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RELATIONSHIP BETWEEN LANDSCAPE SELF-REGULATION POTENTIAL AND TOPSOIL ADDITIVE CONTAMINATION BY TRACE ELEMENTS IN VILNIUS CITY

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Abstract. The aim of investigation was to find out the distribution and relationships between the urban landscape sensitivity to chemical pollution (S) and topsoil additive contamination Zd in the urbanized nucleus of Vilnius taking into account different functional zones. Zd was calculated according to concentration coefficients of 13 chemical elements, and the scores of S were based on integrated evaluation of 7 criteria. Comparison of indices was based on sampling sites. As S indicates the degree of the influence of the load of elements-pollutants in an urban environment, it can only modify, but not predetermine Zd. The linear relationship between lg(Zd) and S is indirect and can be explained by relationship of Zd with percentage of a built-up area. The strict correspondence of the categories of Zd and S is observed only in a small part of sites, and according to percentage of sites with unfavourable categories, Zd exceeds S. In urban territories S is not a reliable indicator of Zd, the significance of S is greater in relatively natural parts of the city. Analysis of both indices reveals the location of contaminated and sensitive to chemical pollution sites. Their highest percentage is in industrial, infrastructural, old town public, old town residential and centre functional zones.

Keywords: urban landscape, urban topsoils, heavy metals, additive contamination index; self-regulation potential, sensitivity to chemical pollution.

1. Introduction

The negative effect of heavy metals and other potentially hazardous trace elements is observed in different environmental compartments: atmosphere, surface and underground water and soil. It is especially noticeable in urban territories where topsoil investigation is used in different countries to reveal the impact of their pollution (Norra *et al.* 2006; Pasieczna 2003; Möller *et al.* 2005). Multivariate statistics and GIS help to analyse the spatial patterns of heavy metals in an urban soil (Zhang 2006). Urbanization and industrialization of the Lithuanian cities also caused their topsoil contamination (Taraškevičius 2000; Taraškevičius, Zinkutė 2003; Kadūnas *et al.* 1999; Zinkutė, Taraškevičius 2005). Recent investigations show that there is cumulative growth of the topsoil contamination level in the greatest cities of Lithuania due to concentration of the population and multifunctional economic activities (Taraškevičius *et al.* 2003; Taraškevičius, Zinkutė 2005).

The genetic capacity of landscape – natural self-regulation potential (P) – is a mechanism ensuring the landscape stability and capacity to reduce possible danger caused by the elements-contaminants. There are many theories explaining this mechanism. They are based on: reversible negative links, inhibiting the chain reactions of impulse transmission; species composition of biocoenoses and activity of microorganisms; hydrothermal factors (Lange 1969; Sochava 1978; Naveh, Lieberman 1990; Antipov *et al.* 1998). and other landscape parameters ensuring the landscape stability (Ivanov *et al.* 1993; Pauliukevičius 2001).

For evaluation of the natural self-regulation potential of an urbanized environment, it is first of all necessary to reveal the integrated response of landscape to pollution. This requires knowledge about the self-regulation potential of discrete landscape components, links between landscape components and the mechanism of elementary territorial units of landscape. The conditions predetermining the natural self-regulation potential in relatively natural territories are more or less known and exhaustively discussed in scientific works (Glazovskaja 1988; Antipov *et al.* 1993; Jankauskaitė 1993; Pauliukevičius, Grabauskienė 1993). Yet, the integrated self-regulation potential of urbanized landscape from the point of view of chemical pollution has not been evaluated and is complicated by a number of specific features of a city (Dobrovolskij 1997; Antipov *et al.* 1998).

The highest self-regulation ability is an attribute of the landscape territorial complexes that are characterized by the high intensity of matter circulation, strong barriers (or buffer capacity) to the fluxes of pollutants or dominance of dispersive fluxes (Jankauskaitė 2002). The dynamic links ensuring the stability of landscape and its ability to treat pollutants exist both in natural and urban territories, but in the latter ones they are greatly disturbed and require a different investigation approach. Though sometimes the territories with a high self-regulation potential, even under a high chemical load, display a comparatively low topsoil total contamination level, it is not always so.

The aim of investigation was to find out the distribution and relationship between the urban landscape sensitivity to chemical pollution (S), which is an opposite index to self-regulation potential, and the total topsoil contamination level (Zd) in the urbanized nucleus of Vilnius city taking into account different functional zones. This is important for estimating the degree of the influence of the load of elements-pollutants in an urban environment and optimization of strategic territory planning.

2. Object and methods of investigation

Topsoil additive contamination index Zd (HN 60-2004 2004). was calculated according to concentration coefficients of 13 elements (their background values in ppm are in parentheses): Ag(0.066), B(21.3), Ba(310), Co(3.5), Cr(24.3), Cu(6.8), Mn(436), Mo(0.64), Ni(9.6), Pb(14), Sn(1.95), V(25.7), Zn(24.9). Their total contents were determined in <1 mm fraction by optical atomic emission spectrophotometry after ashing at 450 °C. Soil samples were taken from the upper 10 cm soil layer and were composite. Sampling density was much higher in the central part of Vilnius and lower in its peripheral part.

