NATURAL SELF-CLEANING POTENTIAL OF URBANIZED ENVIRONMENT (VILNIUS CITY CASE)

MARGARITA JANKAUSKAITE

Institute of Geology and Geography,T. Sevcenkos str. 13, LT 2600 Vilnius, Lithuania
e-mail: jankauskaite@geo.lt

Abstract

Jankauskaite M.: Natural self-cleaning potential of urbanized environment (Vilnius city case). Ekológia (Bratislava), Vol. 25, Supplement 1/2006, p. 96–104.

The article presents a concept of natural self-cleaning potential of urbanized environment. An evaluation methodology of integrated response of landscape to chemical pollution is suggested. The importance of different criteria for self-cleaning potential was determined through expert analysis, depending on certain parameters of operating factors and the weigt of criteria in the general evaluation system. A detailed evaluation (3400 technomorphological cells) lies at the basis of the map of natural self-cleaning potential of Vilnius city urban landscape. The information contained in the map is important for users of urbanized areas – territorial planning and environmental institutions responsible for limiting the use of sensitive territories.

Key words: urban ecosystem, self-cleaning potential, chemical pollution

Introduction

Intensive technogenization, concentration of the population and multifunctional economic activity have produced a negative effect on the atmosphere, state of surface and underground water, and ecological functions of soil and plants in the territories of many Lithuanian cities. Trends of urbanization (Lithuanian…, 1995; Godiene, 2001) imply strengthening of this effect in the future. Optimization of the ecological state of urboecosystems requires correct knowledge of the links of most dynamic interrelations, existing in the systems of natural and technogenic phenomena, and of autoregulation potential, e.i., resistance to various anthropogenic loads.

This work is designed as a presentation of valuation methodology of self-cleaning potential of urbanized landscape with respect to chemical pollution and as a practicle illustration of this methodology on the example of Vilnius city.

This work was supported by the Lithuanian State Foundation of Science and Studies.

Data and methods

The genetic capacity of landscape – natural (ecological) potential – is a mechanism ensuring the landscape stability and capacity to get rid of pollutants. 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-cleaning potential of urbanized environment it is first of all necessary to reveal the integrated response of landscape to pollution. This requires knowledge about the self-cleaning potential of discrete landscape components, links between landscape components and the mechanism of elementary territorial units of landscape. The conditions predetermining the natural self-cleaning potential in relatively natural territories are more or less known and exhaustively discussed in scientific works (Glazovskaja, 1988; Ivanov et al., 1993; Jankauskaite, 1993; Pauliukevičius, Grabauskiene, 1993). Yet, the integrated self-cleaning potential of urbanized landscape from the point of view of chemical pollution has not been evaluated and is made complicate by a number of specific features of a city (Dobrovol'skij, 1997; Antipov et al., 1998).

The following criteria and characterising valuation indices predetermining the genetic resistance (ecological potential) of urban landscape were distinguished; intensity of building up (including the hight of buildings, their density, and area with other kinds of technogenic cover); buffer capacity of soils-grounds (granulometric composition, content of humus, capacity to act as a barrier to flows of toxic substances, activity of microorganisms while decomposing the organic matter); biochemical activitiy of greeneries (the area occupied by greeneries, their physical state, capacity for oxygen emission and retention of pollutants depending on species); character of relief (important indices – hypsometry; discretedness level of a territory; slope angles); level of groundwater protectedness (bedding depth, lithology of aeration zone); aeration intensity of a territory (depending on relief, character and density of building up, system of streets); actual level of pollution of depositing surfaces (soils-grounds); water and air permeability of technogenic cover (material composition and distribution pattern). The work is based on the smallest unit of urban landscape investigation – technomorphological cell – a territory in a certain relief with similar spatial character of technogenic cover (height and density of building up, built up area) and functioning as a whole (certain entity) affected by natural and technogenic/urbanistic factors. The total of mentioned cells in the investigated territory of Vilnius city (109.3 km^2) – distinguished by other authors (Godiene, 2001) and corrected by the authors – was 3400.

