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THE PROBLEM OF LANDSCAPE RELATIVE ENTROPY EVALUATION AND ITS APPLICATION (ON THE EXAMPLE OF LITHUANIAN TERRITORY)

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Introduction

Today, the intensity of natural resources exploitation and technogenic pollution causes the remarkable ecological instability in the landscape system, which with all the whole of inter-systemic links and their proper functioning determines the sustainability of human living environment.

In order to motivate the strategy of environment protection and rational use, it is important to evaluate not only the actual extent of anthropogenic load but also natural-ecological landscape potential (geopotential), that is determined by the landscape genetic possibilities to resist the technogenic load without noticeable changes (Звонкова, 1985; Устойчивость…, 1983; Ландшафты…, 1990). There are many theories explaining this mechanism of landscape stability and self-cleaning, based on reversible negative links, stopping the chain impulse conduction reactions by biogeoceonosis species composition, microorganisms activity, hydrothermal factors (Арманд, 1975; Арманд, 1988; Демек, 1977; Сочава, 1978; Naveh, Liebermann, 1994; Ланге, 1969) and the other indexes ensuring the landscape stability (Ланге, 1969; Pauliukevičius, Grabauskienė, 1993; Pauliukevičius, Kenstavičius, 1995). According to some scientists (Глазовская, 1988; Экогеохимия…, 1995), the highest self-cleaning ability is the mark of the landscape territorial complexes that are characterized by the high intensity of matter circulation, that strongly barrier or buffer the fluxes of pollutants or have dominance of dispersive fluxes. The territories that accumulate pollutants, have weak barriers and slow biogeochemical circulation and are described by a weak self-cleaning ability. These are the territories of low ecological stability, sensitive to anthropogenic influence.

The purpose of this work was to evaluate the ecological stability of Lithuanian territory by distinguishing the areas of different relative entropy, based on the ratio of landscape technogeochemical pressure and sensitivity to chemical pollution.

1. Relative Entropy of Landscape

The entropy of landscape, as understood in this work, comprises the difference between the values of geosystem sensitivity and technogeochemical pressure (Fig. 1). It is assumed that the higher is the landscape system (i.e. a particular territory) sensitivity and the higher is the technogeochemical pressure on it, the greater is the value of landscape relative entropy. Entropy, as per its initial meaning, is the measure of the isolated thermodynamic system disorder, and landscape system (or a particular territory) with all its processes and elements, evolution, dynamics and functioning, energy emissions and other ways of energy loss is one of the examples of thermodynamic systems. However, what make it different from isolated systems is the sun radiation and the Earth inner energy that add a huge and more or less constant quantity of energy rising up the level of the inner energy of landscape. The biosphere organisms assimilate it, keep the energy balance, and landscape territorial organization at some constant level that is fluctuating responding mostly the human impact. As it will be explained bellow, there is a great variety of systems sensitivity (system respond to the human activities impact) degrees and also the ways and quantities of technogeochemic pressure on to geosystems. As it is still too difficult to determine the absolute value of entropy or, to be more precise, the absolute change of entropy after the human intrusion into landscape systems, the term of relative entropy was introduced. The meaning of this term comprises the understanding that sensitive geosystems are subject to lose their primary or initial organisation (in structural and linkage sense) easily. The degree of technogeochemical pressure as one of the most hazardous and destructive impact factors for organisation of landscape system shows the possible risk or threat to the system of certain sensitivity.

