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Differences of Vilnius topsoil contamination in the Neris River valley due to anthropogenic factors

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The differences among topsoil contamination by Zn, Pb, Cu, Sn, Ag, Mo and Ni in various groups and subgroups of 82 sites within the central districts of Vilnius located in the Neris River valley are analysed explaining them by the influence of various anthropogenic factors. These chemical elements are the main contaminants of the study area among 13 elements, the total contents of which have been determined in fraction <1 mm by optical atomic emission spectrophotometry. The territory is rather homogeneous according to natural factors. The general anthropogenic factor of the three main types of land-use has the greatest influence on urban topsoil contamination. In infrastructural-industrial sites, which are influenced by direct anthropogenic factors, the concentration coefficients of most of the main contaminants (Pb, Cu, Mo, Ni) are significantly higher than in residential and public-residential groups in which the role of such indirect anthropogenic factor as density of built-up areas, as well as of the general factor of time-span of urbanisation increases. In the infrastructural-industrial group, present or former industry is the main direct factor, followed by parking or repair of transport and the latter followed by main traffic roads. In the residential and public-residential group, the main variability of contamination is related to the time-span of urbanisation with an increase of Ag, Zn and Cu as the time-span of urbanisation grows. For the factor of density of built-up areas, no significant differences were found, probably because of a simultaneous influence of other anthropogenic factors. The differences between public-residential and residential sites are mostly insignificant, indicating similarity of population exposure. In public-residential sites, a higher contamination by Ag is characteristic of public health care sites and by Sn of public business sites.

Key words: urban soil, contamination, hazardous chemical elements, anthropogenic factors

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INTRODUCTION

The research is aimed at explaining the differences in urban topsoil contamination by the influence of different anthropogenic factors. The following subdivision of anthropogenic factors is proposed: 1) direct – factors related to known pollution sources of the site, usually industry or traffic; 2) indirect – factors that regulate the distribution of pollutants and are related to such human activities as planning and construction; 3) general – history-related anthropogenic factors, such as the main types of land-use and the time-span of urbanisation.

In foreign countries, investigations of the influence of different factors on topsoil contamination are numerous. Much has been done to relate chemical elements to pollution sources (direct anthropogenic factors), e. g. Cu, Pb and Zn to traffic, As to coal and peat combustion for home heating (Zhang, 2006), Cu to railway lines and tramway (Impetato et al., 2003). In a large region including urban and suburban territories, soil contamination has been analysed using GIS technologies together with landscape indices related both to natural and anthropogenic factors (Lin et al., 2002). According to Lee et al. (2006), the enrichment of heavy metals in soils in urban areas compared with industrial or mining areas is not well illustrated. The reason might be that most of industrial sources are often beyond the urban territories. But the main direct anthropogenic factor – traffic – always exists in urban territories, so its relationship with topsoil contamination has been investigated (Lee et al., 2006). Most of urban researchers have studied both natural and anthropogenic factors, e. g. the effects of geomorphology, industrial activities, roads and buildings (Li et al., 2004); geomorphology, road density, location and age of built-up areas, location of major traffic routes (Zhang, 2006). Chen et al. (2005) noticed a higher contamination of soil in urban parks in the densely populated historic centre districts, the location and age of the park being important factors in determining the extent of heavy metal pollution. They explain the high contamination of soil in the centre of the city by the highest road density and a long duration of traffic pollution. According to Chen et al. (2005), differences among cities could have a large impact on the findings of individual studies.

As the greatest cities in Lithuania have been historically industrialised, direct anthropogenic factors (different types of industrial pollution) have been investigated in detail (Taraškevičius, 1994, 2000; Radzevičius et al., 1997; Taraškevičius, Šiaudinienė, 2001; Zinkutė 1999a, 1999b, 2002, 2005; Zinkutė et al., 1999, 2002, 2005). Small Lithuanian towns are less contaminated (Taraškevičius, Zinkutė, 2003), and their direct anthropogenic factors are usually not obvious. Presently, the same concerns also large cities, because most of the enterprises are not industrial, but rather related to trade and marketing. Traffic actually remains the only direct anthropogenic factor. Therefore, the need to search for indirect anthropogenic factors in residential territories is obvious. Still there are urban sites where direct anthropogenic factors can be stated, i. e. present industrial sites, former industrial or military areas, main traffic roads and junctions, parking places, transport repair enterprises. They can be distinguished as infrastructural-industrial sites. Unlike the previous investigation of the relationship between Vilnius topsoil additive contamination and the landscape self-regulation potential, which integrates the expert ranking of both natural and anthropogenic factors (Jankauskaitė et al., 2008), this study concentrates on anthropogenic factors. It has been revealed that the time-span of urbanisation is one of the most important factors related to the contents of hazardous elements in topsoil (Taraškevičius, 2000) and can be used for a rough forecast of the level of topsoil contamination (Taraškevičius et al., 2003). However, joint analysis of several anthropogenic factors has not yet been done.

The aim of this research was to reveal among 13 elements (Ag, B, Ba, Co, Cr, Cu, Mn, Mo, Ni, Pb, Sn, V, Zn) the main contaminants of topsoil in part of the central districts of Vilnius located in the Neris River valley and to analyse the differences in topsoil contamination of the territories under various effects of anthropogenic factors.