For development of evaluation methodology two groups of criteria were distinguished:

- criteria whose importance is ranked in grades depending on the role and distribution of indices. This group includes the following criteria: intensity of building up, biochemical activity of greeneries, and the actual pollution level in depositing surfaces. The expert calculation of the complex index was done using the following formula:

$$K_e = \sum_{i=1}^{3} (B_i \times S_i) \quad ,$$

where K_e – composite index in grades (the maximal sum of grades 100 corresponds with the highest sensitivity of a territory to chemical pollution)

B_i – grading according to *i* criterion (the total of 3 criteria, a system of 10 grades)

S_i – weight coefficient for *i* criterion: area of technogenic cover $S_1 = 6$, biochemical activity of greeneries $S_2 = 3$, chemical pollution of soil-ground $S_3 = 1$

- criteria, which depending on the importance of the index and character of impact, correct the sum of grades through a coefficient expression (able to increase the geopotential of the system by even 100%). This group includes the following criteria: buffer capacity of soil-ground with respect to pollution, aeration intensity of the territory, character of relief, protectedness of the groundwater, and water and air permeability of the technogenic cover. The expert calculation of the complex index was done using the following formula:

$$K_e = \sum_{i=1}^{5} (B_i \times S_i) \ ,$$

where K_e – composite index of coefficients (values within the range of 0 to 1, reduces to the minimum the sum of grades)

B_i – evaluation (0 to 10) according to *i* criterion (the total of 5 criteria)

S_i – weight coefficient for *i* criterion: soil-ground buffer capacity against pollution S_1 = 0.03, aeration intensity of a territory S_2 = 0.03, character of relief S_3 = 0.02, groundwater protectedness S_4 = 0.01, character of technogenic cover S_5 = 0.01.

The distinguished criteria and their characteristic indices were evaluated according to ranked quantitative and qualitative characteristics during field trips and based on the data obtained by other authors (they will be mentioned when analysing each criteria separately).

The value obtained by calculating the grades of concrete technomorphological cell and evaluating their loss at introduction of every correcting criterion will express the self-cleaning potential of a territory. The small grades will indicate a high potential of a territory with respect to pollution; the high grades will indicate a low potential, i.e., high sensitivity of a territory to chemical pollution.

Results and discussion

By evaluation in the mentioned methodological aspects an attempt was made to reveal the territorial differences of natural self-cleaning potential of Vilnius landscape.

For this purpose the territorial distribution sketch maps for 8 criteria – to higher or lower degree affecting the natural self-cleaning potential – were drawn. The limited space of the article is insufficient to introduce all sketch maps. For this reason the authors confined themselves to qualitative description of only most specific areas (discussing the influence of each criteria on geopotential).

While evaluating the influence of building up on self-cleaning potential the authors followed the presumption that with an increasing built up (screened) area, height and density of buildings the quality of an environment deteriorates. The area of technogenic cover in each territorial cell of urban landscape was evaluated on the ground of data obtained by other authors (Godiene, 2001) and then updated by mapping the technomorphological structure during field trips.

Adverse and very adverse impacts of **technogenic cover** on self-cleaning potential are felt by 10.62% of the investigated Vilnius territory. They are the most intensively and continuously screened areas, mainly fulfilling the function of infrastructure (motor roads, territory of the airport, the belt along the railway, fuel stations, garages, and parking sites). The medium level of the influence of technogenic cover on the self-cleaning potential was recorded in 8.01% of the territory. They are mostly industrial - 2.81% (Naujamiestis, the area surrounded by Kareiviu-Kalvariju-Verkiu streets, and the section between the Vilkpedes-Savanoriu avenue and Žemieji Paneriai street), residential – 2.18% (Downtown, Fabijoniškes and Šeškine wards), old town – 1.37%, and public – 1.14% territories. A relatively good ecological environment – resulting from relatively weak impact of technogenic cover on geopotential (low screening level) – was recorded in 24.73% of the territory. They are mostly residential areas (13.99%). Weakly screened areas are also located in public (5.80%)

and industrial (4.57%) territories. The best ecological environment for self-cleaning potential was recorded in the least technogenically affected areas, which make up even 56.65% of the investigated Vilnius territory. This territory is predominated by natural areas (36.25%). The least technogenically affected areas also occur in industrial (7.28%), residential (6.70%), and public and infrastructural (2.53% and 2.04%) territories.

Biochemical activity of greeneries is an important criterion affecting the ecological potential of urban landscape. The level of biochemical activity was evaluated according to their character (lawns, bushes, trees), occupied area and physical state. The authors followed the presumption that the decreasing area and deteriorating state of greeneries – resulting in reduced emission of oxygen and pollution retention potential – increase the landscape sensitivity to pollution.