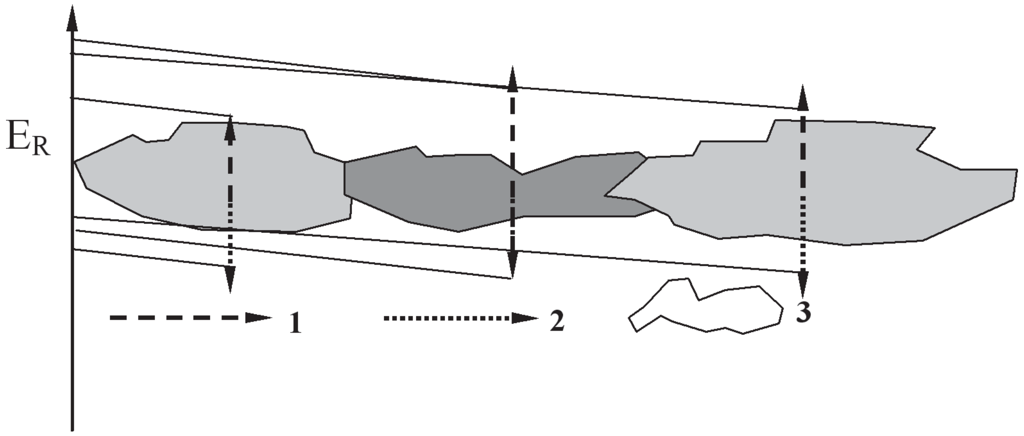

Fig. 1. The relative entropy (E_R) of landscape as the conditional distance between the sensitivity (1) and technogeochemical pressure (2) experienced by a particular geosystem (3).

2. Methods

Relative entropy in landscape systems was estimated in three stages: (1) the sensitivity of landscape systems to chemical impact was evaluated, (2) the territorial distribution of technogeochemical pressure was determined, and (3) based on the result of the first two stages, the classes of relative entropy in landscape systems were distinguished and their distribution mapped. Bellow follows a brief description of methodology of all the stages.

Geosystem sensitivity to chemical impact. Evaluation of landscape resistance, based on the concept of geosystemic links, is very complicated. Therefore, for the environmental purposes in order to standardize the use of natural resources, it is enough to evaluate the partial index, i.e., the sensitivity (vulnerability), which is understood as a short-term geosystem reaction to the outer impact, estimated by the possible relative speed of structure degradation.

The determination of landscape system sensitivity to chemical impact was performed on the ground of the regularities of heavy metals and organic pollutants migration (Jankauskaitė, 1993), evaluating (in grades) the potential geosystems possibilities to neutralize or in a relatively short time to remove the toxic substances. Two different models were offered for evaluation of sensitivity to chemical impact:

1. Landscape system sensitivity to soil pollution. In the process of this evaluation, the soil genetic type was taken as the main factor: the least sensitive are gleysols, the most sensitive – arenosols. The sensitivity of soil with respect to granulo-metric composition rises in range from rough sand to clay. According to relief influence, the least sensitive are geosystems that disperse the pollutants – elevations, the most sensitive – concentrating pollutants – hollows, etc. Besides that, factors of geochemical background, ground water depth, its mineralization, annual precipitation, and soil temperature were taken into account.

2. Landscape system sensitivity to the pollution of ground water. With regard to granulometric composition influence to the ground water pollution, the sensitivity grades rise in the range from clays to sands (the lighter is the soil the higher is the sensitivity to ground water pollution). The evaluation grades with regard to soil genetic type distribute in the same range as in the evaluation of sensitivity to the soil pollution (the most sensitive are the least geochemically active soils). With respect to the ground water depth, the higher is the level of water, the higher is the sensitivity grades. The intensity of run-off and ground water mineralization were the other evaluation factors

The evaluation of integrated landscape system sensitivity to chemical impact was derived from a combination of the above-mentioned evaluations. It was corrected additionally (±30%) by coefficients considering the impact of local factors (stabilizing factor – forests, destabilizing factors – long-term industrial air pollution) (Jankauskaitė, 1993). As a result, with respect to self-cleaning features of landscapes, 7 levels of geosystem sensitivity were distinguished and mapped in the territory of Lithuania.

Evaluation of technogeochemical pressure. Technogeochemical pressure on landscape is caused by emissions from industry and power production, agriculture, transport, pollution of domestic waste. In order to evaluate the relative entropy in landscape systems, it is important to know the territorial distribution of the mentioned pollution sources. To determine directly the actual pollution of each industrial plant, agricultural field or settlement is impossible at this time due to the shortage or imprecision of the data. Statistical data given in reports only for administrative districts and large cities is of insufficient preciseness to analyse the territorial distribution of pollution. Therefore, the method was offered allowing qualitative evaluation of the potential pollution in a landscape using the term of so called technogeochemical pressure. In order to evaluate the strength of technogeochemical pressure the previously published (Jankauskaitė, 1998) methods was adapted. The technogeochemical pressure was evaluated in grades considering the total pressure being made by the mentioned pollution sources (industry and power supply, agriculture, transport, and domestic waste). Every pollution source was given (by expert analysis) the different maximum evaluation in grades, reflecting the relative weight of respective pollution source in technogeochemical pressure (to compare: the industry and power supply got maximum 40 grades evaluation range, agriculture – 30, transport – 20, domestic waste – 10).

