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Man-made formations and geopollution: state of knowledge in Lithuania

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The paper deals with the state of knowledge of man-made strata and geopollution in Lithuania. On the basis of inventories, urban engineering geological and geochemical mapping, the following indicators were estimated: the area (percentage) of man-made-strata in urban areas, the volume of man-made strata per 1 km^2 of the total territory, the number of potential contamination sources of the geological environment, the volume of geochemically contaminated (historical contamination) soil in urban areas. Man-made strata are specific techno-geological formations with multiple and various environmental aspects, which must be better understood and managed.

Key words: man-made strata, geochemical contamination, engineering geological mapping, landslides

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INTRODUCTION

Man-made formations (strata) are widely distributed in urbanised and adjacent areas as a result of anthropogenic (technogenic) activities, especially during an intensive industrial development. Man-made strata could be categorized as technological soils. The World Reference Base for Soil Resources (WRB) provides the term *technosols* as a new reference group in which the central concept is "soils whose properties and pedogenesis are dominated by technic materials or their origin as human-transported material as well as soils with a continuous impermeable constructed liner" (IUSS Working ..., 2006). They contain a significant amount of artefacts (something in the soil recognizably made or extracted from the earth by humans) or are sealed by *technical hard rock* (material created by humans, with properties unlike those of natural rock). They include soils from wastes (landfills, sludge, cinders, mine spoils and ashes), pavements with their underlying unconsolidated materials, soils with geomembranes and constructed soils in human-made materials. Technosols are often referred to as *urban* or *mine* soils. They are recognized in the new Russian soil classification system as *technogenic surface formations*. However, in this study, man-made formations are different from the artificial soil which is made by excavated soil materials, dredged materials, manufactured and treated soils, and fill materials. Artificial soil material is material coming from artificial soil and displaced and / or modified by human activities (ISO 11074 : 2005 / Cor. 1 : 2006 Soil quality – Vocabulary). Therefore, man-made strata comprise cultural layers, landfills, waste sites, abandoned industrial objects, mining tailings, non-remediated pollution sites and other formations accumulated without proper environmental management, monitoring and technical installations. In this respect, the extension and thickness of man-made strata in many places are unknown and / or poorly mapped. However, specific properties of man-made strata are clearly reported and documented: these formations contain a variety of pollutants, geotechnically are weak, unstable and unpredictable grounds; they are subject to severe liquefaction and landsliding during earthquakes. Therefore, man-made strata are specific techno-geological formations with multiple and various environmental aspects which must be better understood and managed.

The IUGS Commission GEM, aiming to an essential contribution of geoscience to sustainable development and environmental management, in 2009 has established the working group "Man-made Strata and Geopollution" (MMS-GP). One of the objectives of this working group is to "generate geoscience information for sustainable use of urbanised land and man-made strata". Following this objective, an overview of man-made strata and geopollution in Lithuania was carried out.

The aim of this study was to estimate and quantify urbanisation, the distribution of man-made strata and related environmental aspects in the Republic of Lithuania.

PECULIARITIES OF PRESENT GEOLOGICAL SURFACE OF LITHUANIA

The geological environment, especially its upper part, is affected by intensive human activity (physical and chemical) due to which the quality of geological environment (soils and groundwater) is deteriorating.

Geological formations exposed at the surface provide a geological background for the accumulation of man-made strata and the concentration of pollutants. The surface of the territory of Lithuania is comprised by Quaternary deposits formed during continental glaciations and ice-free stages. The average thickness of the Quaternary cover is 130 m and varies from 10–30 m in the northern part of the country – the area of the prevailing glacial erosion – up to 200–300 m in marginal and insular glacial highlands and buried valleys or palaeoincisions.