The study area (Fig. 1) includes rather old and formerly partly industrialised districts: Žvėrynas, Šnipiškės and Žirmūnai and the western part of Antakalnis. Due to a similar lithology of subsoil and geomorphology (similar natural factors) this area is a suitable object to reveal the influence of anthropogenic factors. Urban land-use was chosen as the starting point of classification. Previous investigations have shown that the topsoil of infrastructural-industrial land-use is more contaminated than public-residential, and public-residential more than recreational (Taraškevičius, Zinkutė, 2003). So the reseach was based on them.

METHODS

Sampling. Sampling was done by the authors in December 2006 taking composite samples from 82 sites of Vilnius, evenly distributed on the area of about 19 km^2 located in the Neris River valley. Each bulk sample of about 8–10 kg was gathered by zigzag crossing a site area and collecting 20–25 similar mass increments from the upper soil layer (0–10 cm). Sampled material was homogenised and a composite sample reduced to about 1 kg.

Four groups of sites were distinguished according to prevailing land-use in each of them (general anthropogenic factor): I – infrastructural-industrial, E – residential and public-residential, M – former military, R – recreational (Fig. 1). The first two groups were classified according to different principles. Infrastructural-industrial land-use sites, which are obviously affected by pollution sources (former or present), were hierarchically subdivided according to the type of pollution (primary anthropogenic factor), meanwhile E type sites, which are characterised by difuse pollution with unknown sources, were parallelly subdivided according to the time-span of urbanisation (general anthropogenic factor) and the density of built-up areas (indirect anthropogenic factor). Besides, E land-use sites were subdivided hierarchically considering that some sites are possible centres of attraction for the population.

Sample preparation and analysis. Samples were air-dried and sieved. Fraction <1 mm was analysed by optical atomic emission spectrophotometry at the laboratory of the Institute of Geology and Geography for determining the total contents of Ag, B, Ba, Co, Cr, Cu, Mn, Mo, Ni, Pb, Sn, V, Zn. Since 1997, the laboratory participates for quality control in the International Soil-analytical Exchange subprogram organised by Wageningen University (ISE, 2008).

Data treatment. For each site, the additive index Z_d of topsoil contamination, which is one of the indices used for soil quality evaluation in Lithuania (HN 60-2004, 2004), was calculated by summing up the concentration coefficients K_k of all the above-mentioned elements. Regional background values (Kadūnas et al., 1999) in ppm are indicated in parentheses: Ag(0.08), B(26.1), Ba(400), Co(4.8), Cr(32.9), Cu(8.8), Mn(578), Mo(0.71), Ni(12.3), Pb(16), Sn(2.07), V(29.7) and Zn(30.9). For each group and subgroup, the median values of concentration coefficients K_{kmed} and of the additive contamination index Z_{dmed} were calculated together with two generalised additive contamination indices – the non-ferrous index Z_{nf} according to K_{kmed} of Zn, Pb, Cu, Sn and Ag, i. e. elements related to non-ferrous metals, and the ferrous index Z_f according to K_{kmed} of Mo, Ni, Cr, Co and V, i. e. elements related to ferrous metals. These element groups are chalcophile or siderophile-litophile, respectively (Goldschmidt, 2008). The main pollutants were revealed analysing the accumulating associations which included elements with $K_{kmed} > 1.3$ (Zinkutė, 2002). Significant differences of Z_d and K_k of elements between pairs of groups or subgroups were revealed by the Mann–Whitney U-test, while significant differences among various numbers of groups were determined according to parallel classification using the Kruskal–Wallis test. The latter test shows whether several independent samples are from the same population. The significance level of tests was 0.05.

RESULTS

According to the median concentration coefficients K_{kmed}, all the analysed chemical elements in all land-use sites of the study area are arranged in the following sequence: Zn(5.2) > Ag(4.0) > > Cu(3.2) > Pb(2.8) > Sn(1.9) > Mo(1.4) > Ni(1.3) > V, Co(1.1). K_{kmed} of B, Cr, Mn and Ba are lower than the background values for the Vilnius district.

