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APPROACHES TO FORMALIZATION OF ASSESSMENT OF TERRITORY ENGINEERING GEOLOGICAL COMPLEXITY FOR PURPOSES OF SUSTAINABLE URBAN DEVELOPMENT (THE CITY OF MOSCOW CASE STUDY)

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Abstract: The present paper addresses methods for formalization of engineering geological complexity of urban territory based on engineering geological zoning for purposes of urban and spatial planning. Presented is distinguishing three main sets of issues for purposes of urban development complex, improvement of environmental management and assessment of engineering geological complexity distribution, issues being addressed at two levels: at the city level – mapping the engineering geological complexity to scale of 1: 100000 and at municipal level – engineering geological complexity maps to scale of 1: 25000 with derivation of taxonomic formula of geological hazard; at that, cartographical materials are proposed as open data. For the first time it is proposed to use the complexity index and to plot the diversity curves for negative geological processes. Results of distribution analysis for complexity of engineering geological conditions made it possible to reveal a relatively low complexity of the structural uplift megamassif at the territory of the city of Moscow. The proposed methods shall help to develop "geoecological image" of the city and be used for better understanding of geoecological problems related to the city development.

Keywords: engineering geological zoning; negative geological processes; assessment of engineering geological complexity; taxonomic formula of geological hazard; index of diversity of engineering geological massifs by hazard code

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INTRODUCTION

The most complete work revealing features of geological structure, engineering geological conditions, geological processes at urban territory and methodological approaches to assessment of their importance in urban development in Russian Federation is, in our opinion, the monograph (Moscow: Geology, 1997); the monograph is in many ways consistent with issues discussed in international projects considering creation of safe urban environment and with goals of urban and spatial (or territorial) planning (http://unhabitat.org/). In advancement of these problems, Institute of Environmental Geoscience, RAS (IEG RAS) is engaged in studying geoecological aspects of making development of urbanized territories sustainable, which are based on creation of engineering survey database, analysis of structural and geomorphologic zoning, geological mapping, studies of engineering geological conditions and methods of engineering geological zoning with account of negativegeological processes (Antipov, Osipov. 2009, p. 4).Within the framework of development of Russian Federation spatial data infrastructure, the program of unified geo data space for the city of Moscow which took into consideration standardization of spatial data (ISO, CEN) and recommendations of Directive INSPIRE (Directive, 2007, INSPRE, Antipov, 2013), turned out to be the most constructive. Set of large-scale geological maps of the city of Moscow (Osipov, 2010) became the city information resource used by Moskomarkhitektura (Moscow City Architecture Committee) for the urban planning purposes, while the integrated map of engineering geological zoning turned out to be notably in demand (Osipov, Burova, 2011). In succeeding years, Research and Design Institute for General Planning of the city of Moscow formed the ecological urban development plan as part of the information analysis framework for spatial planning (City general plan, urban development zoning, land planning) (Ivashkina, 2011) which determined the main structure comprising 4 data blocks (natural, ecological, urban development and socio-demographic). Methods, assessment and cartographic materials developed by IEG RAS were used in the first three blocks. Formation of geoecological information and methodological support includes several tasks, and first of all – shaping sections of the spatial planning: "Territories open to risks of natural and man-made emergencies" and "Zones with special conditions of land use" which corresponds to international guidelines on urban and spatial planning (International Guidelines, 2015) and is characteristic of spatial planning development in EU and post-Soviet area countries (Greiving S. 2006, UNECE. Ukraine, 2014). Analysis of development of spatial planning methods in Russian Federation territory for the period of time starting from 2011 (during that period amendments to Urban Development Code of the Russian Federation related to spatial planning were adopted) made it possible to single out the main directions which substantiated necessity of: shaping continuity of the concept of social and economic development in string of logic of implementation of current, spatial and strategic planning tasks (Ivashkina, 2009, Lapin, Yu. N. 2010, Avilova, 2015, Collected works, Russian Academy of Architecture and Construction Sciencies (RAACS). V. 1) and shaping concept of spatial development (Lebedinskaya, 2018, Mikheeva, 2018). It is noteworthy to emphasize the steady notion about necessity of studying the geographic space multidimensionality "as a set of relations between geographic objects located within the specific territory and evolving in time" (Alaev, 1983) as well as evolution of concepts of natural, ecological and information framework of territory and complex, rather than industry-specific, approach to territory development tasks. Criticism of the strategic development project makes it possible to substantiate necessity of deciphering of notion of "spatial development strategy" and "fit it in" or its inclusion into the existing system of spatial planning (Lebedinskaya, 2013);