The Quaternary cover is the main source of mineral resources for constructions (sand, gravel, clay) and potable groundwater (ca. 60% of total groundwater volume for centralised water supply is taken from the Quaternary aquifers). The Quaternary is the only ground of soil formation and the geological foundation for all engineering constructions. Recent geological mapping data show that the present topographic surface of Lithuania is composed of Upper Weichselian (Nemunas) sediments (75.86% of the total surface area), Late Glacial and Holocene sediments (20.35%) and Saalian (Medininkai) deposits (2.25%). From the point of genesis of surface topography forming sediments, plains composed of basal till and glaciolacustrine sediments prevail in the present relief of Lithuania. Glacial deposits make 70% of the volume of the total Quaternary cover (Putys et al., 2010). The glaciolacustrine and glaciofluvial sediments (sand and gravel, etc.) make 28% of the Quaternary volume. From the lithological point of view, 70% of the Quaternary cover is made of glacial loams (sandy and clayey); sands of various composition make 21%, gravels make over 4%, and the rest (less than 5%) of the volume is composed of clay, silt and biogenic sediments. It should be noted that the lithological composition of the man-made strata is quite often rather similar to till formations (poorly sorted sandy-clayey loam) or similar deposits.

ESTIMATION OF URBANISATION AND DISTRIBUTION OF MAN-MADE FORMATIONS

Man-made (artificial) formations are very common in Lithuania and occur in each urban territory. The urban areas cover about 3% of the total territory of Lithuania according to CORINE Land cover data (Vaitkus, 2005). Urban territory estimation was made by summarizing areas of CORINE GIS objects with attribute data such as "artificial cover" and "complex agricultural territories". But even outside the inhabited areas, man-made soil occurs frequently. The major accumulations of artificial soil in Lithuania can be divided into three types:

- man-made formations associated with urban territories;
- associated mainly with historical fortification facilities (hillforts, castle hills, etc.)
- formations associated with landfills and contaminated sites.

In a number of cases, other minor types of incidental man-made accumulations could occur, but such type of man-made strata in this study is ignored due to the absence of inventories. Also formations related to mining are excluded, as in Lithuania all mining is of open pit type and all mining tailings are natural soil, i. e. a cover of gravel or sand deposits.

The thickest man-made formations in urban territories occur in the most populated cities of Lithuania, i. e. Vilnius, Kaunas, Klaipėda, Šiauliai and others. Their thickness reaches more than 10 m in the oldest parts of the towns. Man-made formations consist of natural soils, old municipal and construction waste and top soil mixed in various proportions. For example, 26 km^2 of the area is covered with man-made soil formation more than 1 m thick in the Kaunas city. It takes more than 16% of the total area of the city (Fig. 1).

Man-made formations in urban territories are being determined during geotechnical investigations and special urban engineering geological mapping which has been completed at a scale 1 : 10 000 in Kaunas, 1 : 25 000 in Klaipėda, and 1 : 50 000 in Šiauliai.

Engineering geological mapping of the urban territory of Vilnius, the capital of Lithuania, at a scale of 1 : 10 000 is currently under way and is expected to be completed in 2012.

Table 1. **Estimation of urban areas and the cover of man-made strata**
1 lentelė. **Urbanizuotų teritorijų ir technogeninių sluoksnių plotas**

Type of area	km^2	%
Territory of Lithuania	65 000 km^2	100%
Urbanized areas	1950 km^2	3%
Estimated area of man-made strata in urban territories	312 km^2	16% (of urban areas)

On the basis of mapping data, the percentage of the cover of man-made strata in urban areas has been estimated (Table 1).

Geotechnical properties of the man-made soils are very unreliable because usually man-made soil is very compressible and unstable. It can be used as a base for foundations in extra cases only. The usage of man-made soil as a base for foundations leads to destabilization of the structures and failures.

The other type of man-made formations is associated with historical fortifications and occurs in major cities of Lithuania and also outside urban areas. Castle hills (hillforts) are the most common forms of man-made formations accumulated during historical times. Located in strategic territories – near the major roads, larger settlements or near natural barriers such as rivers – they were installed on the entire territory of Lithuania after the 5th–6th centuries. The base of these hills is often a natural height but reshaped to satisfy defence needs. Sometimes the entire hill is formed by man. These man-made formations consist of natural soil, construction waste, often with layers of cultural debris, charcoal, artefacts and top soil.