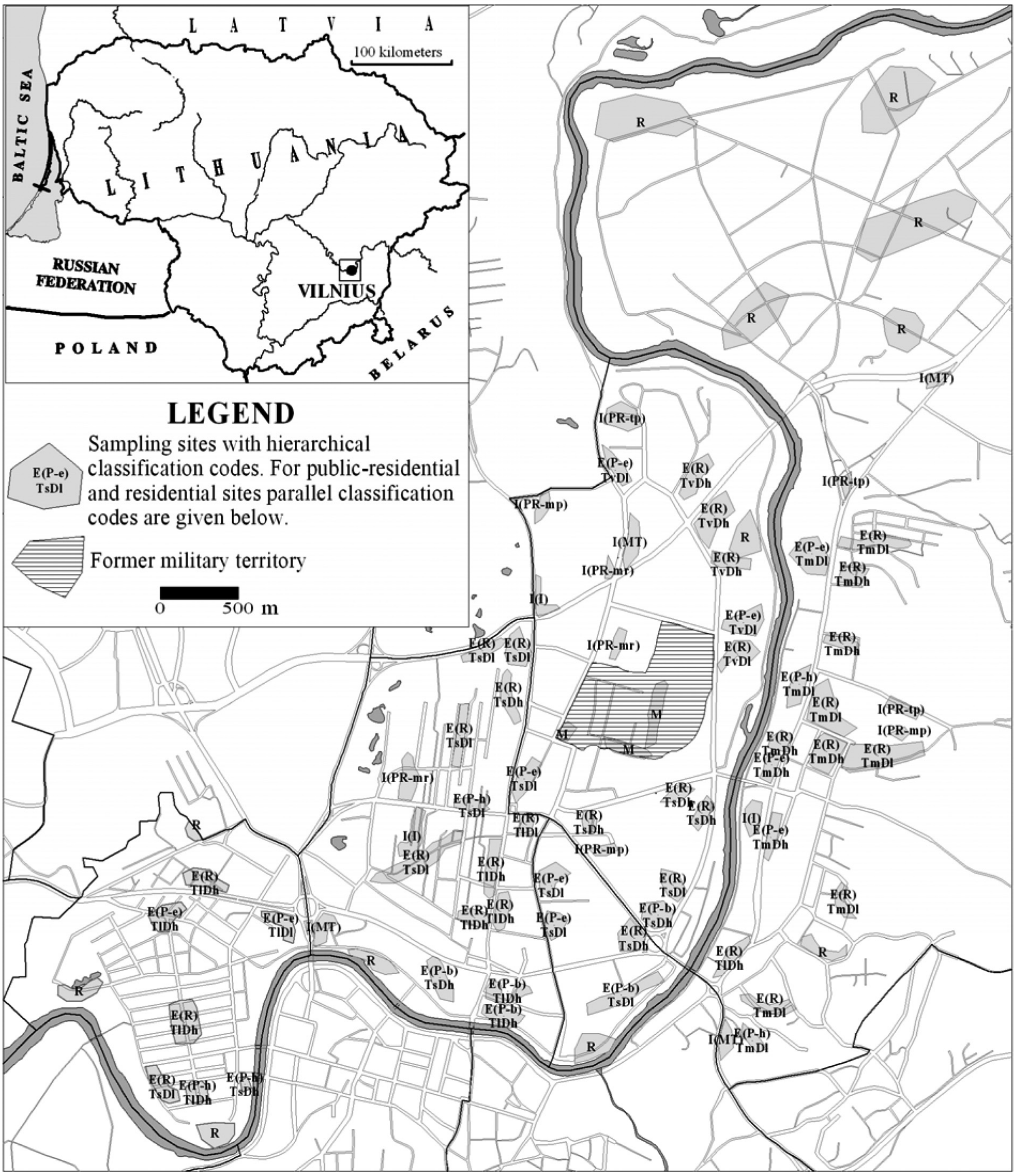

Fig. 1. Groups and subgroups of sites.

Notes. Groups of land-use sites: I – infrastructural-industrial (n = 16), E – residential or public-residential (n = 51), M – former military (n = 3), R – recreational R (n = 12). Hierarchical classification of group I: 1) 1st level subgroups: I(I) – industrial (n = 3), I(PR) – parking and repair of transport (n = 9), I(MT) – main traffic roads (n = 3); 2) 2nd level subgroups for subgroup I(PR): I(PR-tp) – trolley-bus parking (n = 3), I(PR-mp) – motor transport parking (n = 3), I(PR-mr) – motor transport repair (n = 3). Hierarchical classification of E group: 1) 1st level subgroups: E(R) – residential (n = 31), E(P) – public-residental (n = 20); 2) 2nd level subgroups for subgroup E(P): E(P-b) – public business (n = 5), E(P-e) – public education (n = 10), E(P-h) – public health care (n = 5). Parallel classification of E group according to categories of factors: T – maximum time-span of urbanisation (Tl – long, i. e. >100 years (n = 12), Tm – medium long, i. e. 35–100 years (n = 14), Ts – short, i. e. 25–35 years (n = 19), Tv – very short, i. e. <25 years (n = 6)); D – density of built-up areas (Dl – low, i. e. <15% (n = 24), Dh – high, i. e. ≥15% (n = 27)); n in parentheses – number of sites

1 pav. Sklypų grupės ir pogrupiai.

Pastabos. Sklypų grupės pagal žemėnaudą: I – infrastruktūrinė-pramoninė (n = 16), E – gyvenamoji ir visuomeninė-gyvenamoji (n = 51), M – buvusi karinė (n = 3), R – rekreacinė (n = 12). Hierarchinė I grupės klasifikacija: 1) 1-ojo lygio pogrupiai: I(IE) – pramoninis (n = 3), I(PR) – transporto parkavimo ir remonto (n = 9), I(MT) – magistralinių gatvių (n = 3); 2) 2-ojo lygio I(PR) pogrupiai: I(PR-tp) – troleibusų parkavimo (n = 3), I(PR-mp) – autotransporto parkavimo (n = 3), I(PR-mr) – autotransporto remonto (n = 3). Hierarchinė E grupės klasifikacija: 1) 1-ojo lygio pogrupiai: E(R) – gyvenamasis (n = 31), E(P) – visuomeninis-gyvenamasis (n = 20); 2) 2-ojo lygio E(P) pogrupiai: E(P-b) – prekybinis (n = 5), E(P-e) – švietimo (n = 10), E(P-h) – sveikatos apsaugos (n = 5). Lygiagreti E grupės klasifikacija pagal veiksnių kategorijas: T – didžiausia urbanizacijos trukmė (Tl – ilga, t. y. >100 metų (n = 12), Tm – vidutinio ilgumo, t. y. 35–100 metų (n = 14), Ts – trumpa, t. y. 25–35 metai (n = 19), Tv – labai trumpa, t. y. < 25 metų (n = 6)); D – užstatymo tankis (Dl – mažas, t. y. < 15% (n = 24), Dh – didelis, t. y. ≥ 15% (n = 27)). n skliaustuose – sklypų skaičius