formalization of indicators of spatial development and spatial planning (or territorial planning) which synthesize all possible knowledge about the territory as an object of managing (Beregovskikh, Kivva, Lebedinskaya, Shubenkov, Collected works, Russian Academy of Architecture and Construction Sciencies (RAACS). V. 1, 2018). The principle was shaped in works of TsNIIPgradostroitelstva (Main research-and-design institute for urban development) in accordance with which it is convenient "to consider the whole system of natural, ecological conditions and processes, projection of which to the territory determines its changes"; and such approach corresponds to internationally adopted principles, methodology and experience of spatial planning (IG-UTP, Directive, 2007, guidelines on urban and territorial planning). Absence of notions required for analysis of spatial development is a serious obstacle on the way of shaping information framework for spatial planning and regional model for spatial planning with due account for the geoecological aspect (Bachurina, 2016).

Account for uncertainty inherent to the urban development (Moiseev, 2017). Thesis about studying the nature of uncertainty implies necessity of development of probabilistic statistical methods (Christensen, 1985; Lapin, 2010) and detection of uncertainty as a condition for perfection of planning related to adequate and complex assessment of possible risks and dangers (Moiseev, P. 10). Particular concerns are related to risks of different nature, including natural and technogenic risks, as well as to nature and mechanisms of management of conflicts resulting from lack or misreading of information (Vladimirov, 2004).

evolution and use of *open data* required for mutual understanding between the executive authorities, planning organizations and population (concept project, 2012, methodological recommendations, 2014). Communicative theory of planning by J. Forester (Forester, 1989) states that availability of urban development information is the basis for understanding the planning including features of the geoecological situation: complexity of engineering geological conditions, spread of negative geological processes, necessity of elaboration of geoecological limitations. Most comprehensive, though not formalized, is the trend of creating an image of the city in which features of each district are emphasized making it possible to compare districts thus shaping the general mosaic image and generating representation and understanding of the studied problems (K. Linch, 1960, K. Linch, 1982).

In the row of known images (architectural, landscape, social, ethnic and others), the image of the city (that would take into account features of geological structure, engineering geological conditions, display of dangerous or negative (hereinafter – negative), geological processes) is still missing, and this is the look that is suggested to stand for *geoecological image ot the city*. To generate such image, large volume of research, methodological and cartographic groundwork was performed in Moscow, in the first place – engineering geological zoning map to scale of 1: 10 000. The map contains description data for each engineering geological massif and is used by specialists in front-end engineering and design activities; at present, the map is available for specialists in a special access mode. In this situation, the most important part of the map – data on display of the negative geological processes – becomes difficult to access for non-experts and citizens.With regard to the basic thesis of the ecological information openness (in accordance with Article 42 of Constitution of the Russian Federation and Ecological Doctrine of the Russian Federation), in particular on zones of manifestation of the negative geological processes, and with shaping of the open data concept, awareness has come that it is necessary to produce a new map showing zones of display of the negative geological processes and related factors of shaping the engineering geological complexity (Bachurina, 2016, Karfidova, 2016). It is proposed that, based on the engineering geological zoning map, a new map of engineering geological complexity shall be produced at two levels: 1) city level for the spatial planning system to scale of 1: 100 000 showing complexity of engineering-geological conditions, zones of manifestation of the negative geological processes and drawing up *taxonomic formulas of geological hazard* for administrative districts, 2) municipal level to scale of 1: 25 000 showing complexity of engineering geological conditions, zones of manifestation of the negative geological processes and drawing up *taxonomic formulas of geological hazard* for municipalities.Historically, in the Soviet Union, the taxation methods showed sufficiently good results in solving forestry analysis tasks as convenient and informative characteristic of forest areas; until now they are widely used in domestic practice of forest management and legislated in Article 69.1 of Forestry Code of the Russian Federation (Taxation and forest management, 1984, Forest taxation, 2008, Forestry Code of the Russian Federation, 2018). Projection of these methods to geoecological aspects of a territory shall make it possible to obtain an informative indicator of succession (in descending order) of spread area percentage for the negative geological processes. According to the authors, the methods used to take into account natural hazards in urban and spatial planning systems do not pay enough attention to formalizing estimates of the distribution and diversity of negative geological processes and analysis methods that would allow for the comparison of territories by these indicators.