Technogeochemical pressure from industry & power production and agriculture was evaluated according to their occupied part (in %) in the territory. The technogeochemical pressure of transport was evaluated according to the density of the main infrastructure elements (roads and railroads) also taking into account the type and category of these elements, because these determine the extent of pollution along the infrastructure lines. For evaluation of the technogeochemical pressure created by domestic waste the population density indirectly showed the extent of pollution. The main principle of evaluation is: the higher is the pollution source relative index (percentage, density), the higher is the meaning of technogeochemical pressure it was given in a respective territory. Eventually, the sum of all the pollution source evaluations made up the integrated technogeochemical pressure evaluation in the territory. The calculation of the mentioned relative dimensions was enabled by operations and analysis using various GIS data bases (©CORINE Land Cover Lithuania data base, European Commision, Phare Programme, 1998; Topographical information LTDBK50000-V ©State survey of land managing and geodesy, 1996; GDB200 ©GIS-CENTRAS, 1993–1999).

In order to do the analysis of the territorial distribution of technogeochemical pressure the specific system of territorial units – technotopes (relatively independent territorial units of landscape technogenic structure, characterized by specific techogenization type and landuse features) – was chosen. In the whole territory of Lithuania nearly 2000 technotopes were distinguished (Veteikis, 2003). In the mentioned technotopes the relative measures of each pollution source were calculated, converted to grades and finally summed up. The technogeochemical pressure evaluation grades were classified into 5 levels from very low to very high technogeochemical pressure.

Distinguishing the relative entropy classes. The above described information layers (sensitivity to chemical impact and technogeochemical pressure) were superposed using the GIS software and too many (5 × 7 = 35) relative entropy classes were extracted. To simplify this complicated relative entropy assessment, the relative entropy classification matrix was created allowing to reduce the 35 relative entropy variants into 5 classes from very low to very high relative entropy (Table).

3. Results and Discussion

The main three groups of results were obtained by the above methodology. As mentioned, the landscape systems sensitivity to chemical impact of Lithuanian territory was determined. According to the landscape potential for self-cleaning 7 levels of geosystem sensitivity were distinguished and the map of their distribution in Lithuanian territory created (by M. Jankauskaitė). The largest area of extremely sensitive landscapes distinguished in Vilnius–Kaunas belt. Here, as in all the Eastern and South-Eastern Lithuania the luvisols (a kind of soils) are dominant with a light mechanical composition, not having large buffer capacity. Long-term and very intensive atmospheric pollution in this zone have changed the background of soils with low geochemical activity. Much smaller areas of extremely sensitive geosystems are in the middle valley of the Venta River (light luvisols and the long-term impact of Mažeikiai oil-refinement plant). Extremely sensitive territories are also in the Seashore zone and the region of Saugai–Priekulė (sand with the lowest geochemical activity and influence of Klaipėda city).

The results show that territorially the largest part (two thirds of Lithuanian territory) is taken by averagely sensitive (35%) and more than averagely sensitive (32%) geosystems. Not so common is the level of less than averagely sensitive (16%), little sensitive (8%) and very sensitive (6%) geosystems. Extremes (relatively insensitive and extremely sensitive geosystems) occupy a small part of Lithuanian territory (1% each) (Fig. 2).