The scores of sensitivity to chemical pollution (S) were within the interval 0–80 and were based on integrated evaluation of 7 criteria: percentage of a built-up area, percentage of greeneries, buffer capacity of the soil, character of relief, aeration intensity of a territory, depth of a shallow groundwater table and permeability of the technogenic cover. The estimation of criteria was made by landscape expertise using the methodology proposed earlier (Jankauskaitė 2002). Each of these seven criteria had a different weight, depending on their influence on the urban landscape sensitivity to chemical pollution.

In 10 927 ha of Vilnius territory (its urbanized nucleus) there were 3 398 cells (territorial units). These cells were distinguished based on the methods proposed by G. Godienė (2001). Each cell represents a territory situated in a certain relief, having a similar spatial character of technogenic cover (height and density of buildings, built-up area) and having the same socio-economic function. These cells were the basis for preparing the map of the urban landscape sensitivity to chemical pollution. As soil sampling was not based on these cells, but rather on location of potential pollution sources, the number of soil samples was extremely uneven in different cells, and about 54 % of cells were even not sampled, e.g. the cell including the airport. Besides, Zd values within the sampled cells were often highly variable. The map of sensitivity to chemical pollution was based on the territorial units and was prepared using MapInfo software, while other maps were based on sites and prepared using Surface Mapping System Surfer. The post map with a high deviation of common logarithms of Zd from linear regression was compiled using the same software. The 95 % prediction intervals for linear regression of lg(Zd) on S were determined using SPSS software.

3. Results and discussion

According to the approach of techno-morphological cells, the map of sensitivity to chemical pollution (S) was compiled (Fig 1). In 57.5 % of the investigated territory S was very low ($S \le 12.5$). The areas of a low ($12.5 < S \le 25$) and medium ($25 < S \le 37.5$) S accounted for 20.1 % and 14.4 % of the investigated territory, respectively, the areas of a high ($37.5 < S \le 50$) and very high ($50 < S \le 80$) S – 7.0 % and 1.0 %, respectively.

The precise location of pedogeochemical anomalies is shown in the post map of Zd categories (Fig 2). Greatly different sampling density in the central and peripheral parts is obvious: from 2 322 sampling sites, the main part (95.2 %) was taken in the central part, and only 4.8 % – in peripheral. The following Zd categories were used: very low (or allowable lower: $Zd \le 8$), low (or allowable higher: $8 < Zd \le 16$), medium (or medium dangerous: $16 < Zd \le 32$), high (or dangerous: $32 < Zd \le 128$) and very high (or extremely dangerous: $Zd > 128$). In 41.4 % of sites an allowable level of topsoil contamination (HN 60-2004 2004) was observed, and in 58.6 % – an unallowable level.

The percentages of points were also calculated for 5 categories of S index (described by the above-mentioned intervals). They greatly differ from respective percentages of areas within these intervals and are the following: very low – 30.5 %, low – 42.6 %, medium – 10.2 %, high – 12.6 % and very high – 4.1 %. The sites characterized by very low or low categories of Zc and S indices can be called favourable ones, and with medium, high or very high categories – unfavourable ones. It can be seen that the percentage of unfavourable sites according to S (26.9 %) is more than twice lower than the percentage of unfavourable sites according to Zd (58.6 %), indicating that not all highly contaminated sites are very sensitive to pollution. The percentage of favourable sites according to S both in the central (73.1 %) and peripheral (85.6 %) parts is higher than the percentage of unfavourable sites (26.9 % and 14.4 %, respectively). Meanwhile, according to Zd, only in the peripheral part the percentage of favourable sites is higher compared to unfavourable sites (63.1 % and 36.9 %, respectively), and in the central part the situation is contrary: the percentage of unfavourable sites (59.7 %) is higher compared to favourable ones (40.3 %). Besides, in both territories the percentage of favourable ones according to Zd sites is much lower than the percentage of favourable according to S zones. In the peripheral part the highest percentage according to both Zd and S belongs to a very low category. In the central part the situation is different: according to S, the highest percentage belongs to a low category, and according to Zd – to a medium category, indicating that the central part is less favourable according to both indices compared to the peripheral part (Fig. 3).

As Zd categories are based on a logarithmic scale, it is reasonable to calculate correlation between common logarithm of Zd and S. Such a correlation coefficient ($r = 0.274$) is significant ($p < 0.05$) (Smirnov 1981).