It was determined that the central part of Vilnius (Naujamiestis, Old Town, Kirtimai, and Šiaures Miestelis) and wards (Šeškine, Pilaite, Fabijoniškes) are predetermined by low activity greeneries. The greeneries of higher activity were recorded in wards of Žverynas, Lazdynai, Viršuliškes, Žirmunai, Antakalnis, and northern part of Naujininkai. Very biochemically active greeneries occupy even 37.11% of Vilnius area. It includes various natural territories. Greeneries of low and very low activity occupy even 28.20% of the area (mostly infrastructural and industrial territories). Greeneries of medium activity occupy 22.14% of the area (mostly residential territories).

The **actual pollution of a territory** (with trace elements, oil products and other toxic substances). The increasing level of soil-ground pollution also increases the sensitivity of landscape to pollution. The actual chemical pollution of the soils of urban landscape in Vilnius city was evaluated on the basis of data obtained by other author (Zinkute et al., 2002) authors' expert evaluation on pollution with oil products and domestic-municipal wastes. The highest level of soil pollution (included in the category of dangerous pollution) is characteristic of the central part of Vilnius (Naujamiestis, Old Town, Šnipiškes, Žirmunai, Žverynas, and Antakalnis wards), industrial territories, and territories under intensive infrastructural loads (fuel stations, garages, intensive traffic sectors, large crossroad junctions). A slightly lower level of pollution (included in the category of medium pollution) is characteristic of public-residential and residential functional territories. The areas of low soil pollution occupy 39.92% of the territory. They are natural (16.19%) and residential (10.28%) functional zones. Areas of this quality also occur in rural (3.75%), infrastructural (3.38%) and even industrial (0.86%) functional zones. The negative impact of soil pollution on self-cleaning potential was recorded even in 22.84% of Vilnius territory. These are residential (5.94%), industrial (4.87%), and infrastructural (3.33%) functional zones. The areas of very negative impact on self-cleaning potential occupy 3.50% of the territory. They are mostly related with infrastructural function (2.08%).

The **soil-ground buffer capacity to pollution** (higher soil buffer capacity reduces the landscape sensitivity to pollution) is one of the most important correction criteria. This capacity was evaluated during field trips. Basing themselves on the investigation results of other author's (Craul, 1992; Dobrovol'skij, 1997; Antipov et al., 1998) the authors followed the presumption that screened soils are characterized by weak biochemical activity (low temperatures, deficiency of microorganisms decomposing organic matter, etc.) and self-cleaning potential. The low buffer capacity areas account for even 21.42% of Vilnius territory. They are mostly areas in the industrial-municipal-commercial zones (Žemieji Paneriai-Vilkpede, Kirtimai, Naujamiestis-Railway station, the triangle bordered by Kalvariju-Kareiviu-Verkiu streets), zones (10.55%) under intensive infrastructural loads (fuel stations, garages, parking sites, traffic junctions) and city centre. Low buffer capacity areas (with poorly developed, primitive, with low content of humus and partly screened soils) account for 25.27% of the investigated territory. They are typical of densely built up residential zones – 13.55% (Fabijoniškes, Pilaite, Šeškine, etc.), public-commercial zones (5.60%), industrial (1.86%), and infrastructural (1.20%) zones.The relatively good and very good buffer capacity soils (sandy loam – loam partly carbonaceous soils, soils with high content of humus, and soils of high microbiological activity) account for 35.77% of Vilnius territory. They are concentrated in various natural zones (suburban and forest-park areas).

The **aeration level of city territory** is a criterion predetermining the dispersion conditions for pollutants (at higher level of aeration the landscape sensitivity to pollution is lower). The level of urban landscape aeration in Vilnius city was evaluated through determining the possible change of wind velocity in each territorial cell in comparison with the open areas.

From the point of view of dispersion of pollutants the bad and very bad ecological environment was recorded in even 43.63% of Vilnius territory. It mostly includes forest areas in highly dissected (with dominant negative forms) complexes of relief (19.96%), densely built up residential quarters – 8.18% (Downtown, Old Town, Fabijoniškes, Šeškine), industrial (5.48%), infrastructural (4.13%) and public (2.92%) functional zones. Good and very good conditions for dispersion of pollutants exist in 30.73% of the investigated territory. This territory includes open areas and natural areas with positive forms of relief (6.84%) and, in rarer cases, not very densely built up residential (7.81%) and rural (5.50%) zones.