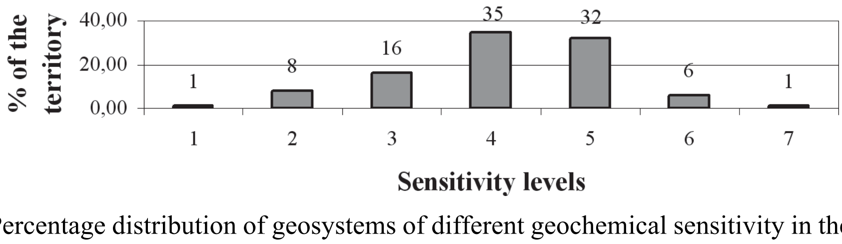

Fig 2. Percentage distribution of geosystems of different geochemical sensitivity in the territory of Lithuania: 1 – relatively insensitive, 2 – little sensitive, 3 – less than averagely sensitive, 4 – averagely sensitive, 5 – more than averagely sensitive, 6 – very sensitive, 7 – extremely sensitive.

With regard to technogeochemical pressure the highest grades belong to the technotopes with the largest part of industrial territories (technotopes comprising Vilnius, Kaunas, Klaipėda, and other large cities, some large industry and power plants). Such territories take up about 1% of Lithuanian area. High evaluation was given to agricultural technotopes (especially in the Middle Lithuania Plain), they are the most frequent (taking up 37% of the territory). The lowest grades were obtained for technotopes in the relatively natural South-eastern sandy plain and other woody territories (26% of the territory).

Medium technogeochemical pressure values are applied to Žemaičių and Aukštaičių elevations, as they are averagely agriculturally cultivated (taking up 26%). Areas with low technogeochemical pressure occupy about 11% of Lithuanian territory (Fig. 3). These data show that Lithuanian landscape under the conditions of intensive exploitation experiences rather remarkable chemical load.

The third group of results reveals the distribution of the potential relative entropy in landscape. The mapped distribution of 5 level relative entropy areas shows a very spotty situation in this regard (Fig. 4). With growing landscape relative entropy its stability diminishes due to the changes of the features upholding the landscape inter-systemic self-regulation potential and because of inability to keep the functioning equilibrium. Therefore the map of relative entropy also shows the areas of unequal landscape stability.

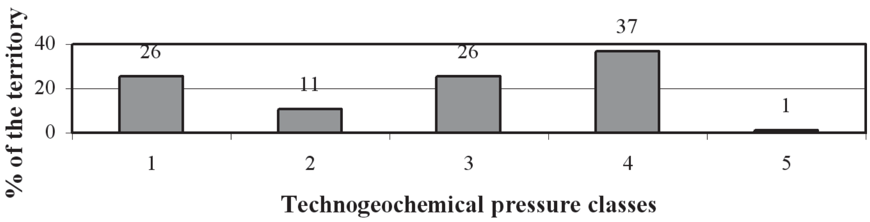

Fig 3. Percentage distribution of areas with different technogeochemical pressure in the territory of Lithuania: 1 – very low, 2 – low, 3 – medium, 4 – high, 5 – very high.

Table. Distinguishing the classes of relative entropy according to the combination of geosystem sensitivity (categories 1 to 7 see fig. 2 caption) and technogeochemical pressure degree (categories 1 to 5 see fig. 3 caption): *i* – very low, *ii* – low, *iii* – medium, *iv* – high, *v* – very high.

Sensitivity of geosystems	*Technogeochemical pressure*				
	1	2	3	4	5
1	*i*	*i*	*i*	*i*	*ii*
2	*i*	*i*	*ii*	*ii*	*ii*
3	*i*	*ii*	*ii*	*iii*	*iii*
4	*i*	*ii*	*iii*	*iv*	*iv*
5	*ii*	*ii*	*iii*	*iv*	*v*
6	*ii*	*iii*	*iv*	*v*	*v*
7	*ii*	*iii*	*v*	*v*	*v*

The areas of the highest relative entropy, though occupying 4% of Lithuanian territory, are more or less scattered across the country. The highest concentration of relative entropy spots is located in the triangle of Vilnius–Kaunas–Kėdainiai cities. This is the area of the most sensitive geosystems and highest, longest-lasting technogenization. The causes of such a situation are the proximity of the largest two cities (Vilnius and Kaunas), the arterial road connecting them, large industrial and power enterprises. In North-western Lithuania the area of very high relative entropy, determined by extremely sensitive geosystems experiencing high technogeochemical pressure, covers the city of Mažeikiai and its surroundings (some parts of the Venta valley, oil refinement plant and railroad territories).