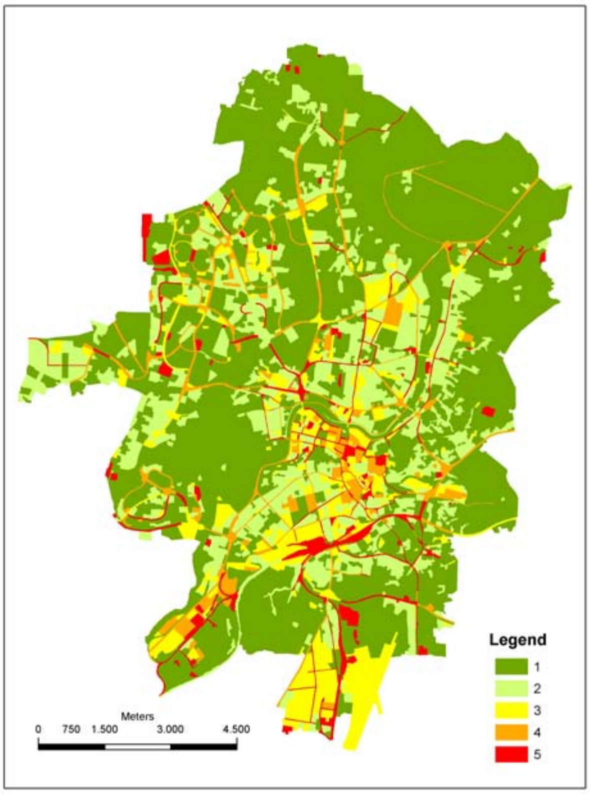

Fig. 1. Sensitivity of territorial units to chemical pollution in urbanized core of Vilnius city Legend of categories according to scores of sensitivity to chemical pollution (S): 1 – very low (S ≤ 12.5), 2 – low (12.5 < S ≤ 25), 3 – medium (25 < S ≤ 37.5), 4 – high (37.5 < S ≤ 50), 5 – very high (50 < S ≤ 80)

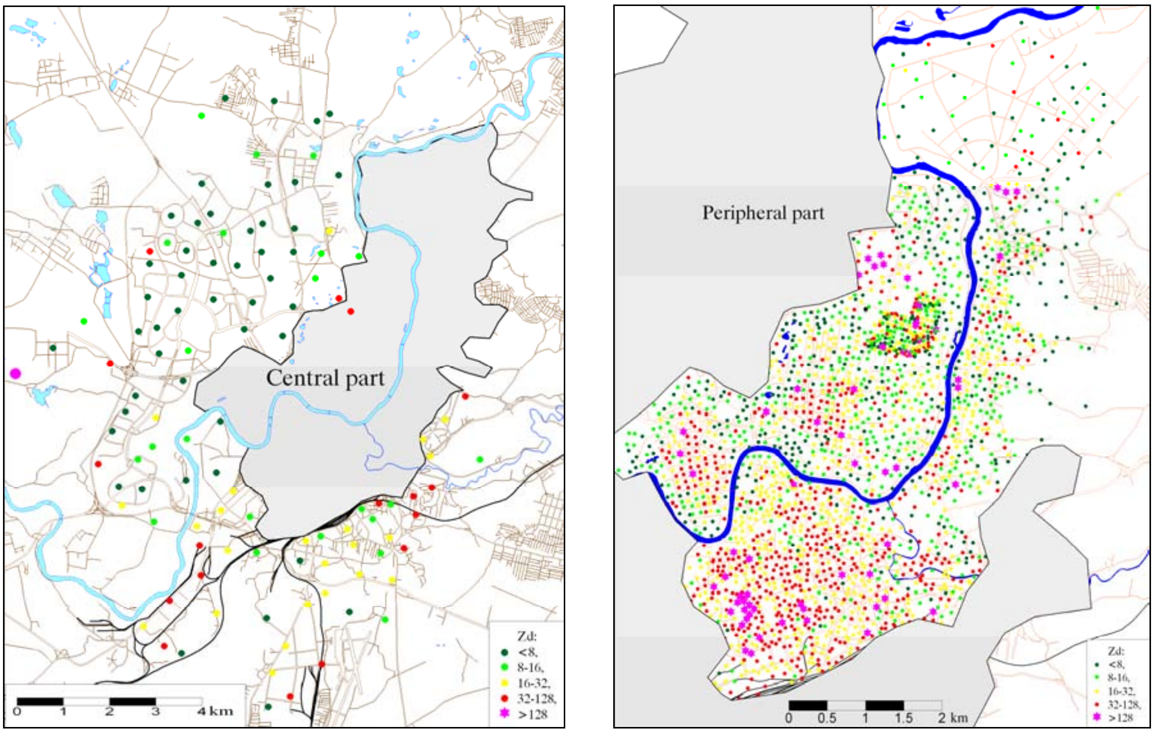

Fig. 2. Additive index Zd of topsoil contamination by Ag, B, Ba, Co, Cr, Cu, Mo, Ni, Pb, Sn, Sr, V, Zn in urbanized core of Vilnius city (peripheral part is on the left figure and central part – on the right figure) Legend: 1 ≤ Zd ≤ 8 – very low (allowable lower) contamination, 8 < Zd ≤ 16 – low (allowable higher) contamination, 16 < Zd ≤ 32 – medium (medium dangerous) contamination, 32 < Zd ≤ 128 – high (dangerous) contamination, Zd > 128 – extremely high (extremely dangerous) contamination

