A comparative study of heavy metals in the soils of cities and arable lands

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The article presents the summarised comparable data on heavy metal amounts (Cr, Cd, Pb, Ni, Cu, Zn) obtained in 1993–2000 in the soils of the Middle Lithuania lowland, Kaunas city and its suburbs exposed to different anthropogenic chemical load.

The content of heavy metals determined in arable land with different soil texture at a depth of 0–20, 20–40, 40–60 cm (in 2M HNO_3 extraction) did not exceed the standard background levels. However, in the soils of Kaunas city industrial districts exposed to intensive technogenic load the levels of heavy metals was considerably higher: zinc on average 4, lead 3.5, copper 2.5 times, while the content of chromium, cadmium and nickel varied from standard to dangerous, exceeding MLC. The MLC for lead (32 mg kg^{-1}) is exceed in 50.6%, for zinc (150 mg kg^{-1}) 31%, for copper (40 mg kg^{-1}) – in 10% of investigated soil samples.

Dangerous soil pollution by heavy metals of technogenic origin according to the total contamination index (Zd > 16) reaches 44% in Žemieji Šančiai, 30% in the Old Town, 20% in the City Centre, while pollution by HM in other investigated districts of the Kaunas City involves only 10% of the area.

The levels of heavy metals in the soils of Kaunas suburbs (at a distance up to 15 km from the city) in 7 directions differed little from those established in the arable land of the lowland of Middle Lithuania, but differ considerably from those in the soils of the Kaunas city.

Key words: soil, soil texture, heavy metals

INTRODUCTION

Contamination by heavy metals (HM) in the environment rises many ecological problems. Pollutants, including heavy metals, are closely connected in different parts of the biosphere, that's why alteration of pollutants must be controlled in the whole system: soil–water–atmosphere–flora–fauna–man.

Heavy metals getting into soil as a result of anthropogenic activity exert a negative effect on the biological, chemical and physical properties of soil and its fertility.

The heavy metals Cr, Cd, Pb, Ni, Cu, Zn which have been investigated at the Agrochemical Research Centre take part in the biological turnover and their excess or lack disturb the metabolism and inhibit vegetation.

It is a confirmed fact that the major part (75–80%) of heavy metals get into human organism with vegetable diet. Plants take it from the soil (Verloo et al., 1982).

The dispersion of heavy metals and their migration in arable land of Lithuania have been investigated by many researchers (Baltakis, 1993; Gipiškis, 1998; Gregorauskienė et al., 1999; Jankauskaitė, Pauliukevičius. 1986; Lubytė et al., 1994; Lubytė et al., 1999; Mažvila et al., 2000; Rimšelis et al., 1997).

Despite the fact that there are numerous investigations (Kadūnas et al., 1999; Kadūnas et al., 1999; Mažvila, Adomaitis, 1997; Radzevičius, 1994; Taraškevičius, 1999; Zinkutė, 1999) on the state of soils in cities where the antropogenic impact on soils is intensive and where soils perform almost the same ecological functions as soils used for agriculture, the number of comparable investigations is rather small.

The purpose of the current study was determination of the concentration of heavy metals, their distribution and content in the soils of cities, suburbs and arable land under different anthropogenic load.

MATERIALS AND METHODS

The soils of the Kaunas city and the surrounding countryside according to the genesis and granulometric composition are similar to soils in the lowland of Central Lithuania (excluding karst region). Light loam, rarely sandy loam and medium loam, also clay gleyic calcareous brown soil and leached soil prevail in this area; there are also soils in which the genetic soil horizon is ruined, with a lot of various inclusions (cinder, slag and other kinds of waste matter).

For comparative investigations were chosen soils exposed to anthropogenic influence which in the Kaunas City is stronger, in the suburbs less, and in soils in Central Lithuanian lowland is very little.

Investigations were carried out by the plot principle: in the lowland arable land – 20 × 20 m, in the Kaunas City and suburbs – 5 × 5 m; observation was carried out in 10 districts of also the Kaunas City every 3 months (3 plots in each district); the grid method was used: 200 × 200 m in the Kaunas City (100 × 100 m in the center, 300 × 300 m and more in the outskirts).

Samples of soil were taken from the depth of 0–5, 5–20, 0–10, 0–20, 20–40, 40–60 cm and analyzed by AAS (2M HNO_3 extraction) at Agrochemical Research Centre.