Besides the mentioned large areas, there are several smaller spots with very high relative entropy worth to be mentioned: Klaipėda seaport, established in very sensitive seashore geosystems, Radviliškis town with railroad node and Panevėžys city creating very high technogeochemical pressure for sensitive geosystems, etc. Percentage of relative entropy classes distribution in Lithuanian territory is given in Fig. 5. Each of low, medium and high relative entropy classes occupy about one fourth of Lithuanian territory. Areas with very high relative entropy take up 4%, very low – 17% of Lithuanian territory.

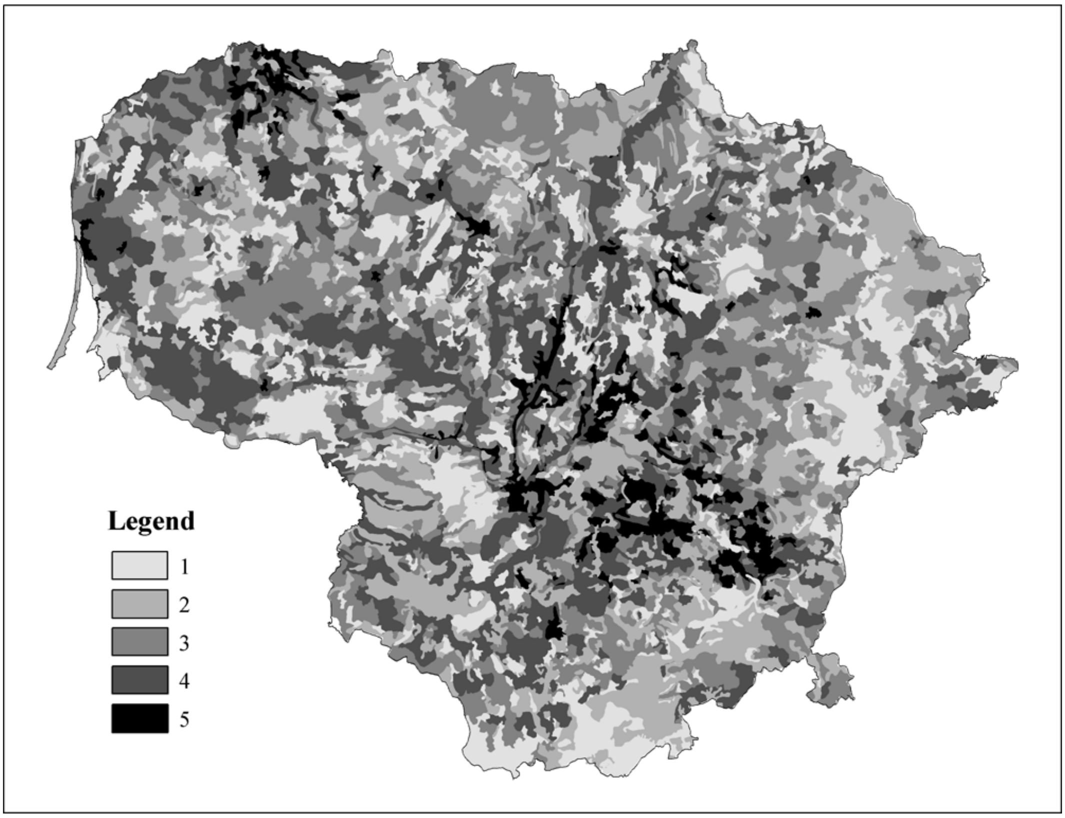

Fig. 4. Distribution of relative entropy in the Lithuanian landscape systems. Relative entropy: 1 – very low, 2 – low, 3 – medium, 4 – high, 5 – very high.

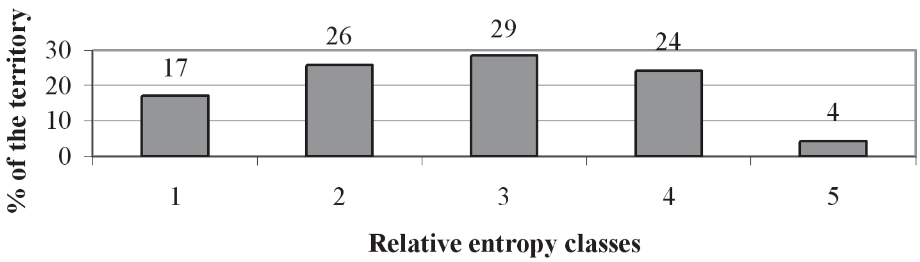

Fig. 5. Percental distribution of relative entropy classes in the Lithuanian territory. For class names see Fig. 4 caption.