Table 1. **Accumulating associations and contamination indices in hierarchical groups of sites**
1 lentelė. **Kaupimosi asociacijos ir užterštumo rodikliai hierarchinėse sklypų grupėse**

Group or subgroup of sites	Accumulating association
Industrial-infrastructural sites – I	Zn > Cu > Pb > Ag > Mo > Sn > Ni
Industrial sites – I(I)	Zn > Ag > Cu > Pb > Sn > Mo > Ni > Cr
Parking and repair of transport sites – I(PR)	Cu > Zn > Pb > Ag > Sn > Mo > Ni > Co
Motor transport repair sites – I(PR-mr)	Zn > Cu > Pb > Ag > Mo > Sn > Ni > Co
Motor transport parking sites – I(PR-mp)	Zn > Cu > Pb > Ag > Sn > Mo > Co > Cr > Ni
Trolley-bus parking sites – I(PR-tp)	Cu > Zn > Pb > Ag > Mo > Sn
Sites near main traffic roads – I(MT)	Cu > Zn > Pb > Ag > Sn > Mo
Residential and public-residential sites – E	Zn > Ag > Cu > Pb > Sn > Mo
Residential sites – E(R)	Zn > Ag > Cu > Pb > Sn > Mo > Ni
Public-residential sites – E(P)	Zn > Ag > Cu > Pb > Sn > Mo
Public health care sites – E(P-h)	Ag > Zn > Cu > Pb > Sn > Mo
Public education sites – E(P-e)	Zn > Ag > Cu > Pb > Sn
Public business sites – E(P-b)	Zn > Sn > Ag > Pb > Cu > Mo
Former military sites – M	Pb = Ag > Zn
Recreational sites – R	Ag > Zn > Pb

Group or subgroup	N	Z_d	Z_{nf}	Z_f	Zn	Cu	Pb	Ag	Sn	Mo	Ni	Cr	Co	V	B	Ba	Mn
I	16	20.2	17.5	3.1	**6.62**	**6.09**	**4.06**	**2.69**	**2.04**	**2.05**	**1.48**	1.12	1.24	1.17	0.88	0.78	0.89
I(I)	3	57.7	35.7	4.5	**12.65**	**7.40**	**5.00**	**11.6**	**4.05**	**2.22**	**2.11**	**1.88**	1.12	1.13	0.98	0.8	0.93
I(PR)	9	23.2	20.4	3.3	**7.26**	**9.19**	**4.17**	**2.72**	**2.06**	**2.02**	**1.53**	1.13	**1.43**	1.23	0.86	0.87	0.86
I(PR-mr)	3	19.6	18.9	4.0	**9.02**	**6.15**	**3.95**	**2.72**	**2.06**	**2.54**	**1.61**	1.13	**1.43**	1.27	0.97	0.95	1.06
I(PR-mp)	3	23.2	15.3	4.0	**7.26**	**4.33**	**3.69**	**2.92**	**2.12**	**2.02**	**1.53**	**1.64**	**1.68**	1.15	0.86	0.79	0.75
I(PR-tp)	3	25.9	21.4	2.2	**5.97**	**11.81**	**5.05**	**2.13**	**1.44**	**1.49**	1.29	0.83	1.19	1.23	0.85	0.66	0.69
I(MT)	4	10.5	7.9	2.1	**3.03**	**3.65**	**2.32**	**2.17**	**1.77**	**1.55**	1.29	0.85	1.17	1.12	0.88	0.73	0.93
E	51	17.2	14.7	2.0	**6.07**	**3.12**	**2.81**	**4.69**	**1.97**	**1.37**	1.27	0.88	1.14	1.17	0.88	0.83	0.85
E(R)	31	17.9	14.7	2.0	**6.11**	**3.20**	**2.75**	**4.77**	**1.91**	**1.38**	**1.32**	0.89	1.15	1.18	0.87	0.88	0.91
E(P)	20	15.3	13.6	1.8	**5.36**	**2.97**	**2.86**	**4.35**	**2.02**	**1.32**	1.16	0.80	1.14	1.14	0.90	0.80	0.82
E(P-h)	5	26.1	24.9	2.0	**6.36**	**3.56**	**2.44**	**11.8**	**2.02**	**1.53**	1.16	0.79	1.17	1.11	1.04	0.70	0.73
E(P-e)	10	11.7	14.8	1.7	**4.45**	**3.44**	**2.91**	**3.85**	**1.72**	1.27	1.17	0.87	1.10	1.17	0.89	0.80	0.82
E(P-b)	5	14.6	13.7	1.8	**3.81**	**2.57**	**2.83**	**2.97**	**3.10**	**1.37**	1.09	0.78	1.15	1.14	0.87	0.89	0.92
M	3	6.1	5.2	1.3	**1.98**	1.20	**2.43**	**2.43**	1.20	1.11	0.93	0.64	1.10	1.05	0.84	0.83	0.73
R	12	5.6	3.5	1.0	**1.66**	1.21	**1.44**	**1.93**	1.28	0.98	0.9	0.73	0.97	0.84	0.88	0.56	0.91

Notes. Medians of concentration coefficients of elements K_{kmed} and Z_d are given. $K_{kmed} > 1.3$ are in bold. N – number of sites, Z_d – additive contamination index, Z_{nf} – non-ferrous index, i.e. generalised additive contamination index according to K_{kmed} of elements related to non-ferrous metals (Zn, Pb, Cu, Sn, Ag), Z_f – ferrous index, i.e. generalised additive contamination index according to K_{kmed} of elements related to ferrous metals (Mo, Ni, Cr, Co, V).