Landfills of municipal waste in Lithuania can be divided into three main groups: (1) small ones near villages and settlements, (2) medium or main municipal ones, and (3) city landfills. There existed about 20–30 landfills of various scale in each municipality of Lithuania before joining the European Union (Fig. 2). Most of landfills were closed, and regional landfills were installed after 2008. Wastes of the smallest landfills were relocated to the medium ones, while the rest of the landfills were re-cultivated. As a result of those activities, sites of man-made soils covering 8.63 km^2 have been

Fig. 1. Thickness of man-made soil in Kaunas (Paukštė, Mikulėnas, 2004)
1 pav. Technogeninio grunto storis Kaune

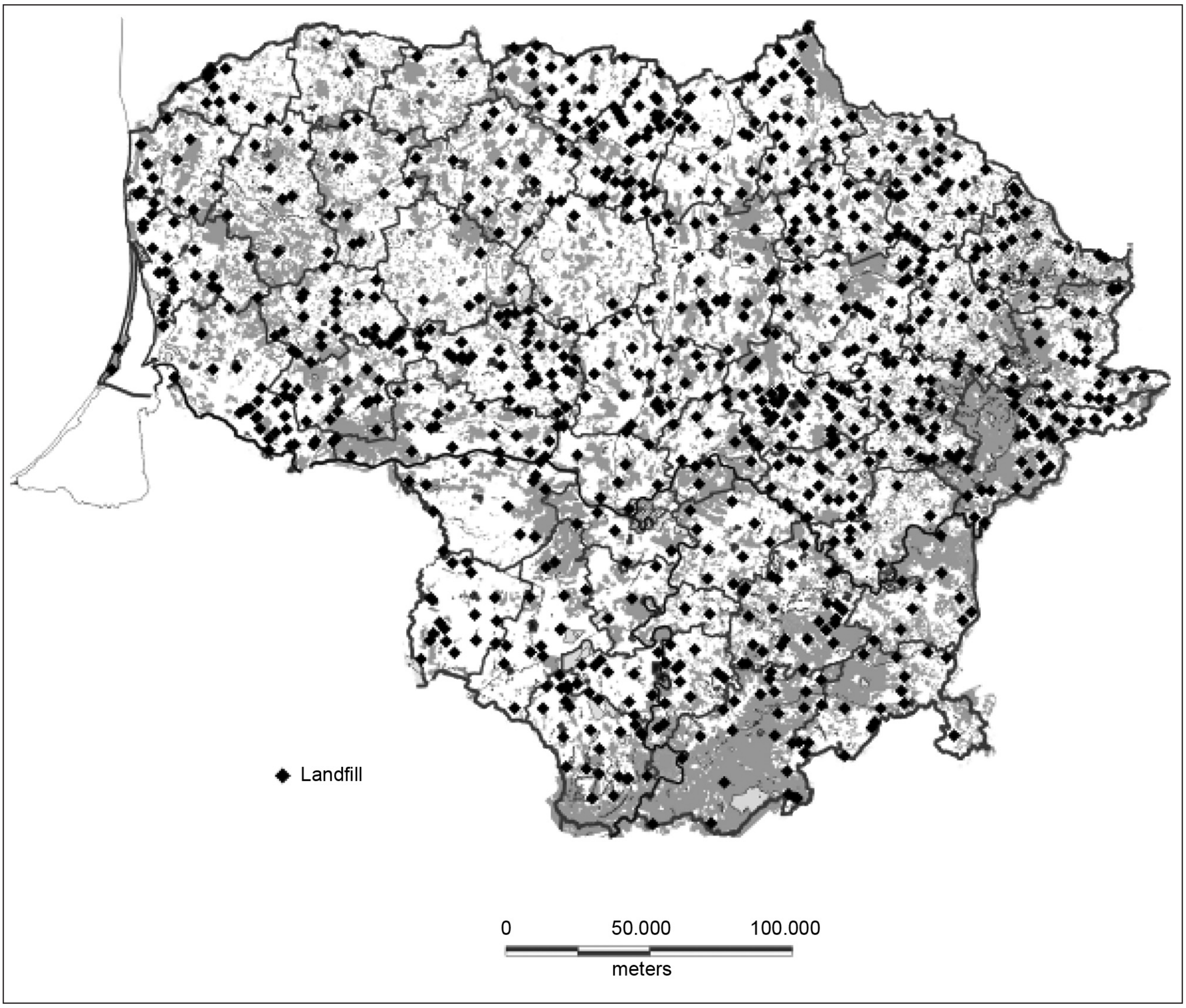

Fig. 2. Location of former (now closed) landfills in Lithuania

2 pav. Buvusių sąvartynų išsidėstymas Lietuvoje

formed (Vaitkus, 2005). The thickness of man-made strata is 20–40 m in city landfills. The process of forming man-made soils from municipal waste depositories is going on in 10 regional landfills with arrangement of proper environmental protection means.

In Lithuania, the estimated volume of man-made strata in urban territories, landfills and hillforts makes approximately 0.7966 km^3, or 12 256 m^3 per 1 km^2 of the total territory (Table 2).

TYPICAL GEOHAZARDS RELATED TO MAN-MADE FORMATIONS

Landslides are the most dangerous process for buildings and most frequent among the engineering geological processes that occur on slopes of different nature in Lithuania. The anthropogenic factors also contribute to downslope movements, which damage both natural and artificial slopes. Mostly they affect the developing of landslides in

Table 2. **Estimated volume of man-made strata**

2 lentelė. **Apskaičiuotas technogeninių sluoksnių tūris**

Volume of man-made strata in:	km^3	Volume of man-made strata (m^3/1 km^2 of the country territory)
Urban area	0.6240	12 256
Landfills (total number 850)	0.1726	
Hillforts (total number 840)	0.000029	
Total	0.7966	

urban and cultural areas, such as coasts of artificial water ponds (Kauno Marios, etc.), slopes of ancient objects of cultural heritage – hillforts (e. g., Gediminas Hill in Vilnius, Mindaugas Throne in Kernavė, Lizdeika, Punia, Seredžius, Ukmergė, Gandinga, etc.), slopes of pits, road-beds, walls of quarries of mineral deposits (Dysna in Ignalina district, Rašnava in Kaunas district, Tonribis in Kelmė district and Tauragė clay deposits), as well as slopes of large landfills (Fabijoniškės in Vilnius, Aukštrakiai and Kairiai in Šiauliai, Liūdynė in Panevėžys) (Mikšys et al., 2002; Satkūnas et al., 2008).