Discussion may rise regarding the practical application of the research carried out. To prove the applicability of the results, the overlay operation was performed with the relative entropy map and Nature Frame scheme included into the National Plan of Lithuania (National…, 2003). The Nature Frame of Lithuania (already acknowledged legally) distinguished according to the general geoecological principles, consists of geoecological divides (functioning as entering windows of circulating matter), migration corridors, and nodes of geoecological stabilization (National…, 2003; Kavaliauskas, 1992), most of them ranged from microregional to international level. The Nature Frame covers about 51% of Lithuanian territory (divides occupy 24%, corridors – 10%, stabilization nodes – 17%). The overlay operation with relative entropy map revealed that some of these territories fall into the areas of high and very high relative entropy (Fig. 6). Such territories (taking up 10% of

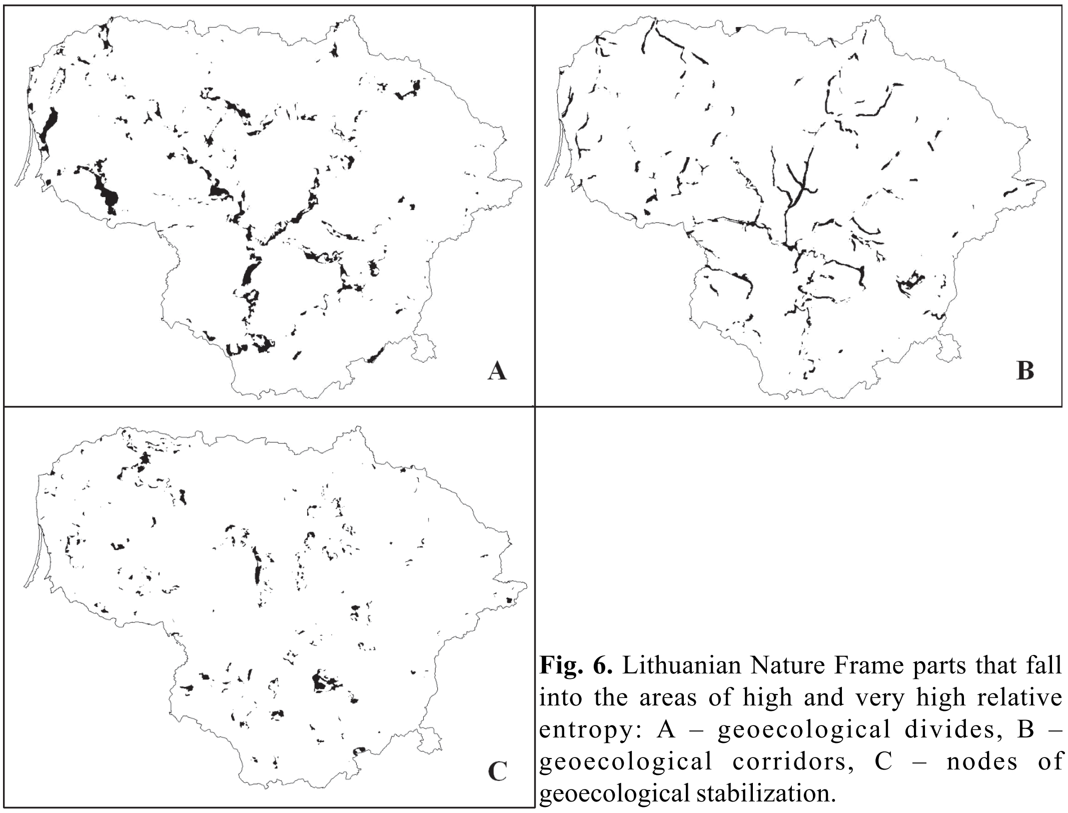

Fig. 6. Lithuanian Nature Frame parts that fall into the areas of high and very high relative entropy: A – geoecological divides, B – geoecological corridors, C – nodes of geoecological stabilization.