Pastabos. Pateiktos elementų koncentracijos koeficientų ir Z_d medianos. $K_{kmed} > 1,3$ paryškintos. N – sklypų skaičius, Z_d – bendras užterštumo rodiklis, Z_{nf} – spalvotasis rodiklis, t. y. generalizuotas adityvinis užterštumo rodiklis pagal su spalvotaisiais metalais susijusių elementų (Zn, Pb, Cu, Sn, Ag) K_{kmed}, Z_f – juodasis rodiklis, t. y. generalizuotas adityvinis užterštumo rodiklis pagal su juodaisiais metalais susijusių elementų (Mo, Ni, Cr, Co, V) K_{kmed}.

Land-use factor. The median values of the additive contamination index Z_d and non-ferrous and ferrous indices decrease in the following sequence of land-use sites: I(infrastructural-industrial) > E(residential or public-residential) > M(former military) > R(recreational) (Table 1). The median Z_d of I and E sites belongs to the medium-dangerous category ($16 < Z_d < 32$) (HN 60-2004, 2004). All the four groups of land-use sites are characterised by the non-ferrous index higher than the ferrous index, indicating the overall prevalence of pollution by Zn, Cu, Pb, Ag and Sn. These elements are obviously related to traffic. Besides them, the accumulating association of infrastructural-industrial sites includes also Mo and Ni, and that of the residential or public-residential sites contains Mo. Their sources might be not only industrial technological processes, e. g. the former plant of fuel equipment (Taraškevičius, Šiaudinienė, 2001), but also transport; e. g. Mo might be related to traffic (Zhang, 2006). To conclude, the following seven elements may be called the main contaminants of the study area: Zn, Cu, Pb, Ag, Sn, Mo, Ni. They will be analysed in more detail. There is an obvious decrease of their number in accumulating associations of the above-mentioned sequence of land-use sites. A similar decrease was observed for K_{kmed} of Zn, Pb, Mo and Ni. The distribution of Cu and Sn in the land-use sequence is also very similar, because the difference between their K_k in military and recreational groups is not significant. The low contamination level of former military zones indicates that the new soil cover there does not reflect the previous history of pollution. These zones are presently used for living and are not yet considerably contaminated. Though Z_d values of I and E sites do not differ significantly, for most of the main contaminants (except Zn, Sn and Ag) the accumulation level in infrastructural-industrial sites is significantly higher than in E sites (for all the main contaminants, except Ag, it is also significantly higher than in military and recreational sites). This is quite natural due to obvious pollution sources in I sites. However, the behaviour of Ag is different: its highest accumulation level is observed in E sites. Besides, it is significantly higher than in infrastructural-industrial and recreational sites. A much more important role of Ag in accumulating association of E sites is also obvious. Silver might be related to de-icing salts and coal or firewood use for heating of the houses. Other investigators suppose that Ag has domestic sources (Han et al., 2006). The K_{kmed} of Sn in E sites is almost the same as in I sites, and the difference between both groups in Zn is insignificant. The high K_{kmed} of Zn and Ag in E sites is in agreement with data from Russia, which have shown that these two elements are the first indicators of the beginning of urbanisation (Головин и др., 1997). It is quite natural that the values of Z_d and K_k of all the main pollutants in E sites are significantly higher than in the recreational group and in former military sites (except Pb and Ag). Like in E sites, the high concentration coefficients K_k of Pb and Ag in the new residential districts on the former military zone can be explained by traffic load and the use of de-icing salts.

Type of pollution in infrastructural-industrial sites (I). The decrease of Z_{dmed} and K_{kmed} of almost all the main contaminants (except Cu), also Cr, non-ferrous and ferrous indices was observed in the following sequence of subgroups: I(I – industrial) > I(PR – parking and repair of transport) > I(MT – main traffic roads). This regularity indicates that the present or the former industry is still the most dangerous in I group; the topsoil of these sites belongs to the dangerous category ($32 < Z_d < 128$). The topsoil of parking and repair of transport belongs to the medium-dangerous category ($16 < Z_d < 32$). Despite the higher K_{kmed} of Zn, Ag and Sn in industrial sites in comparison with sites of parking and repair of transport, the differences in all contamination indices between these two subgroups of sites are insignificant, most probably due to a large variability of indices. The accumulating associations of both subgroups include eight elements (with either Cr or Co added to the main pollutants). The contamination level of sites near main traffic roads is significantly lower than of the previous two subgroups of sites, and the accumulating association includes six elements (five related to non-ferrous metals and Mo). In comparison with this subgroup, in sites of parking and repair of transport K_k of Cu and in industrial sites K_k of Cu, Mo and Ni are significantly higher. So there is a higher input of elements related to ferrous metals in industry-related sites. In sites of parking and repair of transport I(PR), there are no significant differences between parking types (trolley-bus or motor transport), also between subgroups related to motor transport (repair or parking). However, a significantly higher contamination by Mo and Ni was found in motor transport repair sites compared to trolley-bus parking sites, indicating a higher input of elements related to ferrous metals in technological processes of repair. According to the distribution in sites subgroups of parking and repair of transport I(PR), the main contaminants can be subdivided: Cu and Pb – mostly contaminating trolley-bus parking sites, Zn, Mo and Ni – mostly contaminating motor transport repair sites, Ag and Sn – mostly contaminating motor transport parking sites.