An example of a well-investigated slope failure is the landslide in the Dvarčionys pottery territory on 11 August 2000 (Fig. 3). The pottery is located in the northeastern part of the Vilnius city. The landslide ruined two ready-made produce (tiles) warehouses. The losses, apart from rebuild work, make up over 1 million USD. The pottery is located on the slope dissected by ravines which flow into the Dvarčia rivulet. The length of the rivulet slope is 285 m, its height ranges from 10 to 15 m. The slope was artificially formed 15 years ago. The slided part is made of technogenic soil (sand, gravel, tile waste and clay). The bulk soil thicknes is 13.5 m on the slope and 0.7–4.6 m in the glissaded part. Deeper, a 0.3–2.6 m thick organogenous (loamy sand and peat) Middle Pleistocene lacustrine fine- and medium-grained (0.5–5.2 m) layer occurs. Clay of soft and firm consistency lies below. The groundwater level of the slope occurs at a depth of 9.4 m from the surface. At the foot of the slope, water discharges as water springs. The groundwater is drained by the Dvarčia rivulet. According to the Hydrometeorological Station data, the precipitation was 209 mm in July. It exceeded the annual perennial precipitation 2.6 times. The heating, water supply and sewerage manifolds were netted on the slope. On the slope of the landslide, two warehouses of production had been established. The load on soil was as high as 60 kN/m^2. Machinery and transport were in operation. The parameters of the landslide are as follows: the height of the massive pane 7 m, length near the slope 115 m, the angle at the top 90°, in the middle 50°, at the base 30–35°. The maximum length of the massive is 120 m, the width being 75–90 m, volume 24 000 m^3, and the thickness of slided down soil 0.7–4.6 m (mean, 2.5 m). The landslide is not sequential, the slide-plane crosses the technogenical soil, and the form of the landslide is of stream type. It forms a circus at the top and is elongated to the down-flow direction (Mik ys et al., 2002). There are much more cases of landsliding in urban areas (Fig. 4). Technogenic soil compaction under building foundations causes also deformations in constructions.