RESULTS AND DISCUSSION

Most soils in the lowland of Central Lithuania (excluding karst region) are of moraine origin. The content of heavy metals in them is different, although it does not exceed the standard-background level (according to LAND 20–96) and varies within narrow limits (Table 1). In the arable layer (0–20 cm) of soil, the average level of chromium is 10.9, cadmium 0.51, lead 11.8, nickel 9.2, copper 6.9, zinc 25.7 mg kg^{-1}. The content of zinc and copper varies most significantly. The levels of Cr, Cd, Ni and Cu at a depth of 20–40 and 40–60 cm was found markedly larger than in the surface layer.

It has been determined by the Kaunas City monitoring program in 1993–1997 that the level of lead, copper and especially zinc is considerably larger in the soils of the Kaunas City (30 plots in 10 Kaunas City districts) as compared to data obtained in arable soils. A negligible difference has been defined for chromium, cadmium and nickel (Figure). The average level of Cr is 9.9, Cd 0.47, Pb 18.9, Cu 9.7, Zn 58.8 mg kg^{-1} in the layer 0–20 cm. It is the result of a 5-year observation of the study plots. A similar tendency was observed in deeper layers. The level

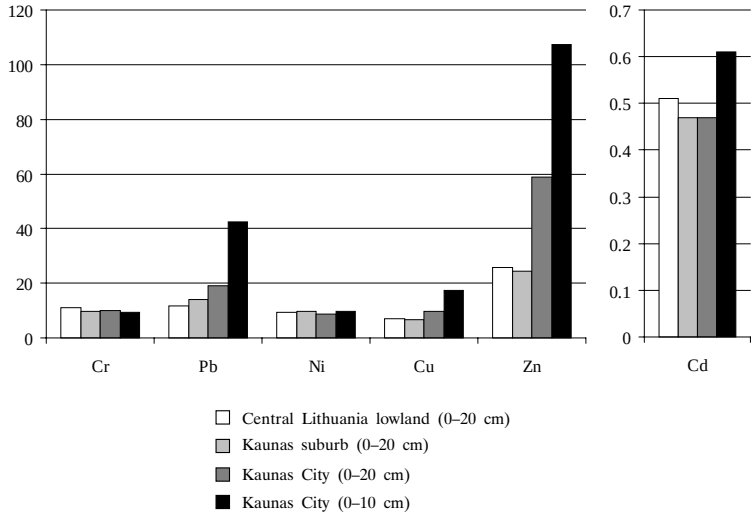

Figure. Heavy metals in the soils under different anthropogenic and chemical load, mg kg^{-1}

Table 1. **Heavy metals in the soils of Central Lithuania lowland in 1993–1997, mg kg^{-1}**

Soil texture	Depth cm	n	Cr	Cd	Pb	Ni	Cu	Zn
Sand	0–20		4	0.4	8	4	3.6	18.4
	20–40		4	0.4	6.8	4	2.8	14.8
Sandy loam	0–20		10.7 ± 2.5	0.44 ± 0.13	11.0 ± 1.9	8.4 ± 2.1	7.1 ± 3.0	25.9 ± 8.0
	20–40		10.4 ± 2.1	0.41 ± 0.12	10.4 ± 1.8	8.5 ± 2.1	6.1 ± 1.7	23.6 ± 6.8
	40–60		12.5 ± 3.6	0.55 ± 0.17	10.1 ± 1.4	11.4 ± 3.3	7.5 ± 1.9	25.4 ± 6.2
Light loam	0–20		10.9 ± 2.4	0.56 ± 0.26	12.3 ± 3.0	9.6 ± 2.1	6.5 ± 1.5	25.5 ± 6.5
	20–40		11.6 ± 2.4	0.62 ± 0.31	12.2 ± 3.1	10.8 ± 2.8	6.6 ± 1.6	25.0 ± 6.9
	40–60		12.3 ± 3.2	0.69 ± 0.35	11.7 ± 2.5	12.5 ± 3.0	7.5 ± 2.8	22.3 ± 4.8
Medium, clay	0–20		15.3 ± 2.0	0.53 ± 0.11	13.5 ± 2.0	12.4 ± 0.5	10.9 ± 2.4	28.5 ± 7.3
loam and clay	20–40		15.5 ± 4.0	0.53 ± 0.11	13.6 ± 1.5	13.9 ± 2.5	9.6 ± 2.3	31.1 ± 5.8
	40–60		11.7 ± 6.3	0.73 ± 0.42	10.6 ± 4.8	9.5 ± 3.9	6.7 ± 3.8	23.4 ± 6.6
Average	0–20	62	10.9±2.7	0.51±0.22	11.8±2.7	9.2 ± 2.3	6.9 ± 2.4	25.7 ± 7.0
	20–40	62	11.2±2.7	0.54±0.27	11.5±2.8	10.0 ± 3.0	6.5 ± 1.9	24.7 ± 6.9
	40–60	31	12.3±3.5	0.65±0.30	11.0±2.5	11.9 ± 3.2	7.4 ± 2.6	23.4 ± 5.4