Centres of attraction in residential and public-residential sites (E). Median Zd, median contamination of most of the main pollutants, except Pb and Sn, and both generalised indices are slightly higher in residential E(R) than in public-residential E(P) sites. However, the U-test did not reveal any significant differences between these sites, except Ni, the K_k of which is significantly higher in residential as compared with public-residential sites. The accumulating associations of both groups of sites are almost identical. Therefore, to reveal the influence of different anthropogenic factors, the whole E group of sites can be analysed as one population (see analysis below). In public-residential sites E(P), there is a significantly higher contamination of public health care sites E(P-h) by Ag compared to public education E(P-e) and public business E(P-b) sites and a significantly higher contamination of public business sites E(P-b) by Sn as compared with E(P-e) sites. This is also reflected in accumulating associations of public health care and public business sites. The highest K_{kmed} are observed in different subgroups of E(P): for Ag, Zn, Cu, Mo in public health care sites, Sn in public business sites, Pb and Ni in public education sites. So, the arrangement of subgroups according to Zd, non-ferrous and ferrous indices slightly differs, public health care sites being most highly contaminated, probably due to local pollution sources in health care institutions.

Anthropogenic factors in residential and public-residential sites (E). The Kruskal–Wallis H test of the parallel influence of anthropogenic factors on topsoil contamination in the E group of sites revealed significant differences for Z_d, K_k of Ag, Cu, Pb, Sn and Zn according to the factor of time-span of urbanisation and no significant differences according to the factor of the density of built-up areas, indicating that the main variability of contamination, especially by elements related to non-ferrous metals, can be expected according to the first factor. This can be clearly seen according to median Z_d values calculated for categories of both anthropogenic factors (Fig. 2).

There is an obvious decrease of Z_{dmed}, K_{kmed} of Ag, Zn, Cu and Z_{nf} as the time-span of urbanisation decreases (Table 2). The U-test revealed the greatest number of significant differences for K_k of Ag (except for sites of a long and medium time-span). For Zn, Cu and Z_d, there is a significantly higher accumulation in long time-span sites compared to short and very short and in medium time-span sites compared to very short, indicating greater differences between more distant categories of this general anthropogenic factor. The distribution patterns of Pb and

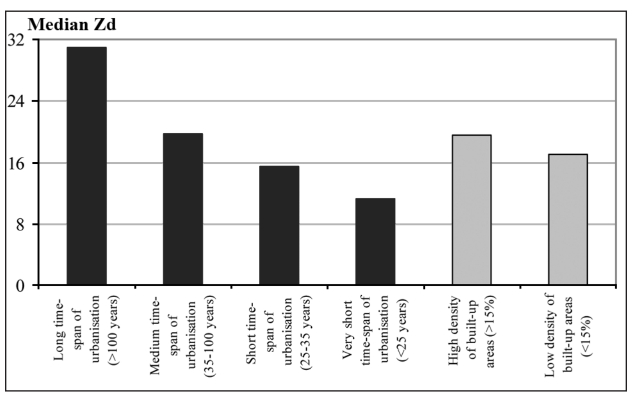

Fig. 2. Median additive contamination indices in public-residential and residential sites with different time-span of urbanisation and density of built-up areas

2 pav. Skirtingos urbanizacijos trukmės ir užstatymo tankio visuomeninių-gyvenamųjų ir gyvenamųjų sklypų medianiniai suminiai užterštumo rodikliai

Table 2. **Accumulating associations and contamination indices in subgroups of public-residential and residential sites distinguished according to parallel factors**
2 lentelė. **Kaupimosi asociacijos ir užterštumo rodikliai pagal lygiagrečius veiksnius išskirtuose visuomeninių-gyvenamųjų ir gyvenamųjų sklypų pogrupiuose**

Group or subgroup of residential and public-residential sites	Accumulating association
Long time-span of urbanisation (>100 years) – E(Tl)	Zn > Ag > Pb > Cu > Sn > Mo
Medium time-span of urbanisation (35–100 years) – E(Tm)	Ag > Zn > Cu > Pb > Sn > Ni >
Short time-span of urbanisation (25–35 years) – E(Ts)	Zn > Ag > Cu > Pb > Sn > Mo
Very short time-span of urbanisation (<25 yars) – E(Tv)	Zn > Pb > Ag > Cu > Sn > Mo > Ni
High (>15%) density of built-up areas – E(Dh)	Zn > Ag > Pb > Cu > Sn > Mo
Low (<15%) density of built-up areas – E(Dl)	Zn > Ag > Cu > Pb > Sn