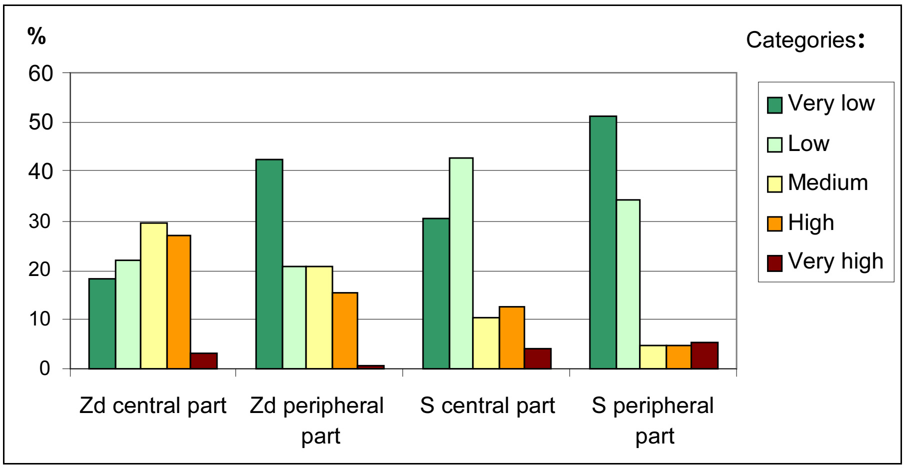

Fig. 3. Percentages of sites belonging to different categories of additive contamination Zd and sensitivity to chemical pollution S in central and peripheral parts

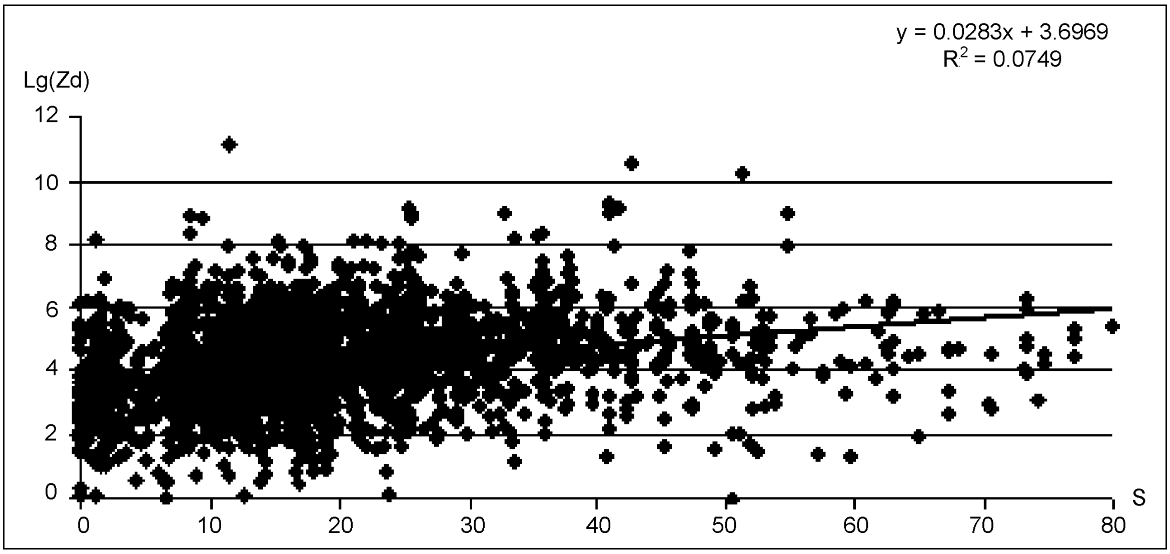

Fig. 4. Linear regression between common logarithm of additive contamination Zd and sensitivity to chemical pollution S

However, the linear relationship between lg(Zd) and S shows many deviations (Fig 4), despite that the regression is significant according to F-test ($p < 0.05$) and both coefficients of equation are significant according to t-test ($p < 0.05$). This is quite natural, because the sensitivity to chemical pollution cannot be the reason of a higher contamination level of topsoil, while Zd values are predetermined by the existing pollution sources, but not by characteristics of the territory. High correlation between lg(Zd) and S is of course indirect and can be explained by good relationship of some of the separate components included into calculation of S, first of all percentage of a built-up area. When the latter is high, there is high probability that the territory is older and has more pollution sources. Older time-span of urbanization always implies the accumulation of elements-pollutants in topsoil, if the soil cover is not disturbed.

Though there are many sampling sites within the 95 % prediction intervals for Zd determined according to the latter linear regression equation, but 4.9 % of the sites are outside these intervals. Positive deviations (2.8 %) are more often than negative (2.1 %) indicating that the contamination level is often higher than that expected according to theoretical relationship. This is because the equation was determined on the whole data set, which includes mainly sites from the central part of the city which is more contaminated.