Table 2. **Average amount of heavy metals in the soil of Kaunas districts (0–10 cm) in 1998–2000, mg kg^{-1}**

Districts (n)	n	Cr		Cd		Pb		Ni		Cu		Zn	
		$\frac{\bar{x} \pm s}{min - max}$ *median*											
City districts													
The Old City	23	9.1 ± 3.7 4.6–20.0	***7.8***	0.56 ± 0.37 0.2–2.0	***0.4***	79.8 ± 87.3 13.0–376.0	***40.0***	10.1 ± 3.7 5.6–21.8	***8.8***	25.1 ± 19.0 7.0–76	***8.0***	124.0 ± 78.8 27.2–350	***106.0***
The City Centre	119	8.0 ± 4.6 2.0–41.1	***7.2***	0.81 ± 1.29 0.2–14.0	***0.6***	41.8 ± 37.7 7.4–340.0	***33.8***	9.1 ± 10.1 2.0–80.0	***7.2***	35.4 ± 100.1 3.8–1020.0	***17.2***	176.2 ± 116.0 26.6–622.0	***144.0***
Low Šančiai	103	12.0 ± 14.8 3.4–151.3	***9.2***	0.83 ± 0.57 0.2–4.7	***0.6***	81.9 ± 119.6 8.2–1022	***45.6***	9.2 ± 5.47 1.2–33.6	***7.6***	34.8 ± 47.4 3.6–304.0	***20.4***	262.2 ± 256.1 28.0–1636.0	***188.0***
High Šančiai	90	10.4 ± 4.42 5.2–40.0	***9.8***	0.93 ± 0.63 0.4–5.5	***0.8***	79.3 ± 237.5 11.2–1650.0	***27.6***	10.3 ± 3.8 4.0–24.2	***9.7***	25.7 ± 53.3 3.8–369.0	***12.5***	143.0 ± 217.3 22.4–1900.0	***98.5***
Žaliakalnis	255	9.6 ± 6.29 3.2–74	***8.6***	0.65 ± 0.28 0.2–2.6	***0.6***	35.7 ± 25.0 9.0–181.0	***28.0***	9.8 ± 5.93 2.4–45.6	***8.8***	18.3 ± 26.3 3.6–318.0	***13.0***	125.1 ± 109.8 20.4–720.0	***92.0***
Dainava	270	9.8 ± 4.1 3.4–38.8	***9.2***	0.64 ± 0.30 0.2–2.8	***0.6***	27.4 ± 18.8 9.0–158.0	***21.0***	10.3 ± 4.1 2.8–31.4	***9.6***	16.1 ± 19.5 3.4–221.0	***11.4***	81.5 ± 75.9 20.0–800.0	***59.0***
Naujasodis. Amaliai	96	9.0 ± 4.7 2.0–26.6	***8.3***	0.58 ± 0.52 0.2–4.8	***0.4***	28.8 ± 41.5 5.4–282.0	***17.8***	10.8 ± 9.6 1.6–56.0	***8.0***	11.2 ± 11.6 1.4–85.4	***8.8***	63.4 ± 98.6 5.7–836.0	***38.6***
Petrašiūnai	112	9.5 ± 9.2 1.8–56.2	***7.2***	0.63 ± 0.44 0.2–2.8	***0.6***	36.2 ± 71.9 4.2–560.0	***20.4***	11.1 ± 24.5 1.2–242.0	***6.7***	19.0 ± 59.8 1.4–620.0	***8.3***	123.4 ± 239.2 9.6–2205.0	***64.2***
Palemonas	130	10.2 ± 4.9 3.2–26.0	***8.9***	0.50 ± 0.26 0.2–1.8	***0.4***	33.0 ± 37.0 6.4–280.0	***21.2***	10.5 ± 5.6 2.2–31.2	***9.4***	17.1 ± 48.1 1.6–530.0	***9.3***	76.2 ± 110.3 12.0–948.0	***48.1***