MATERIAL AND METHODS

Acquisition of input data for assessment of the engineering geological complexity is based on: 1) Methodical framework of the spatial planning system (Methodological recommendations, 2013), 2) requirements for representation of the system objects (Requirements, 2018), 3) data base for engineering surveys performed by Mosgorgeotrest (Moscow municipal trust for geological-geodetic and cartographical works) (Mironov, 2017), 4) set of large-scale geological maps (Osipov, 2011), 5) new cartographic materials based on remote sensing data (Osipov, 2016), 6) unified state cartographic base for the city of Moscow and 7) borders of administrative and cadaster division of State real estate cadaster. **Table 1** shows data of the existing classification of objects of the spatial planning system and new objects, which are proposed by IEG RAS for solving problems of the city development in the context of ensuring geoecological safety.

As the spatial planning system evolves, number of classes of geoecological content increases, and it is possible to state that the key feature of the geoecological block is its openness to evolution; that is, as knowledge of the city geoecology increases and cognitive processes evolve, along with introduction of new tools, also shall increase number of the object classes determining geoecological situation, taking into account vulnerability of natural resources and shaping geoecological limitations for the sustained development (for example, **h**ydrogeological windows, zones of land runoff influence, zones of potential radon danger and zones of reclamation or preservation of disturbed land).

THEORY/CALCULATION

Table 1. Classification of objects of the spatial planning system

No.	Classes of objects	Directory/object code name
	The existing classification of objects of the spatial planning system for purposes of the geoecological situation assessment	
1.	Territories at risk of emergency situation occurrence of natural and man-induced character	EME_SOURCE
2.	Urgent alarm zone	HazardArea
3.	Objects of State unified system of prevention and responce to emergency situations	EmergencyProtectionObj
4.	Objects of engineering protection against hazardous geological processes	EngProtectionObj.
5.	Objects of accumulated damage to environment, water bodies subject to rehabilitation	EnvDanger
6.	Objects of utilization, deactivation and disposal of production and consumption wastes	WasteFacility
7.	Subsoil plot* with mineral rights as well as for other than mineral production purposes	MineralArea
8.	Zones with special conditions of land use	SpecialUseTerritory

Note: *- For urban territories, this applies to zones of subsided areas within the limits of which underground workings were earlier developed.

No.	Name of object class	Purpose/Relation to object class	Reference
	The proposed objects of the spatial planning system for the purpose of ensuring geoecological safety*		
9.	Hydrogeological windows	Protection of the strategic reserves of underground waters/SpecialUseTerritory	[Pozdnyakova, 2015]
10.	Catchment areas of land runoff	Safety control of buildings and facilities/New class	[Osipov, 2016]
11.	Zones of potential radon danger	Safety control of residential buildings/New class	[Miklyaev, 2012]
12.	Zones of land reclamation, preservation, and zones of disturbed land	Protection of land resources/ EnvDanger	[Rules, 2018]

*Tthe proposed objects have not yet obtained regulatory and methodological approval in the spatial planning system.

It is proposed to break the methods of formalization of the city engineering geological complexity into three blocks according to the designated purpose: 1) block of urban development complex, 2) block of improvement of environmental management (including municipal services and facilities, inspections and supervisors) and 3) block of assessment and comparative analysis of the engineering geological complexity distribution through the city territory.