Sites with contamination higher than expected are often near industrial plants, e.g. in the territories of the former plants of drills, fuel equipment or machines, in the former territory of a military unit, or at streets with heavy traffic (Fig. 5). Sites with lower Zd than expected are often in the valley of the Neris river and other relief depressions, which are usually in the peripheral part of the city where the number of pollution sources is lower.

The categories of index Zd strictly correspond to the categories of S only in 28.7 % of sites, in 50.7 % of sites Zd category is higher, and in 20.6 % of sites it is lower than S category (Table 1).

The links of Zd and S with the territorial function of the cells (10 types of zones) were analysed (Table 2).

There are some similar features of distribution of both indices in 3 zones: both of them have the highest percentage of a very low category in natural (predominated by greeneries of a high biochemical activity – forest parks, suburban forests) and agricultural zones and the highest percentage of a high category – in old-town public zones. However, in most of the other zones (7) there are differences in distribution of the indices. These zones, according to the most abundant categories, can be subdivided into 2 groups: 1) zones with lower Zd categories compared to S categories; 2) zones with higher Zd categories compared to S categories.

More than a half of infrastructural zones (railway junctions, sectors of intensive traffic, junctions of motor roads, fuel stations, garages) are characterized by a very high sensitivity to pollution, however, their most usual contamination category is medium dangerous, and only 5.4 % of such sites are extremely dangerously contaminated. Similar situation is observed in industrial territories: there are more sites with high S than with medium S, but there are more sites with medium Zd than with high Zd. It shows that not all industrial and infrastructural sites are contaminated so much as it is expected. It depends on the type of industry and the quality of environmental management.

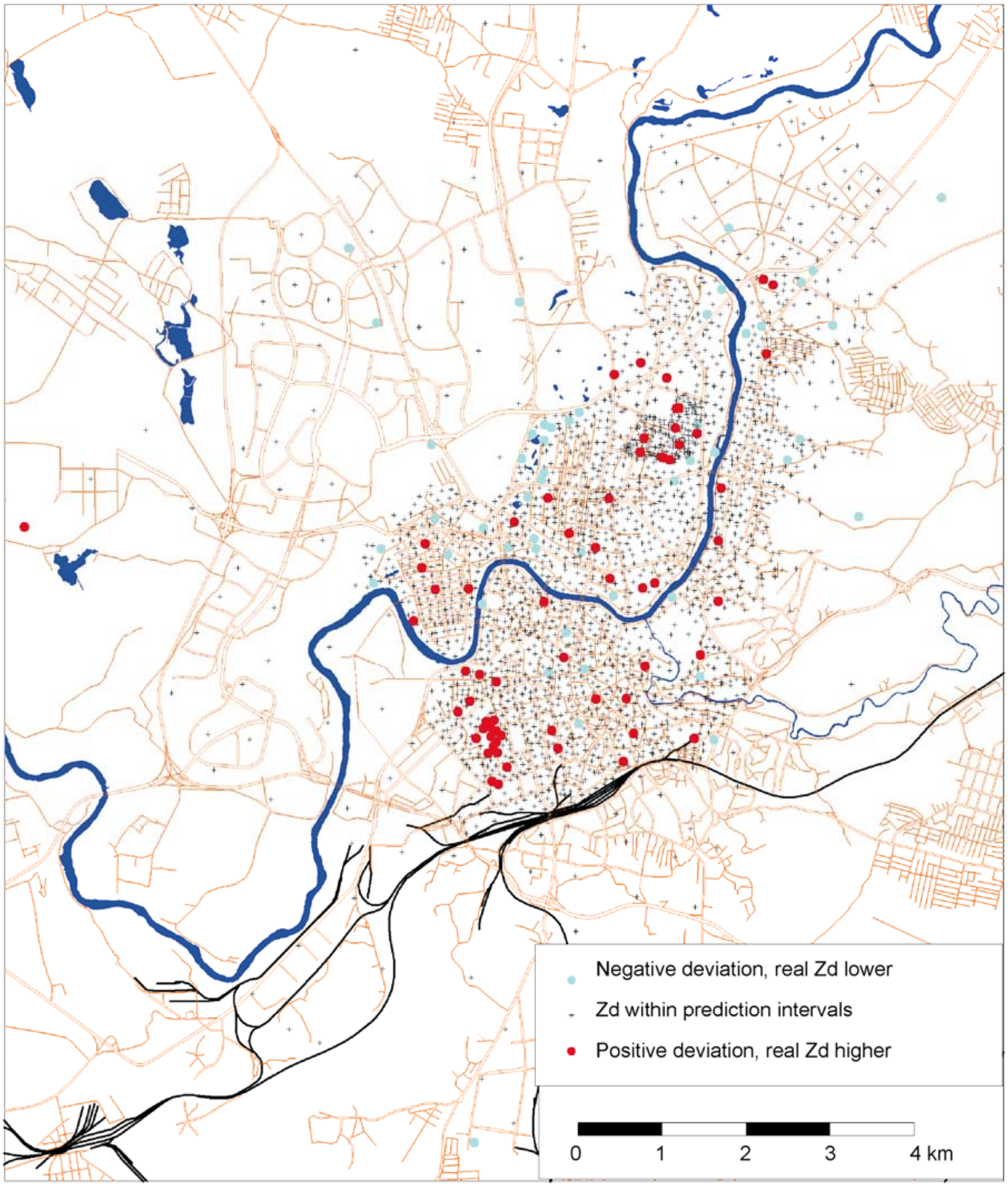

Fig. 5. Sampling sites within the linear regression 95 % prediction intervals for lg(Zd) according to S and outside these intervals