Kalniečiai. Eiguliai	105	9.0 ± 3.1 2.8–24.2	***9.0***	0.54 ± 0.19 0.2–1.4	***0.6***	21.2 ± 18.9 7.8–176.0	***16.2***	9.4 ± 3.8 2.6–27.0	***9.0***	11.2 ± 11.4 2.4–98.0	***8.8***	58.7 ± 37.9 4.8–296.0	***49.6***
Šilainiai, Linkuva	122	9.2 ± 4.6 1.6–33.8	***8.8***	0.42 ± 0.18 0.2–1.0	***0.4***	13.6 ± 10.5 6.6–113.0	***12.0***	9.8 ± 4.6 2.4–23.4	***9.0***	7.9 ± 5.1 1.2–52.0	***7.3***	47.2 ± 32.6 9.2–206.0	***38.5***
Vilijampole	226	9.5 ± 7.6 2.0–85.0	***8.2***	0.60 ± 0.31 0.2–2.4	***0.6***	32.7 ± 31.4 6.0–308.0	***23.8***	9.3 ± 4.3 2.6–33.1	***8.4***	13.1 ± 9.1 1.3–68.0	***11.0***	119.0 ± 131.2 13.6–840.0	***75.3***
On average	1651	9.6 ± 6.7 1.6–151.3	***8.6***	0.64 ± 0.50 0.2–14.0	***0.6***	44.8 ± 253.2 4.2–9270	***22.6***	9.9 ± 8.5 1.2–242.0	***8.6***	18.3 ± 41.2 1.2–1020.0	***11.4***	112.9 ± 145.0 4.8–2205.0	***69.8***
Western outskirts of the city													
Romainiai. Lampėdžiai. Kaniūkai	94	6.5 ± 3.9 1.0–25.6	***5.7***	0.37 ± 0.17 0.2–1.2	***0.4***	13.6 ± 7.1 3.9–41.0	***12.0***	8.0 ± 4.7 2.2–32.0	***6.8***	7.7 ± 10.4 0.6–80.0	***5.4***	37.1 ± 33.7 5.8–270.0	***28.0***
Vijūkai. environs of IXth fort	34	9.0 ± 5.2 1.6–21.0	***9.2***	0.31 ± 0.13 0.2–0.6	***0.2***	10.1 ± 3.0 4.6–19.6	***9.9***	10.1 ± 5.5 2.0–20.6	***10.2***	6.6 ± 3.9 1.0–17.2	***6.8***	32.4 ± 15.0 9.2–74.0	***33.0***
Average	128	7.2 ± 4.4 1.0–25.6	***6.1***	0.35 ± 0.16 0.2–1.2	***0.4***	12.7 ± 6.5 3.9–41.0	***10.6***	8.5 ± 5.0 2.0–32.0	***7.4***	7.4 ± 9.2 0.6–80.0	***5.6***	35.9 ± 29.9 5.8–270.0	***29.4***
Average of all districts	**1779**	**9.5 ± 6.6 1.0–151.3**	***8.4***	**0.61 ± 0.49 0.2–14.0**	***0.6***	**42.5 ± 243.9 3.9–9270**	***21.4***	**9.8 ± 8.3 1.2–242**	***8.6***	**17.5 ± 39.8 0.6–1020**	***10.8***	**107.3 ± 141.2 4.8–2205**	***64.0***
Background of Lithuania arable soils (according to ATC data)		10.6 ± 4.0		0.45 ± 0.19		11.8 ± 2.5		9.7 ± 3.5		6.6 ± 2.7		28.4 ± 9.5	

Table 3. **Average content of heavy metals in the soil of Kaunas suburbs located up to 15 km from the city in 1993–1997, mg kg^{-1}**