In the first block of urban development complex, indicators are developed which are used in the urban planning and when solving problems of the spatial planning. The problems are resolved using methods of mapping the engineering geological complexity (based on the engineering geological zoning map) at two management levels: at the city level to scales of – 1: 100 000 – 1 : 50 000 and at the municipal district level – 1 : 25 000.

Map legend is based on the key notion of taxon of engineering geological massif (EGM) having its unique identifier which ties a new map with the engineering geological zoning map and includes attribute of the engineering geological complexity – EGM_{atr}. Attribute of the engineering geological complexity determines: 0 – no negative geological process and values from 1 to 7 – codes of negative geological processes detected in the territory of the city of Moscow and data adopted in the engineering geological zoning map on type, degree and spread, as well as presence of specific soils in the geological section: 1 – underflooding, 2 – shallow landslides, 3 – potential karst-suffosion, 4 – karst-suffosion, 5 – deep landslides, 6 – technogenic soils, and 7 – weak soils. Map legend includes the layers determining boundaries of the allocated territory for which the planning tasks are solved: administrative division, municipal district, cadastral district and cadastral block, as well as general geographical layers.

Public access to the map eliminates uncertainty between the executive authorities, designers, and population and can be used for working out urban development regulations and Land use and construction rules.

Assessment of the combined engineering geological complexity of the planning territory is performed on the basis of quantitative indicator of percentage ratio for three categories of complexity of the engineering geological conditions (**Table 1**) (Osipov, 2015).

Additional qualitative indicator for assessment of complexity distribution of the territory engineering geological conditions is EGM density factor per unit of area – K_{plEGM} which is calculated using the traditional equation:

$$K_{pl\ EGM} = \frac{N}{P} \quad (1)$$

Or density of EGM taxons with attribute of the engineering geological complexity - EGM_{atr}:

$$K_{pl\ EGMatr} = \frac{N_{EGMatr}}{P} \quad (2)$$

where: $N_{ИГМ}$ - number of all EGMs, $EGM_{atr.}$ – number of EGM taxons with attribute of the engineering geological complexity within boundaries of the territory, P – area of the planning territory.

At the next stage, taxonomic formula for assessment of geological hazard in the planning territory is worked out in the following form:

K1NP1, K2NP2, K3NP3 …, where:

a

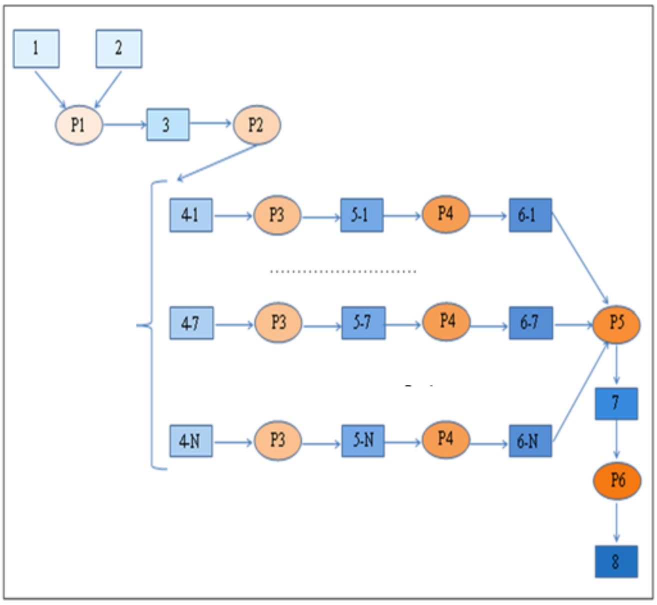

Fig. 1. The model for working out the taxonomic formula of geological hazard for the planning territory (by the example of cadastral district). Logic module Model Builder ArcGIS ESRI is used to create the model.

K1> K2 >K3 – percentage of area (integral part) occupied by NP1, NP2, NP3... – negative geological processes in descending order. The model for working out the taxonomic formula of geological hazard is presented in **Fig. 1**.