Besides, industrial anomalies are not always so large as to include totally an industrial district. Still seeking to reduce chemical pollution of sensitive territories, much attention should be given to them. Distribution of objects, which act as sources of pollution, should be improved and protective greeneries created. The first group also includes the centre, where the category with the highest percentage of Zd is medium, while the most abundant category of S is high, indicating lower than expected contamination there.

Four zones in the second group (public, residential, old town residential and centre residential) are characterized by the highest percentage of sites with a low category of S and the highest percentage of sites with a medium category of Zd. It means that public-residential districts are often contaminated more than expected. Household pollution, wastes and traffic might be the reason of that. An older history of urbanization and higher density of population also result in a higher accumulation of elements-contaminants.

Only in zones of the above-mentioned first group (industrial, infrastructural and centre) the percentage of sites with unfavourable categories of S index exceeds the percentage of sites with unfavourable categories of Zd, meanwhile in all the other types of zones the relationship is opposite, indicating the prevalence of contamination (Fig. 6).

The sites unfavourable according to Zd are not necessarily unfavourable according to S and vice versa (Table 3).

However, in zones with multiple pollution sources (industrial, infrastructural) or with a longer time-span of urbanization (old town public, old town residential and centre) the percentage of sites unfavourable according to both indices is the highest among 4 possible combinations of Zd and S, indicating that these territories need special attention. In a greater part of public-residential territories, which are not so old (residential, public, centre residential), the highest percentage of sites is unfavourable only according to Zd, indicating the beginning of pollution in the districts, which were built in rather favourable for self-cleaning territories and confirming that pollution goes on independent of sensitivity to chemical pollution. In natural and agrarian zones the greatest part of sites is favourable according to both indices, and the sites unfavourable according to Zd do not coincide with the sites unfavourable according to S.

The outliers of the Zd prediction intervals (Table 4) in most of the zones (7) can be both higher and lower than Zd determined according to the regression equation (positive and negative outliers, respectively).

Table 1. Correspondence between percentage of categories of Zd and S indices

Categories of S	Total number of samples	Categories of Zd				
		Very low	Low	Medium	High	Very high
Very low	708	**33.2**	27.3	20.1	18.1	1.4
Low	990	16.4	23.1	**31.5**	26.7	2.3
Middle	236	8.5	19.9	**35.6**	32.2	3.8
High	293	7.5	10.2	35.8	**39.6**	6.8
Very high	95	14.7	10.5	33.7	**37.9**	3.2
Total	2322	19.5	21.9	29.1	26.7	2.8

Explanation: the highest percentage of Zd for each category of S is in bold.

Table 2. Distribution of percentage of categories of contamination and sensitivity to chemical pollution in types of functional zones

	Categories of contamination					Categories of sensitivity				
Zones	C1	C2	C3	C4	C5	S1	S2	S3	S4	S5
Industrial	12.1	17.1	**33.5**	31.9	5.4	0.4	22.6	30.7	**45.1**	1.2
Infrastructural	15.3	17.7	**34.7**	27.4	4.8	4.8	26.6	3.2	12.1	**53.2**
Old town public	3.9	15.6	37.7	**41.6**	1.3	1.3	22.1	23.4	**40.3**	13.0
Centre	3.8	9.4	**47.2**	39.6	0.0	0.0	9.4	34.0	**50.9**	5.7
Public	22.0	25.8	**29.2**	18.9	4.0	26.5	**48.3**	13.8	10.5	0.9
Old town residential	3.5	11.5	29.2	**52.2**	3.5	6.2	**42.5**	8.0	36.3	7.1
Centre residential	5.6	5.6	**55.6**	33.3	0.0	0.0	**55.6**	22.2	22.2	0.0
Residential	16.1	23.8	**28.9**	**28.9**	2.4	28.5	**66.0**	4.5	1.0	0.0
Natural	**43.4**	24.6	18.9	12.8	0.3	**95.3**	3.0	0.7	1.0	0.0
Agricultural or allotment gardens	**50.0**	25.0	11.4	13.6	0.0	**84.1**	13.6	0.0	0.0	2.3

Explanation: zones were distinguished on the basis of territorial units used in dissertation of G. Godienė, the last two types are generalized by the authors. Categories: S1, Zd1 – very low, S2, Zd2 – low, S3, Zd3 – middle, S4, Zd4 – high, S5, Zd5 – very high. The highest percentage for each zone is indicated in bold.