Direction	n	Depth cm	Cr	Cd	Pb	Ni	Cu	Zn	Hg
North	18	0–20	9.4 ± 4.8	0.35 ± 0.15	10.3 ± 2.4	10.8 ± 3.0	6.5 ± 1.8	22.8 ± 5.3	0.0204 ± 0.042
		20–40	8.5 ± 5.3	0.36 ± 0.15	10.1 ± 2.0	10.4 ± 3.6	5.4 ± 2.4	20.6 ± 5.4	0.0175
Northwest	74	0–20	10.9 ± 7.0	0.55 ± 0.23	13.6 ± 5.7	9.8 ± 3.6	8.0 ± 4.0	26.7 ± 6.0	0.0296 ± 0.0432
		20–40	10.9 ± 5.5	0.60 ± 0.25	13.2 ± 5.4	10.4 ± 4.5	7.4 ± 3.3	25.5 ± 5.4	0.0271 ± 0.0117
South	28	0–20	8.9 ± 3.8	0.41 ± 0.21	14.3 ± 7.4	10.2 ± 4.8	5.7 ± 2.2	25.4 ± 5.8	0.0205 ± 0.0064
		20–40	8.8 ± 3.5	0.42 ± 0.18	12.5 ± 6.1	9.3 ± 3.7	5.7 ± 2.2	24.1 ± 8.2	0.0193 ± 0.0119
Southwest	30	0–20	7.4 ± 2.5	0.44 ± 0.15	15.4 ± 6.3	8.4 ± 3.6	4.9 ± 1.6	20.3 ± 5.4	0.0202 ± 0.0075
		20–40	8.7 ± 3.9	0.45 ± 0.15	14.2 ± 5.5	8.6 ± 4.2	4.9 ± 1.9	18.2 ± 6.0	0.0200
West	62	0–20	10.9 ± 5.2	0.49 ± 0.17	16.9 ± 7.1	10.1 ± 4.3	7.0 ± 4.6	25.1 ± 9.0	0.0185 ± 0.0075
		20–40	13.0 ± 6.2	0.50 ± 0.18	15.7 ± 7.5	11.7 ± 5.9	7.5 ± 4.6	26.7 ± 10.7	0.0188 ± 0.0099
East	14	0–20	7.5 ± 5.4	0.39 ± 0.16	10.9 ± 2.3	7.2 ± 2.3	4.6 ± 2.0	23.0 ± 7.7	0.0233 ± 0.0095
		20–40	7.9 ± 4.1	0.36 ± 0.13	10.0 ± 1.5	7.6 ± 1.9	4.3 ± 1.1	21.4 ± 6.6	0.0272 ± 0.0102
Southeast	8	0–20	8.9 ± 5.2	0.25 ± 0.10	7.8 ± 3.4	6.9 ± 3.6	4.3 ± 2.7	18.3 ± 11.9	0.0210
		20–40	6.7 ± 1.7	0.25 ± 0.10	6.6 ± 2.6	5.5 ± 1.5	3.8 ± 2.5	15.3 ± 8.4	0.0135
Kaunas suburbs on average	292	0–20	9.8 ± 5.5	0.47 ± 0.20	14.2 ± 6.3	9.6 ± 3.9	6.6 ± 3.7	24.5 ± 7.3	0.0233 ± 0.0258
		20–40	10.4 ± 5.4	0.49 ± 0.21	13.3 ± 6.1	10.1 ± 4.7	6.5 ± 3.5	23.6 ± 8.1	0.0219 ± 0.0108

of heavy metals in the monitored plots did not exceed the maximum limit, because the plots were chosen in areas where pollution is moderate – rather far from large factories, industrial establishments, mobile streets, crossroads, petrol stations and other sources of intensive technogenic load, where the genetic soil horizon is ruined minimally in grass-covered places, near schools, hospitals, kindergartens, etc. Meanwhile, the high levels of zinc, lead and copper determined by the grid method in the soils of the Kaunas City districts (Old Town, City Centre, Šančiai, Žaliakalnis, Vilijampolė, Dainava, Petrašiūnai) resulted from intensive technogenic load. According to the average data, they are 4.0, 3.5 and 2.5 times, respectively, higher than in arable land. Their amount varies from standard limit to harmful exceeding MLC from several to some tens of times (Table 2). According to the investigations performed during the period 1998–2000, the level of lead exceeds MLC (32 mg kg^{-1}) by 50.6%, of zinc (150 mg kg^{-1}) 31%, copper (40 mg kg^{-1}) 10%, in analyzed soil samples of Kaunas. Particularly contaminated are soils of industrial Kaunas City districts, such as Žemieji Šančiai (the average amount of Zn is 262.0, Pb 81.9, Cu 34.8 mg kg^{-1}), Old Town (Zn 124, Pb 79.8, Cu 25.1 mg kg^{-1}), City Centre (Zn 176.2, Pb 41.8, Cu 35.4 mg kg^{-1}). There is a dangerous contamination according to the total contamination index (Zd > 16), which rises correspondingly to 44, 30 and 22%, while in the soils of all other districts only 10%. The average levels of other heavy metals in the soils of the city and arable land differ less, although in particular parts of the city the level of heavy metals is markedly larger than in arable land. The smallest difference is for chromium and nickel, because the level of these elements mainly depends on soil texture. Also, pollution by chromium and nickel in the Kaunas City is minimal, and only in a few places their concentration exceeds the standard-background level, whereas in some anomalous places it exceeds even MLC. The content of chromium in the soils of the lowland of Central Lithuania (layer 0–20 cm) is 39.4, nickel 43.0 mg kg^{-1}, meanwhile in the Kaunas City it reaches 151.3 and 242 mg kg^{-1}, respectively.