Fig. 3. Landslide in Dvarčionys pottery territory (photo by V. Mikulėnas)

3 pav. Nuošliauža Dvarčionių keramikos gamyklos teritorijoje (V. Mikulėno nuotr.)

Fig. 4. Landslide developed in Slėnio street, Kaunas city, 1996 (photo by V. Marcinkevičius)

4 pav. Nuošliauža Slėnio gatvėje Kaune (V. Marcinkevičiaus nuotr.)

MAN-MADE SOIL OF CONTAMINATED SITES IN LITHUANIA

The objects of human activity that chemical substances could come from and reach the soils or groundwater are called potential contamination sources of geological environment.

Since 1999, the Lithuanian Geological Survey (LGT) has been performing the inventory of potential contamination sources – sites of potentially contaminating human activities on the territory of Lithuania; it also manages the Integrated Digital State Information System of Contamination Sites (ISCS). All kinds of possible contamination sites are classified into four types and more than 40 subtypes. Types of potential contamination sites are:

1) objects of industry, energetics, transport and service;
2) objects of waste collection and regeneration;
3) livestock objects;
4) accidental chemical spill sites.

By the end of August 2010, data on 11 038 potential contamination sites were collected and stored in the ISCS. There are data on 4 499 sites of the first type, 4 039 of the second type, 2 497 of the third type and 3 of the fourth one. By the inventory date, 2 745 objects of the first type were operating, 958 were inoperative, 647 were demolished, 2 were fire-damaged, 114 were reconstructed and 33 site territories were remediated.

There are data on 4 039 sites of the second type, stored in the ISCS. By the inventory date, 1953 objects of the second type were operating, 784 were inoperative, 887 were demolished, 21 were fire damaged, 89 were reconstructed and 305 site territories were remediated.

Data on 2 497 objects of the third type are stored in the ISCS. By the inventory date, 731 objects of the third type were operating, 713 were inoperative, 1 018 were demolished, 3 were fire-damaged, 31 were reconstructed and only one site territory was remediated.

The smallest part of the stored data is related to the sites of the fourth type. There are only 3 objects inventoried. This was caused by the difficulties of collecting data in field and by the malevolence of organizations responsible for the management of spills.

Collection of data in the digital ISCS allows to perform an analysis of potential soil or groundwater contamination, the spatial distribution of contamination sites and the evaluation of a possible occurrence of man-made soil in Lithuania's territory. According to the ISCS data, the total area covered by potential contamination sites reaches about 380 km^2. The thickness of man-made soil is quite different in each site of economic activities. However, the approximate amount of man-made and potentially contaminated soil could be evaluated. Taking into account the possible average thickness of man-made soil at each site, which could be about 1.2 m (the average depth of freezing, minimal depth for water supply infrastructure, close to the average depth of groundwater, etc.), the total amount of man-made soil related to economic activity objects could be about 0.456 km^3 or 7 015 m^3 per 1 km^2 of the country territory.