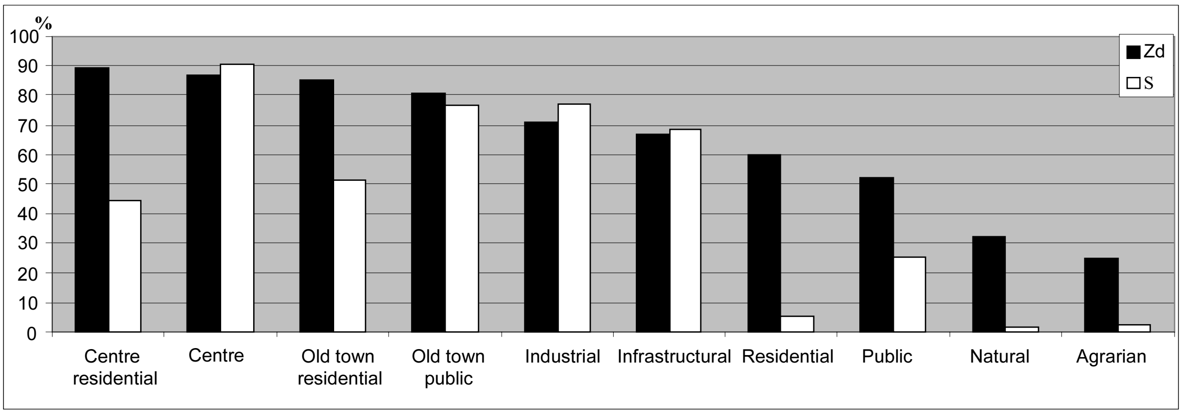

Fig. 6. Percentage of sites with unfavourable categories of Zd and S in different types of zones

Table 3. Percentage of favourable and unfavourable sites in different types of zones

Zones	Favourable	Unfavourable according to S	Unfavourable according to Zd	Unfavourable according to Zd and S
Industrial	9.3	19.8	13.6	**57.2**
Infrastructural	12.1	21.0	19.4	**47.6**
Old town public	7.8	11.7	15.6	**64.9**
Centre	3.8	9.4	5.7	**81.1**
Public	40.1	7.8	**34.7**	17.4
Old town residential	9.7	5.3	38.9	**46.0**
Centre residential	0.0	11.1	**55.6**	33.3
Residential	39.0	0.9	**55.5**	4.6
Natural	**68.0**	0.0	30.3	1.7
Agrarian or allotment gardens	**72.7**	2.3	25.0	0.0

The highest percentage for each zone is indicated in bold.

Table 4. Percentage of sites within and outside the prediction intervals for Zd

Zones	Below the lower limit	Within confidence interval	Above the upper limit
Industrial	0.8	95.3	**3.9**
Infrastructural	**8.9**	87.1	4.0
Old town public	0.0	98.7	**1.3**
Centre	0.0	100.0	0.0
Public	2.9	93.5	**3.6**
Old town residential	0.9	96.5	**2.7**
Centre residential	**5.6**	94.4	0.0
Residential	1.3	95.7	**2.9**
Natural	**2.7**	96.3	1.0
Agrarian	**2.3**	97.7	0.0

A higher percentage of two types of outliers is indicated in bold.

The percentage of negative outliers in natural and agrarian territories is higher than that of positive outliers, indicating that in these zones the regression more often overestimates than underestimates the real value of Zd. It can be supposed that in zones with a higher contamination the percentage of positive outliers will be higher than that of negative outliers. This is true in industrial, old town public, old town residential and residential zones, but not true in centre residential and infrastructural zones. The latter zones are characterized by a high percentage of all outliers: infrastructural (12.9 %), centre residential (5.6 %). The outliers are also often in public (6.5 %), industrial (4.7 %) and residential (4.3 %) zones confirming that the sensitivity to pollution cannot predetermine the pollution itself and the values of topsoil Zd. It can only modify the Zd values in some of the sites, where the pollution of the territory is not very high.

4. Conclusions

As sensitivity to pollution indicates the degree of the influence of the load of elements-pollutants in an urban environment, it can only modify but not predetermine topsoil additive contamination values Zd. Despite this, the linear relationship between lg(Zd) and sensitivity to chemical pollution S exists in an urban environment. The latter relationship is indirect and can be explained by good relationship of Zd with percentage of built-up area, which often implies a longer time-span of urbanization and a greater number of various pollution sources and therefore a higher accumulation of elements-pollutants in topsoil if the soil cover is not disturbed. This relationship in urban territories is more complicated compared to natural territories. Therefore, the strict correspondence of the categories of Zd and S is observed only in a small part of sites (28.7 %), and there are both positive and negative outliers from Zd values determined by regression, especially in infrastructural, public, centre residential, industrial and residential zones. There are also many differences in distribution of the categories of indices in functional zones.