The **character of relief** (smaller number of morphocomplexes concentrating the flows of pollutants and higher number of morphocomplexes dispersing them reduce the urban landscape sensitivity to pollution) is an important criterion correcting the grade of self-cleaning potential. Very sensitive morphocomplexes of relief account for 7.93% of Vilnius territory. These morphocomplexes occur as small areas with ravines, gullies, valleys and depressions in the zones of natural functions. Erosional hill terrains (Karoliniškes-Viršuliškes, Sapiegine, Antakalnis-Dvarčionys, Verkiai) and morphocomplexes of small and steep hills, that are sensitive to pollution and disperse or concentrate the flows of pollutants, occur as small areas in different parts of Vilnius city (12.62%). These areas were mostly recorded in the zones of natural function. Morphocomplexes of medium sensitivity to pollution (plateaus, plains, terraces) account for 44.85% of Vilnius territory. They occur in equal portions in infrastructural, public, residential and natural functional zones.

The groundwater protectedness criterion is also important for self-cleaning potential of urban ecosystems (higher level of protectedness reduces the sensitivity of a territory to pollution). The groundwater protectedness was evaluated on the basis of data provided by the Geological Survey of Lithuania. From the point of view of groundwater protectedness the very bad and bad ecological environment in urban ecosystems accounts for even 36.69% of Vilnius territory, including the Neris and Vilnia valley morphocomplexes, the north-eastern (Valakampiai-Dvarčionys) and western (Pilaite ward) peripheral parts of the city. They are mostly areas in the territories of natural and residential zones. Some such areas are also recorded in the potentially tending to pollution infrastructural and industrial zones. Territories with well and very well protected groundwater account for only 13.08% of the investigated territory (the southern periphery of the city). They are mostly zones of natural, infrastructural, and rural zones.

The last criterion – the **character of technogenic cover** (from the point of view of water and air permeability) – is designed for correction of grades obtained by evaluation of the area of technogenic cover in the territorial cells (the higher the aeration capacity of the cover – the lower the sensitivity of the territory). The aeration capacity was evaluated on the basis of material composition and type of paving. The most unfavourable ecological environment for self-cleaning potential was recorded in territories with a continuous asphalt-concrete cover. Such territories account for 16.38% of Vilnius area. They are mostly infrastructural (9.22%), industrial (4.96%), and public (1.11%) functional zones. A slightly better ecological environment was in the territories with open-work type of technogenic cover (brick paving, worn asphalt-concrete cover). Such territories make up 9.47% in public, industrial, infrastructural functional zones and residential (Downtown, Old Town) quarters. Good and very good ecological environment is characteristic of areas distinguished by open-work paving (sparse brick paving, shingle-gravel lanes). Such areas account for even 44.22% of the investigated territory in the natural (34.36%) and rural (6.02%) functional zones.

The **integrated evaluation of natural self-cleaning potential** of Vilnius urban landscape (comparing the kernel of densely built up areas with suburban areas) was derived by summing up the evaluation grades of each technomorphological cell of urban landscape – based on the discussed natural and technogenic urbanistic indices (taking into account their weight coefficients) – and subtracting the grades of correction criteria (Fig. 1). It turned out that in more than half (54.86%) of the investigated Vilnius territory the natural self-cleaning potential is relatively very good (though from the point of view of sensitivity to chemical pollution Vilnius is situated in rather sensitive geosystems. This is predetermined by the dominance of soils with relatively low buffer capacity (sod podzolic strongly and weakly podzolized, sandy loam-light loam) and relief morphocomplexes sensitive to chemical pollution). The areas of relatively good and medium self-cleaning potential account for 21.97% and 20.57% of the investigated territory and the areas of relatively bad and very bad potential – 2.61%.