GEOCHEMICAL POLLUTION OF URBAN TERRITORIES

Environmental geochemical maps of urban areas are needed to display the geographical distribution of chemical elements and compounds and to allow a reliable recognition of contaminated areas. In Lithuania, the geochemical mapping of urban areas started in the Vilnius city in 1985. Topsoil, stream sediments, snow cover, manufactory dust and other sampling media are used in eco-geochemical investigations. The aim of investigations is to detect sources of contamination, its geochemical properties, as well as the level and spread. The sampling grid in urban areas is usually irregular with regard to the supposed anthropogenic load. The least disturbed residential areas are mapped at a grid of 250 × 250 m or 100 × 100 m, depending on population density and the distance from industrial areas. The sampling sites are selected in such a way that the amount of soil samples according to types based on anthropogenic load or land use units (parkland, areas of cottages, areas of apartment houses, old town, etc.) would be statistically reliable, i. e. 100 ± 10. The industrial areas, territories of enterprises are mapped at a grid of 25 × 25 m or 10 × 10 m, depending on soil sealing and the diversity of industrial activities. Stream sediments, sediments of lakes and ponds, as well as sediments of dug wells are investigated additionally during urban soil mapping to estimate the route of contamination and its impact on groundwater quality. The latter one is the only drinking water source in Lithuania. The geochemical matrix of manufactory dust from vents and filters is used to detect the individual "geochemical fingerprints" of different enterprises and their contaminated areas. Snow dust (filtered residual) is also used to detect areas of industrial emissions transported by air and deposited on soil.

At present, the geochemical data on soil contamination in the areas of Vilnius, Panevėžys, Mažeikiai, Šiauliai, Alytus, Biržai, Pasvalys, Rokiškis, Kupiškis and other towns are stored by geochemists of the Geological Survey of Lithuania and the Institute of Geology and Geography. In the soil of most of the cities, an increased concentration (up to some tens, in some enterprises up to some thousands of times) of most elements occurs. Contamination is mainly related to local industrial activities. For example, at some enterprises the concentration of Zn, Cu, Ag, Pb and Cr in soil exceeds the permissible level more than thousand times and of other elements dozens, hundreds of times. Especially high concentrations of specific elements, such as Sb, Mn and W, was observed on territories of former enterprises that produced battery cells, agricultural machines, drills, etc. In the contaminated sites, and especially on the territories of enterprises, associations of elements-contaminants include non-ferrous and ferrous metals not characteristic of natural element associations. These associations often reflect the specific features of a contamination source and, in certain cases, could help to determine the boundaries of its contamination area.