Determination of Zd according to S can be partly useful in natural and agricultural territories, because the results show that in this case the number of negative outliers of Zd prediction intervals is higher compared to positive ones, and therefore the probability of overestimation of Zd exceeds the probability of its underestimation. In such areas the modification of the load of elements-pollutants by sensitivity to pollution plays a noticeable role and can be closer related to actual topsoil Zd.

In most of the zones, except for industrial, infrastructural and centre, the percentage of sites with unfavourable categories of Zd is higher than the percentage of sites with unfavourable categories of S, confirming the primary influence of chemical pollution (load) and the secondary influence of sensitivity to chemical pollution on topsoil Zd as well as the absence of a direct causal dependence of Zd and S indices. So in urban territories sensitivity to chemical pollution is not a reliable indicator of topsoil contamination by hazardous chemical elements and cannot be used alone for planning functional zones of a city. Its significance for planning is greater in relatively natural parts of cities.

Complex analysis of distribution of both indices is especially useful because it reveals the location of contaminated sites in territories sensitive to chemical pollution, where constant observation and strict nature protection measures are necessary. Their highest percentage is in zones with multiple pollution sources (industrial, infrastructural) or with a longer time-span of urbanization (old town public, old town residential zones and the centre).

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RYŠYS TARP KRAŠTOVAIZDŽIO SAVIVALOS POTENCIALO IR PAVIRŠINIO DIRVOŽEMIO SUMINIO UŽTERŠTUMO MIKROELEMENTAIS VILNIAUS MIESTE

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Santrauka

Tyrimų tikslas buvo išaiškinti miesto kraštovaizdžio jautrumo cheminei taršai (S) ir paviršinio dirvožemio suminio užterštumo (Zd) pasiskirstymą ir ryšį urbanizuotame Vilniaus miesto branduolyje, atsižvelgiant į įvairias funkcines zonas. Zd skaičiuotas pagal 13 cheminių elementų koncentracijos koeficientus, o S balai buvo pagrįsti integruotu 7 kriterijų įvertinimu. Rodikliai buvo lyginami pagal ėminių rinkimo vietas. Kadangi S rodo teršiančių elementų apkrovos įtakos laipsnį urbanizuotoje aplinkoje, jis gali tik modifikuoti, bet ne lemti Zd. Tiesinis ryšys tarp lg(Zd) ir S yra netiesioginis, jį galima paaiškinti Zd sąsaja su užstatymo procentine dalimi. Griežtas Zd ir S kategorijų atitikimas yra tik nedaugelyje vietų, o pagal vietų su nepalankiomis kategorijomis procentinę dalį Zd lenkia S. Urbanizuotose teritorijose S nėra patikimas Zd indikatorius, S reikšmingumas yra didesnis santykinai gamtinėse miestų dalyse. Abiejų rodiklių analizė atskleidžia užterštų ir jautrių cheminei taršai vietų išsidėstymą. Didžiausia jų procentinė dalis yra pramoninėse, infrastruktūros, senamiesčio visuomeninėse, senamiesčio gyvenamosiose ir centro funkcinėse zonose.

Reikšminiai žodžiai: miestų kraštovaizdis, miestų dirvožemiai, sunkieji metalai, suminio užterštumo rodiklis, savivalos potencialas, jautrumas cheminei taršai.

СВЯЗЬ МЕЖДУ ПОТЕНЦИАЛОМ САМООЧИЩЕНИЯ ЛАНДШАФТА И СУММАРНЫМ ПОКАЗАТЕЛЕМ ЗАГРЯЗНЕНИЯ ПОВЕРХНОСТНОЙ ПОЧВЫ В ГОРОДЕ ВИЛЬНЮСЕ

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Резюме

Целью исследования было выявление зависимости между чувствительностью городского ландшафта к химическому загрязнению (S) и суммарным показателем загрязнения поверхностной почвы (Zd) в урбанизированном ядре города Вильнюса с учетом разных функциональных зон. Расчет Zd проводился по коэффициентам концентрации 13 химических элементов, а показатель химического загрязнения S в баллах – на основании интегрированной оценки 7 критериев. Индексы сравнивались с учетом мест опробования. Поскольку S показывает степень влияния нагрузки загрязняющих элементов в урбанизированной окружающей среде, он способен только модифицировать, но не предопределять Zd. Линейная зависимость между lg(Zd) и S является косвенной, ее можно объяснить связью Zd с процентной частью застроенности. Строгое соответствие между категориями Zd и S наблюдается только на небольшой части мест, а по процентной части точек с неблагоприятными условиями Zd обгоняет S. На урбанизированных территориях S не является надежным индикатором Zd, значимость S увеличивается в сравнительно более природных частях городов. Анализ обоих показателей выявляет расположение загрязненных и чувствительных к загрязнению мест. В основном эти места находятся в индустриальных, инфраструктурных, общественных и жилых функциональных зонах старого города и центре.

Ключевые слова: городской ландшафт, городская почва, тяжелые металлы, суммарный показатель загрязнения, потенциал самоочищения, чувствительность к химическому загрязнению.

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