The soils in the Kaunas City contain a large diversity of heavy metals (the variety is 80–120%). A fluctuation of the concentration is characteristic also of cadmium: in arable land it is no more than 2.2 and in the Kaunas City 14.0 mg kg^{-1}.

The soils of Kaunas outskirts (at a distance of 15 km) are like a buffer zone between the districts exposed to intensive technogenic load and the area where the anthropogenic influence is small.

According to the data of investigations (7 directions from the city), the average amount of heavy metals in the comparable soils of arable lands differs little (Table 3). We can conclude that soils if Kaunas outskirts are little effected by technogenic pollution, because the level of HM does not exceed the standard-background level and almost comes up with the soils in the minimal pollution level.

CONCLUSIONS

1. The content of heavy metals in the soils of the city and arable land differs markedly: in the lowland of Central Lithuania with different soil texture

(at a depth of 0–20, 20–40 and 40–60 cm) it does not exceed the standard-background level (the average level of Cr is 10.9, Cd 0.51, Pb 11.8, Ni 9.2, Cu 6.9, Zn 257 mg kg^{-1}, while in soils of the Kaunas City the content of heavy metals varies from the standard to the harmful level exceeding MLC.

2. The level of zinc in the soils of the city exceeds about 4 times that in comparable arable land. The level of lead is 3.5, of copper 2.5 times higher.

3. The content of heavy metals in the soils of Kaunas outskirts (7 directions from the city) is very similar to that in the lowland of Central Lithuania and considerably less than in the Kaunas City.

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PALYGINAMIEJI SUNKIŲJŲ METALŲ TYRIMAI MIESTO IR LAUKO DIRVOŽEMIUOSE

S a n t r a u k a

Pateikiami apibendrinti palyginamieji sunkiųjų metalų (Cr, Cd, Pb, Ni, Cu, Zn) kiekių skirtingos antropogeninės cheminės apkrovos Vidurio Lietuvos žemumos, Kauno miesto ir jo užmiesčio dirvožemiuose 1993–2000 m. duomenys.

Įvairios granuliometrinės sudėties Vidurio Lietuvos žemumos dirbamų laukų dirvožemiuose (0–20, 20–40, 40–60 cm gyliuose) sunkiųjų metalų (2M HNO_3 ištraukoje) kiekiai nėra didesni už etaloninius-foninius kiekius. Intensyvios technogeninės apkrovos Kauno pramoninių rajonų dirvožemyje tirtų sunkiųjų metalų yra kur kas daugiau: cinko vidutiniškai iki 4, švino 3,5, Cu 2,5 karto, o chromo, kadmio ir nikelio kiekiai kinta nuo foninių iki kenksmingų, didesnių už didžiausią leistiną koncentraciją (DLK). Švino DLK (32 mg kg^{-1}) viršijama 50,6%, cinko (150 mg kg^{-1}) – 31%, vario (40 mg kg^{-1}) – 10% dirvožemio bandinių. Pavojingas dirvožemio užterštumas technogeninės kilmės sunkiaisiais metalais pagal suminį užterštumo rodiklį (Zd > > 16) Žemuosiuose Šančiuose yra 44, Senamiestyje – 30, Centre – 22%, o kituose miesto rajonuose – 10% ploto.

Kauno užmiesčio zonos (iki 15 km nuo miesto) 7-iomis kryptimis tirtuose dirvožemiuose sunkiųjų metalų kiekiai mažai skiriasi nuo Vidurio Lietuvos žemumos dirbamų laukų, bet labai – nuo Kauno miesto dirvožemių.

Raktažodžiai: dirvožemis, dirvožemio sudėtis, sunkieji metalai