	N	Z_d	Z_{nf}	Z_f	Ag	Zn	Cu	Pb	Sn	Mo	Ni	Co	V	Cr	B	Ba	Mn
E(Tl)	12	30.98	23.53	1.99	**6.98**	**9.11**	**4.29**	**4.45**	**2.72**	**1.37**	1.29	1.15	1.19	0.96	0.96	0.73	0.83
E(Tm)	14	19.66	16.11	1.84	**6.88**	**6.20**	**3.22**	**2.10**	**1.73**	1.24	**1.35**	1.17	1.09	0.88	1.03	0.77	0.85
E(Ts)	19	15.47	13.65	1.81	**4.42**	**5.34**	**3.06**	**2.92**	**1.91**	**1.38**	1.14	1.11	1.18	0.86	0.85	0.91	0.89
E(Tv)	6	11.23	7.92	1.96	**2.37**	**3.66**	**1.72**	**2.64**	**1.54**	**1.37**	**1.32**	1.11	1.16	0.84	0.88	0.86	0.95
E(Dh)	27	19.54	17.11	1.96	**4.67**	**7.63**	**3.12**	**3.41**	**2.28**	**1.37**	1.28	1.13	1.18	0.89	0.88	0.84	0.89
E(Dl)	24	17.02	13.79	1.81	**4.73**	**5.60**	**3.04**	**2.67**	**1.77**	1.28	1.24	1.16	1.14	0.88	0.89	0.80	0.82

Explanations of indices are given in Table 1.
Rodiklių paaiškinimai pateikti 1 lentelėje.

Sn are similar according to a significantly lower K_{kmed} in medium time-span sites compared with long ones. However, unlike Sn, the accumulation of Pb in short time-span sites is significantly higher as compared with those medium, most probably reflecting a higher topsoil contamination by leaded gasoline due to the high traffic intensity in relatively younger areas built in the 60s, compared with slightly older ones. Besides, the areas of short time-span are in formerly more industrialised districts and could be affected by former military pollution, its main indicator being Pb (Taraškevičius, Šiaudinienė, 2001). The accumulation of Sn in the very short time-span subgroup is significantly lower compared to the short time one.

The U-test for E sites of a lower or higher built-up density has not revealed significant differences in contamination indices, though both generalised indices, Z_{dmed} and K_{kmed}, of almost all the main contaminants, except Ag, are slightly higher in more built-up sites. Increase of built-up density mostly enhances contamination by Zn, Pb and Sn, resulting in changes of accumulating associations, though not yet significant due to a possible parallel influence of other factors. A comparison of lower or higher built-up density sites in groups of the same urbanisation level has not revealed significant differences in contamination indices, either.

CONCLUSIONS

1. Zn, Ag, Cu, Pb, Sn, Mo and Ni are the main elements-contaminants of the urbanised territory of the Neris River valley in Vilnius. According to the median concentration coefficients K_{kmed}, all analysed chemical elements are arranged in the following sequence: Zn(K_{kmed} = 5.2) > Ag(4.0) > Cu(3.2) > Pb(2.8) > > Sn(1.9) > Mo(1.4) > Ni(1.3) > V, Co(1.1). K_{kmed} of B, Cr, Mn and Ba are lower than the background of the soil region. In different land-use sites, the generalised additive contamination index Z_{nf} calculated according to K_{kmed} of Ag, Cu, Pb, Sn, Zn is higher than the generalised additive contamination index Z_f calculated according to K_{kmed} of Mo, Ni, Cr, Co, V.

2. The general anthropogenic factor of three main groups of land-use – infrastructural-industrial, residential or public-residential, recreational – has the greatest influence on urban topsoil contamination, because the median additive contamination Z_{dmed}, as well as Z_{nf} and Z_f decrease in the sequence of these land-use sites. The low contamination level of the former military zones which are now used for living indicates that the new soil cover there does not reflect the previous history of pollution.

3. In infrastructural-industrial land-use sites which are influenced by direct anthropogenic factors, i.e. various types of pollution, the concentration coefficients K_{kmed} of most of the main contaminants (Pb, Cu, Mo, Ni) are significantly higher than in the residential and public residential groups in which the diffuse and household pollution prevails, and therefore the role of the indirect anthropogenic factors such as the density of built-up areas, as well as of the general factor of the time-span of urbanisation increases.

4. In the infrastructural-industrial group, the present or the former industry is the main direct factor, followed by the parking or repair of transport, and the latter is followed by main traffic roads; both generalised additive contamination indices, Z_{dmed} and K_{kmed} of all the main pollutants, except Cu, decrease in this sequence. The highest K_{kmed} of Cu is characteristic of transport parking or repair sites, in the latter group trolley-bus parking places being mostly contaminated by Cu and Pb, motor transport parking places by Ag and Sn, and motor transport repair zones by Zn, Mo and Ni.

5. In residential and public-residential sites, the main variability is related to the time-span of urbanisation with significant differences for Z_d, K_k of Ag, Cu, Pb, Sn and Zn and an increase of Z_{nf}, Z_{dmed} and K_{kmed} of Ag, Zn and Cu as the time-span of urbanisation grows. For the factor of density of built-up areas, no significant differences were found, probably due to a simultaneous influence of other anthropogenic factors.

6. The differences between public-residential and residential sites are mostly insignificant, indicating a similarity of population exposure in both land-use types. In public-residential sites, a higher contamination by Ag is characteristic of public health care sites and by Sn of public business sites.