Analysis of the links between the natural self-cleaning potential and territorial function revealed that the territories of relatively very good self-cleaning potential are mainly situated in natural functional zones, predominated by greeneries of high biochemical activity (forest parks, suburban forests). Small such areas also occur in other functional zones (sparsly built up residential – 8.24%, rural – 6.87%, and some other zones exept Downtown and

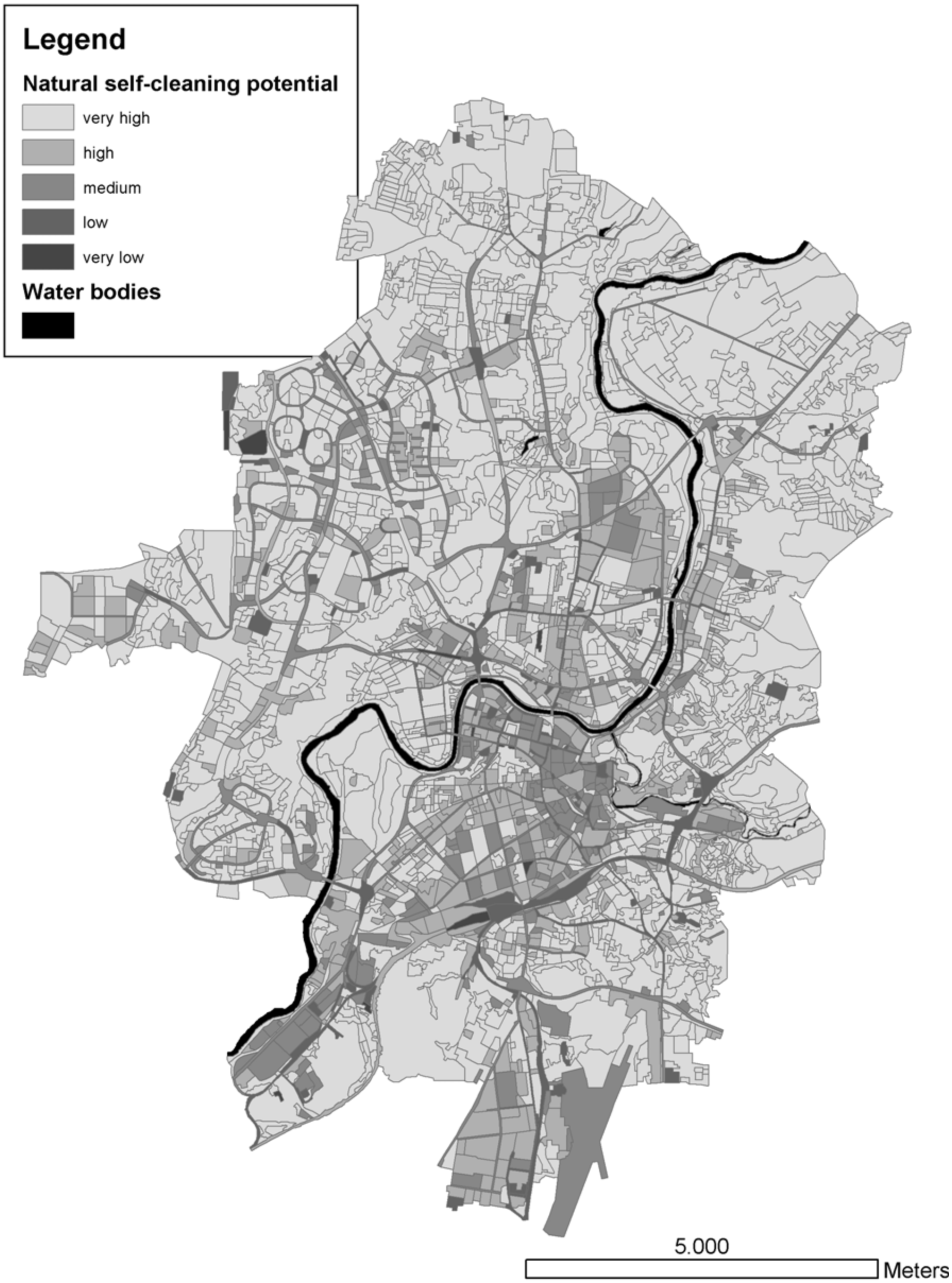

Fig. 1. Natural self-cleaning potential of Vilnius City urboecosystem.