Lithuanian area and about 20% of Nature Frame) become the priority tasks for territorial planning and landscape optimisation.

Knowledge of the relative entropy areas allows the rendering of recommendations to economy units for their economical activity organization that should be developed considering the means of landscape ecological stability maintenance like increase of forest percentage, formation of geochemical barriers, proper distribution of land use. Besides that, the research results obtained can be interpreted in many other ways (like entropy, ecological planning, etc.) therefore they can be applied for the further analysis of landscape systems in Lithuanian territory.

Conclusions

1. In order to optimise the landscape destabilized by the contemporary intensive land use, it is important to evaluate the sensitivity of landscape systems, their technogeochemical load, and by the ratio of the both to distinguish the problematical areas of potential relative entropy. These areas should be associated with the primary installation of environment protection means. Some important results were obtained by application of methods evaluating the geosystems sensitivity and technogeochemical pressure, using the cartographic, statistical and field research data as well as GIS technologies; the cartographic models of landscape systems sensitivity to chemical impact and technogeochemical pressure in landscape technotopes; and finally, the overlay of the last mentioned two cartographic models enabled creating the landscape relative entropy map of Lithuania.

2. The territory of Lithuania with regard to geosystem sensitivity to chemical impact is rather contrasting, having the dominance of averagely and more than averagely sensitive geosystems. Relativly insensitive and extremely sensitive geosystems cover a little part of

Lithuania (each for about 1%). The most sensitive are the Baltic highlands, especially in the belt of Vilnius–Kaunas, characterized by intensive and long-term pollution, weakenning the natural landscape self-cleaning features. Besides that, the rather large area of very sensitive geosystems is located in the north-western part of Lithuania (around Mažeikiai city).

3. Due to the vast agricultural areas in Lithuania, the largest part of the country is occupied by the technotopes with high technogeochemical pressure sharing its part with less frequent technotopes experiencing low and medium technogeochemical pressure. Areas of very high technogeochemical pressure mostly are related with intensive industrial and residential built up and cover only about 1% of the territory.

4. Various combinations of geochemical sensitivity and technogeochemical pressure allowed distinguishing large variety of relative entropy types, that were classified into 5 main classes and mapped. The cartographic view shows relatively high relative entropy of Lithuanian landscape. The highest relative entropy is characteristic to the triangle area of cities Vilnius–Kaunas–Kėdainiai and the region of Mažeikiai city. The areas of the lowest relative entropy, i.e. the areas of the most stable landscape, are determined in the largest forested territories (South, East, South-western Lithuania). Areas of very high relative entropy occupy about 4% of Lithuanian territory.

5. The example of the applications of presented results can be the overlay of the relative entropy and Lithuanian Nature Frame maps. It was estimated that about 20% of the Nature Frame territories fall into the areas of high and very high relative entropy. These territories should become the priority tasks of territorial planning and landscape optimisation.

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Kraštovaizdžio santykinės entropijos įvertinimo ir jo pritaikymo problema (Lietuvos teritorijos pavyzdžiu)

Santrauka

Dabartinis intensyvus gamtinių išteklių naudojimas ir technogeninė tarša kelia didelę grėsmę kraštovaizdžio ekologiniam stabilumui, tad jo vertinimas darosi ypač aktualus. Kraštovaizdis – tai sistema, kurios funkcionavimo pusiausvyros palaikymas užtikrina žmogaus gyvenamosios aplinkos tvarumą. Tam tikslui svarbu pažinti esamą kraštovaizdžio būklę skirtingose teritorijose, pasižyminčiose nevienodu jautrumu cheminiam poveikiui ir egzistuojančio arba potencialaus technogeocheminio poveikio sąlygų įvairove. Galima teigti, kad cheminiam poveikiui jautrių geosistemų vidinė organizacija sutrinka greičiau dėl cheminio poveikio, kita vertus, augant išoriniam technikos sukeltam cheminiam poveikiui, taip pat išauga geosistemos dezorganizavimosi rizika. Taigi kraštovaizdžio sistemų vidinio dezorganizavimosi riziką, vartojant termodinamikos terminiją, galima vadinti santykine entropija. Siekiant įvertinti kraštovaizdžio sistemų santykinę entropiją, nustatyti technogeocheminės apkrovos veiksniai – pramonė, žemės ūkis, transportas, gyventojų sukeliama buitinė tarša. Šiame darbe pabandyta nustatyti santykinės entropijos pasiskirstymą skirtingose kraštovaizdžio sistemose Lietuvos teritorijoje. Santykinės entropijos dydį lemia technogeocheminio poveikio agresyvumo ir geosistemų jautrumo santykis (1 pav.).