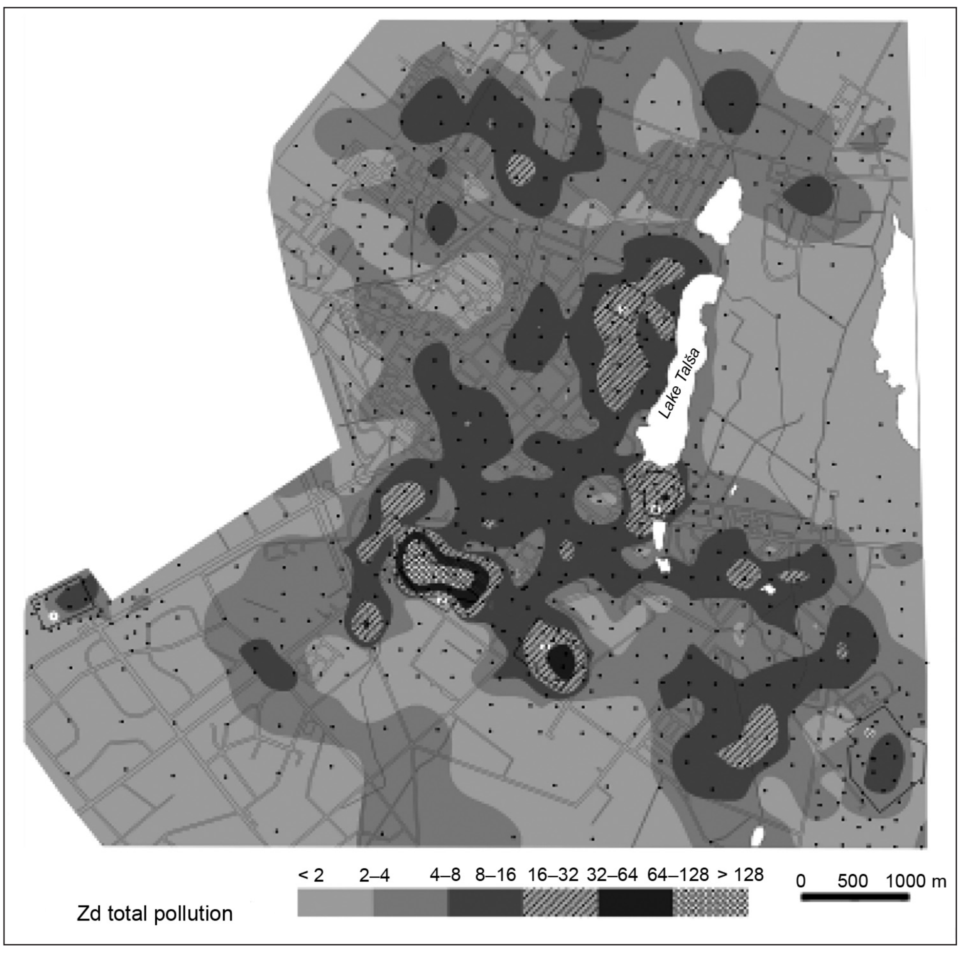

Fig. 5. Contamination by heavy metals of soils of Šiauliai industrial city (Lithuania) according to the total contamination index Zd (Kadūnas et al., 1999)

5 pav. Dirvožemio užterštumas sunkiaisiais metalais. Šiauliuose pagal bendrąjį užterštumo indeksą Zd (Kadūnas ir kt., 1999)

The sanitary assessment of urban soil is based on the available geochemical data, the Lithuanian soil quality standard HN 60 : 2004 and the Hygiene Standard HN 97 : 2004. The objects of these standards are obligatory limit values of toxic substances (heavy metals, pesticides, hydrocarbons, PAH and PCB) for the soil (the whole soil layer from the surface to soil parent material) of residential, recreational and agricultural areas. Furthermore, the level of soil contamination with heavy metals is assessed not only according to the highest allowable concentrations (HAC), but also according to peculiar indices – the risk index K_0 and the total contamination index Zd (e. g., Fig. 5); they are related to the criteria of human health. According to the level of contamination, different actions in contaminated areas are required.

The soil geochemical background values obtained by geochemical mapping of natural areas and suburb land are always used for the assessment of contaminated urban areas. Part of geochemical background and contamination data are published in the Geochemical Atlas of Lithuania (Kadūnas et al., 1999). Some geochemical data and soil contamination maps are in use of the town municipalities on whose order and funds the geochemical investigations of urban areas were performed. However, geochemical investigations lag behind the planning, development and reclamation projects of urban areas; therefore, new dwelling houses are often built on hazardous sites with "historical contamination" which may threaten human health.

According to the available urban geochemical maps, the total contamination index Zd indicates the heavily contaminated soil which comprises 2–5 percents of urban areas (or some 15.6 km^2). Accordingly, the volume of such contaminated soil in urban areas is estimated at 0.0187 km^3. Thus, the volume of the geochemically contaminated soil is 9 600 m^3 per 1 km^2 of the urban area or 288 m^3 per 1 km^2 of the total area of the country.

CONCLUSIONS

The figures of estimated man-made strata are tentative and could be revised in the course of new precise investigations, inventories and, in particular, urban engineering geological mapping. On the other hand, the volumes of man-made strata are changing rapidly due to re-cultivation of landfills, remediation of contaminated sites and other economic activities.

The state of man-made strata and geopollution has been estimated in Lithuania, and the following indicators are proposed:

1. The area (percentage) of man-made strata in urban areas. In Lithuania, the man-made strata have been estimated to comprise 16% of urban areas.

2. The volume of man-made strata per 1 km^2 of the total territory. In Lithuania, the estimated volume of man-made strata in urban territories, landfills and hillforts makes approximately 0.7966 km^3 or 12 256 m^3 per 1 km^2 of the total territory.