Old Town). The territories with good self-cleaning potential were mostly found in the residential (13.62%) and the public (4.86%) functional zones. The relatively medium self-cleaning potential is characteristic of infrastructural (8.14%), industrial (6.52%), densely built up public (2.29%), residential (1.47%), and Old town (1.42%) zones. Small areas of bad and very bad self-cleaning potential are scattered in almost all functional zones. Yet, most of them (2.43%) are concentrated in the infrastructural zones (railway junction, sectors of intensive traffic, junctions of motor roads, fuel stations, garages). These are the areas where the quality of environment management (regulation of the distribution of objects – which act as sources of pollution – traffic flows, protective greeneries) should be improved as soon as possible seeking to reduce the chemical pollution of sensitive territories.

Conclusions

The natural self-cleaning potential of urban landscape with respect to chemical pollution was investigated as the integrated reaction of urban landscape to chemical pollution (not confining to evaluation of self-cleaning potential of discrete landscape components).

The evaluation methodology of self-cleaning potential of urban landscape is based on the groups of evaluation criteria and their characteristic parameters, Through expert analysis the importance of each criteria was determined depending on the parameters of certain impact factors and the 'weight' of criterion in the general evaluation system.

The self-cleaning potential of Vilnius urban landscape was evaluated according to 8 criteria in 3400 technomorphological cells. Each cell represents a territory situated in certain relief, having similar spatial character of technogenic cover (height and density of buildings, built up area), and functioning as an entity affected by natural and technogenic-urbanistic factors.

It was determined that in more than half of the investigated Vilnius territory (54.86%) the self-cleaning potential is very good. These are mostly zones of natural function, predominated by greeneries with high biochemical activity (forest-parks, suburban forests), and small areas scattered in other functional zones.

The territories of relatively good self-cleaning potential account for 21.97% of the investigated area. Most of them are located in sparsely built up residential and public functional zones.

The territories of medium self-cleaning potential account for 20.57% of the investigated area. They are found in the infrastructural, industrial, and densely built up public and residential functional zones and territories of Old Town.

The territories of bad and very bad self-cleaning potential account for 2.61% of Vilnius area and occur as small areas in almost all functional zones, yet are most abundant in infrastructural functional zones.

For optimisation of the urban environment in the most sensitive to chemical pollution areas of urban landscape it is necessary to improve the management of the quality of environment (regulation of the distribution of pollution sources, traffic flows, distribution of greeneries), what would reduce the chemical pollution of sensitive territories.

Translated by the author

References

Antipov, A.N. et al. (ed.), 1998: Ecological Problems of Urbanized Territory (in Russian). Irkutsk, 199 pp.

Craul, P.G., 1992: Urban Soils in Landscape Design. New York, 396 pp.

Dobrovol'skij, V.G. (ed.), 1997: Soil, City Environment (in Russian). Moskow, 320 pp.

Glazovskaja, M.A., 1988: Geochemistry of Natural and Technogenical Landscapes of USSR (in Russian). Vy'sshaja shkola, Moskow, 328 pp.

Godienė, G., 2001: The tendencies of technogenization changes in the urban landscape (on the example of Lithuanina towns). Dissertation.

Ivanov, M.V. et al. (ed.), 1993: Biogeochemical Fundamentals of Environmental Normalization (in Russian). Nauka, Moskow, 304 pp.

Jankauskaite M., 1993: Assessment of geosystem's sensitivity to chemical impact. Geografija, 29**,** p. 78–84.

Lange, O., 1969: Whole and development in light of cybernetics (in Russian). In Research in general system theory. Moskow, p. 181–251.

Lithuanian Environmental Strategy, 1995, Vilnius.

Naveh Z., Lieberman S., 1990: Landscape Ecology. New York.

Pauliukevicius, G., Grabauskiene, I., 1993: Methods forecasting the resistance of geosystems to human impact. In Structural, dynamical and functional properties of the Lithuanian landscape. Geography Institute, Vilnius, p. 149–171.

Pauliukevičius, G., 2001: Water Protection Forests (in Lithuanian). Vilnius, 179 pp.

Sochava, V.B., 1978: Introduction to Teachnings About Geosystems (in Russian). Novosibirsk, 320 pp.

Zinkute, R., Taraskevicius, R. Radzevicius, A., 2002: Ecological state and change tendencies of urban soil and water bodies bottom sediments (in Lithuanian). The state and change of urbanized environment-report. Geology and Geography Institute, Vilnius, 220 pp.

Received 18. 11. 2003