree of their contamination will remain on the present level. However, this is only an indicative value, which does not mean that these effects will occur or not occur at all [20].

Table 7. Calculated HQ for an adult person for the selected heavy metals in root vegetables analyzed

Vegetable	Cd	Pb	Cu	Zn
parsley	0.396	0.1371	0.0180	0.00094
carrots	0.1875	1.0721	0.0749	0.00471
beetroots	0.1682	0.6710	0.0618	0.00362
celery	0.3177	0.1579	0.1939	0.00071

For the metals analyzed, the HQ value was below 1, except for carrots where the HQ exceeded 1. Such a high HQ is the result of the highest daily consumption of carrots compared to other vegetables. The HQ values showed the following sequence, depending on the established value of the indicator for:
– parsley, carrots, and beetroots: Pb > Cd > Cu> Zn;
– celery: Cd>Cu>Pb> Zn.

The HQ values indicate the lack of risk for health during daily consumption of parsley, beetroots, and celery, at the metal concentration levels specified in these products. The results demonstrated that among the elements analyzed, lead showed the highest potential risk for human health, compared to other metals. However, it is noteworthy that the HQ value for carrots showed the highest potential health risk for consumers eating carrots from allotment gardens in Warsaw.

The study also determined the hazard index (HI) for all trace metals due to the fact that frequently more than one metal may increase risk for the organism.

The calculated HI for an adult person for the selected heavy metals was: parsley – 0.55204, carrots – 1.33921, beetroots – 0.90462, and celery – 0.670021. This index indicates the potential risk of the occurrence of adverse health effects caused by the consumption of carrots grown in allotment gardens in Warsaw. This means that in allotment gardens in large cities it is safest to grow fruit trees and bushes from the point of view of the lowest potential risk for consumers' health. Growing carrots, however, is not acceptable. In addition, it should be noted that this indicator calculated for beetroots was also close to the unacceptable value.

Analysis of the cancer risk for human health resulting from exposure to substances with a threshold effect, i.e. not having genotoxic or carcinogenic properties, is calculated from the formula below:

$$CR = \frac{D}{SF}$$

where:
CR – cancer risk;
D – dose of exposure to a substance in units mg/kg/day.

The Slope Factor (SF) is the term used in toxicology and assessment of health risk, which refers to slope factor used in the modelling of cancer risk related to exposure to carcinogens. This is a measure that estimates the risk of developing cancer as a result of exposure to a specified chemical. SF is usually expressed as a number of cancer cases per unit of absorbed dose of the substance (e.g. per mg/kg body weight daily), assuming that the substance is carcinogenic [20]. Table 8 presents cancer risk for human health resulting from exposure to Cd and Pb.

The CR index is defined as the likelihood of developing cancer over lifetime by the exposed population/person as a result of 24-hour exposure to a given daily dose of carcinogen for 70 years. CR higher than 10^{-4} indicates an increased

Table 8. Calculated CR for an adult person for Cd and Pb in root vegetables analyzed

Vegetable	Cd	Pb
parsley	6.4×10^6	5.8×10^5
carrots	3.074×10^5	$4. 54 \times 10^4$
beetroots	2.67×10^5	1.91×10^5
celery	5.21×10^3	6.69×10^5

risk of carcinogenic effect of the element. It is assumed that allowable CR limits are from 1×10^{-6} – $<1\times10^{-4}$ for a single carcinogen and multi-element carcinogens. For example, CR on the level of 10^{-4} suggests that 1 per 10,000 population may develop cancer. The SF is defined as a risk generated by the mean amount 1 mg/kg/day of a carcinogen throughout the whole life, and is specific for an element [23]. The calculated CR for the examined root vegetables grown in allotment gardens in Warsaw was higher than 10^{-4}. This means that the consumption of these vegetables indicates an increased risk of carcinogenic effect of the examined elements [23].

For Cu and Zn the CR was not calculated due to the fact that these elements are classified as toxic in certain conditions, although they are not classified as carcinogenic substances in standard classifications, such as the International Agency for Research on Cancer (IARC) [17].

CONCLUSIONS

The results obtained in the study allow the following conclusions to be drawn:

1. The content of Mn and Cd in soil from AGs was close to the geochemical background; soil in the central part of the AGs shows an elevated content of Pb, Cd, Zn and Cu, whereas soil from AGs located in the vicinity of busy communication routes, to various degrees, was contaminated with Pb, Cd and Zn.
2. The above ground part of vegetables contained more Zn, Mn and Cd than their underground parts.
3. Assessment of the health risk carried out indicated that the consumption of root vegetables (parsley, carrots, beetroots and celery) grown in AGs in Warsaw showed an increased risk of carcinogenic effect of Cd and Pb. For health reasons, their consumption should be very limited, or completely eliminated from the diet.
4. In order to avoid contamination with heavy metals of vegetables grown in AGs in Warsaw, it is justifiable to surround the gardens near communication routes with a dense and high hedge performing the role of a filter retaining dust pollution.

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