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ANTROPOGENINIŲ VEIKSNIŲ NULEMTI VILNIAUS PAVIRŠINIO DIRVOŽEMIO UŽTERŠTUMO NERIES UPĖS SLĖNYJE SKIRTUMAI

Santrauka

Analizuojami Vilniaus centre Neries upės slėnyje esančių 82 sklypų, sujungtų į grupes ir pogrupius pagal įvairių antropogeninių veiksnių įtaką, paviršinio dirvožemio užterštumo Zn, Pb, Cu, Sn, Ag, Mo ir Ni skirtumai. Šie cheminiai elementai yra pagrindiniai tiriamos teritorijos teršalai tarp 13 tirtų cheminių elementų. Visų jų bendri kiekiai yra nustatyti optinės atominės emisijos spektrofotometrinės analizės metodu < 1 mm frakcijoje. Pagal gamtinius veiksnius teritorija vienalytė. Bendras antropogeninis trijų pagrindinių žemėnaudos grupių – infrastruktūrinės-pramoninės, gyvenamosios ar visuomeninės-gyvenamosios, rekreacinės – veiksnys turi didžiausią įtaką miesto dirvožemių užterštumui. Infrastruktūriniams-pramoniniams sklypams, kuriuos veikia tiesioginiai antropogeniniai veiksniai, lemiami įvairių taršos šaltinių, yra būdingi reikšmingai didesni pagrindinių teršalų – Pb, Cu, Mo, Ni – koncentracijos koeficientai negu gyvenamiesiems ar visuomeniniams-gyvenamiesiems, kur vyrauja įnaša iš išsklaidytų šaltinių ir padidėja netiesioginio antropogeninio veiksnio – užstatymo tankio – bei bendrojo antropogeninio veiksnio – urbanizacijos trukmės – santykinis vaidmuo. Infrastruktūriniuose-pramoniniuose sklypuose pagrindinis tiesioginis veiksnys yra pramonė, toliau eina transporto parkavimas ir remontas, po jo – magistralinių gatvių transporto įtaka. Gyvenamųjų ar visuomeninių-gyvenamųjų sklypų pagrindinė užterštumo kaita susijusi su urbanizacijos trukme, kuriai didėjant auga Ag, Zn ir Cu kiekiai. Nors tankiau užstatytuose (>15%) sklypuose užterštumo rodikliai didesni, skirtumai nėra statistiškai reikšmingi. Visuomeninių-gyvenamųjų ir gyvenamųjų sklypų dirvožemio užterštumo skirtumai dažniausiai nereikšmingi. Visuomeninės-gyvenamosios žemėnaudos grupėje sveikatos apsaugos įstaigų sklypams būdingas didesnis užteršumas Ag, o prekybinių objektų sklypams – Sn.

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РАЗЛИЧИЯ ЗАГРЯЗНЕНИЯ ПОВЕРХНОСТНОЙ ПОЧВЫ Г. ВИЛЬНЮСА В ДОЛИНЕ РЕКИ НЯРИС ПОД ВОЗДЕЙСТВИЕМ АНТРОПОГЕННЫХ ФАКТОРОВ

Резюме

Анализируются различия загрязнения поверхностной почвы Zn, Pb, Cu, Sn, Ag, Mo и Ni между группами и подгруппами 82 участков центральных районов Вильнюса, находящихся в долине реки Нярис, с целью объяснить их воздействием различных антропогенных факторов. Эти микроэлементы являются главными загрязнителями на исследуемой территории, выявленными среди 13 микроэлементов, валовые содержания которых определены оптическим атомным эмиссионным спектрофотометрическим анализом во фракции <1 мм. Территория является сравнительно однородной в отношении природных факторов. Общий антропогенный фактор трех главных групп землепользования (инфраструктурно-промышленной, селитебной или общественно-селитебной, рекреационной) оказывает наибольшее влияние на загрязнение почв. В группе инфраструктурно-промышленных участков, на которые воздействуют прямые антропогенные факторы – типы источников загрязнения, коэффициенты концентрации большинства основных загрязнителей (Pb, Cu, Mo, Ni) статистически значимо выше, чем в группе селитебных или общественно-селитебных участков, где преобладает вклад рассеянного загрязнения и сравнительно возрастает роль таких антропогенных факторов, как плотность застройки (косвенный) и длительность урбанизации (общий). В группе инфраструктурно-промышленных участков основным прямым фактором является промышленность, далее следует паркование и ремонт транспорта, затем – транспорт на магистральных улицах. В группе селитебных или общественно-селитебных участков основная вариабельность загрязнения связана с длительностью урбанизации, при увеличении которой возрастает содержание Ag, Zn и Cu. Хотя для участков с большей плотностью застройки (>15%) характерны более высокие показатели загрязнения, статистически значимых различий загрязнения поверхностных почв на этих участках не выявлено, видимо, из-за одновременного воздействия других антропогенных факторов. Различия между загрязнением поверхностных почв общественно-селитебных и селитебных участков в основном незначительны, поэтому жители этих несколько различных типов землепользования подвергаются схожему опасному воздействию. В подгруппе общественно-селитебного землепользования для участков здравоохранительных учреждений характерно более высокое накопление Ag, а для коммерческих участков – Sn.