3. The number of potential contamination sources of the geological environment. By the end of August 2010, data on 11 038 potential contamination sites were stored in the information system at the Lithuanian Geological Survey. The total amount of man-made soil in potential contamination sites could be about 0.456 km^3, or 7 015 m^3 per 1 km^2 of the country territory.

4. The total amount of man-made strata in the country. In Lithuania, the estimated total volume of man-made strata makes approximately 1.2526 km^3, or 19 271 m^3 per 1 km^2 of the territory, or 19 litres per 1 m^2 of the territory.

5. The volume of geochemically contaminated (historical contamination) soil in urban areas. This volume in Lithuania is 0.0187 km^3, or 288 m^3 per 1 km^2 of the total area.

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TECHNOGENINIAI DARINIAI IR SU JAIS SUSIJUSI GEOLOGINĖS APLINKOS TARŠA: ŽINIŲ BŪKLĖ LIETUVOJE

Santrauka

Tarptautinės geologijos mokslų sąjungos (IUGS) komisija Geomokslai apinkos formavimui (IUGS-GEM) 2009 m. inicijavo technogeninių gruntų ir geologinės aplinkos taršos problemų tarptautinę apžvalgą, kuriai buvo parengta straipsnyje pateikiama duomenų ir informacijos šaltinių apie technogeninius gruntus ir geologinės aplinkos taršos būklę Lietuvoje analizė.

Technogeniniams dariniams priskirtini istoriškai susiklostę kultūriniai sluoksniai, savavališki sąvartynai ir atliekų sankaupos, gruntas geologinės aplinkos taršos židinių vietose ir kiti žmogaus veiklos padariniai, be inžinerinio projektavimo, techninės bei aplinkosauginės priežiūros susiformavę grunto sankaupos ar sluoksniai. Technogeniniai dariniai dažniausiai yra užteršti įvairiomis medžiagomis, geotechniniu požiūriu tai – silpni gruntai, kuriuose dažnai formuojasi deformacijos, nuošliaužos. Todėl technogeniniai gruntai turi būti kartografuojami ir tinkamai vertinami aplinkosaugos bei aplinkotvarkos požiūriu.

Remiantis žemėnaudos (CORINE žemės dangos duomenų bazės), Kauno, Klaipėdos, Šiaulių urbanizuotų teritorijų inžinerinio geologinio kartografavimo, geologinės aplinkos taršos židinių duomenų bazės, geocheminio kartografavimo ir kitais duomenimis, apskaičiuota, kad urbanizuotose teritorijose (jos sudaro apie 3 % šalies teritorijos), istorinėse gyvenvietėse (piliakalniuose) ir smulkiuose sąvartynuose susikaupusio technogeninio grunto tūrio Lietuvoje tenka apie 0,7966 km^3, arba 12 256 m^3, vienam šalies teritorijos kvadratiniam kilometrui.

Iki 2010 m. rugpjūčio pabaigos Lietuvos geologijos tarnybos Geologinės aplinkos taršos židinių duomenų bazėje buvo sukaupta duomenų apie 11 038 potencialius taršos židinius. Juose esantis technogeninio grunto tūris gali siekti apie 0,456 km^3, arba 7 015 m^3, vienam šalies teritorijos kvadratiniam kilometrui. Geochemiškai užterštas (miestų istorinė tarša) gruntas gali sudaryti apie 0,0187 km^3, arba 288 m^3, vienam šalies teritorijos kvadratiniam kilometrui.

Bendras technogeninio grunto tūris Lietuvoje siekia 1,2526 km^3, arba 19 271 m^3, vienam šalies teritorijos kvadratiniam kilometrui.

Šie skaičiavimai yra preliminarūs ir gali keistis priklausomai nuo tolesnio inžinerinio geologinio, geocheminio kartografavimo, taršos židinių inventorizavimo ir kitų tyrimo darbų rezultatų. Pateiktus skaičius siūloma naudoti kaip lyginamuosius technogeninių gruntų erdvinio paplitimo (apimčių) vertinimo rodiklius.

Raktažodžiai: technogeniniai dariniai, geologinės aplinkos tarša, aplinkos taršos židinių duomenų bazės