Kraštovaizdžio sistemos Lietuvos teritorijoje pasižymi skirtingu jautrumu cheminiam poveikiui. Atsižvelgiant į kraštovaizdžio savivalos savybes išskirti 7 geosistemų jautrumo lygiai, sudarytas jų pasiskirstymo Lietuvos teritorijoje žemėlapis. Didžiausią ploto dalį užima vidutiniškai ir daugiau nei vidutiniškai jautrios geosistemos, mažiausiai (beveik po lygiai) yra santykinai nejautrių ir ypač jautrių geosistemų (2 pav.).

Atlikta detali kraštovaizdžio technomorfologinės struktūros analizė tapo kraštovaizdžio technogeocheminio spaudimo nustatymo pagrindu. Lietuvos teritorijoje išskirta apie 2000 įvairaus technogenizacijos laipsnio (pagal urbanizacijos lygį, kelių tankį, žemės naudojimo pobūdį ir kt.) technotopų – savarankiškų technogeninės kraštovaizdžio morfostruktūros dalių. Minėtuose technotopuose technogeocheminė apkrova buvo įvertinta pagal pramonės ir kitų užstatytų teritorijų, žemės ūkio naudmenų užimamą plotą, kelių tinklo tankį, pakoreguotą pagal eismo intensyvumą, ir buitinę taršą, įvertintą remiantis gyventojų tankumu naudojantis GIS duomenų bazėmis. Kiekvienam iš minėtų veiksnių suteikti skirtingi svorio koeficientai adaptuojant jau anksčiau pasiūlytą cheminės apkrovos kraštovaizdžiui vertinimo sistemą. Nustatytas skirtingo technogeocheminės apkrovos laipsnio teritorijų procentinis pasiskirstymas Lietuvos teritorijoje (3 pav.).

Perdengus geosistemų jautrumo cheminiam poveikiui ir technogeocheminės apkrovos žemėlapius gauta kartoschema, atskleidžianti santykinės entropijos Lietuvos kraštovaizdžio sistemose pasiskirstymą. Pažymėtini Vilniaus–Kauno–Kėdainių–Jonavos bei Mažeikių probleminiai didžiausios santykinės entropijos kraštovaizdžio sistemose arealai. Ekologiniu požiūriu stabiliausi (pasižymintys mažiausia santykine entropija) išlieka mažai technogenizuoti miškingi Pietryčių lygumos, Karšuvos ir Užnemunės arealai (4 pav.). Didžiausią Lietuvos teritorijos dalį beveik po lygiai užima vidutinės (29%), mažos (26%) ir didelės (24%) santykinės entropijos arealai, tuo tarpu labai mažos santykinės entropijos arealams tenka 17%, labai didelės – 4% Lietuvos teritorijos.

Pateiktas ir santykinės entropijos įvertinimo kraštovaizdžio sistemose pritaikymo pavyzdys, kai kartografinis santykinės entropijos pasiskirstymo Lietuvos teritorijoje vaizdas perdengtas su *Lietuvos bendrajame plane* pateikta gamtinio karkaso kartoschema. Apskaičiuota, kad apie 20% gamtinio karkaso teritorijų patenka į didelės ir labai didelės santykinės entropijos arealus (6 pav.). Tai teritorijos, kurioms būtina taikyti tinkamą aplinkosauginių priemonių planavimą, užtikrinantį kraštovaizdžio ekologinės pusiausvyros palaikymą.