Input and calculated data are represented by rectangles numbered from 1 to 8, which color intensity changes with the processing progress. Operators are represented by ellipses which color intensity changes with the processing progress: P1 – Intersection of the engineering geological zoning layer with the layer of the cadastral division boundaries, P2 – Selection of EGM by category and process, P3 – Calculation of area of EGM of certain category and given process, P4 – Calculation of EGM area share in the total area of the cadastral district, P5 – Sorting EGM in descending order by share in the total district area, P6 – Concatenation of numerical (share) and text (process indentifier) values into the taxonomic formula.

In the second block, it is proposed to consider the objects forming the geoecological limitations in the city development, in the first place responsible for the climate change trends in urbanized territories: zones of land runoff which significantly influence both the geographical landscape (gullying, channel and slope erosion, river valley erosion depth) and engineering systems of surface water disposal, storm-water runoff drain and municipal sewer systems as well as frequency of buildings and facilities inspection and monitoring (GOST, Burova, 2018). In 2016, based on open scientific data of Earth remote sensing, surface runoff net for the territory of the city of Moscow was calculated for the first time (Osipov, 2016, Karfidova, 2018). Model of the surface runoff net comprised valleys of rivers including those earthed and ducted but not reflected in the digital terrain model. Based on the calculated surface runoff net in the geographic information system, using means of ArcGIS-ArcView, on the basis of GRID of the runoff accumulation zones Flacc, summations of surface runoff accumulation GRID SumFlacc were calculated using neighborhood operation in radius of 5 cells; based on them, isolines of summation of surface runoff accumulation were plotted. When threshold value of significant volume of the summarized runoff accumulation SumFlacc >=1,2 $km^{2,}$ is set, the chosen values of isolines are converted into zones of significant influence of the surface runoff.

Additional indicator in this block is zones of influence of the shallow metro lines. Based on open data of the metro lines route map and information about their construction depth, the shallow lines were chosen, and buffer zones of 50-m radius were added to them. Metro line-induced vibration occurs in these zones, thus increasing vulnerability of buildings and facilities; at that, norms for frequency of inspections of buildings and facilities increases. When further developing this block, the following zones shall be taken into account: hydrogeological windows, increased potential radon danger and reclamation or preservation of disturbed land.

In the third block, analytical comparative assessment is performed for distribution of the engineering geological complexity indicators in the planning territory: at levels of the city, administrative district, municipal or cadaster area. When assessing distribution of the quantitative indicators, their statistical estimates are calculated (minimum and maximum values, average value, rank, standard deviation, coefficient of variation). When assessing distribution of the geological hazard, the following parameters are analyzed: character of the negative processes distribution (uniform, random or cluster), singling out those parts of the territory where values of indicators sharply differ from indicator values for the total city territory, modal split of danger of the taxonomic formula and singling out the repeated combinations of the negative geological processes.

More informative estimation of the diversity is studying distribution of taxons of the engineering geological massif (EGM_{atr}) with different codes of the negative processes. To assess diversity of distribution of EGM taxons with different negative geological processes in the allocated territory, it is proposed to use Simpson diversity assessment index I_{Sim} acording to the following equation adopted in the ecology (Whittaker, 1965):

$$I_{Sim} = 1 - \sum_{i=1}^{N_{np}} p_i^2 \qquad (3)$$

where: p_i –proportion of the area occupied by EGM_{atr}, N_{atr} – number of taxons of EGM_{atr} in the allocated area (for example, administrative district).

At the city level, it is proposed to perform analysis of complexity of the engineering geological conditions and single out zones of low complexity, to plot diagrams of percentage of EGM_{atr} taxon area, to calculate estimation of the diversity of EGM_{atr} taxons and to plot diversity curves for EGM taxons of the administrative districts.

At the municipal level, it is proposed: to run comparative analysis of the taxonomic formulas based on the geological hazard map, with derivation of a municipal area taxonomic formula, to determine character of distribution of the negative geological processes in the territory of municipal areas, to plot diversity curves for EGM_{atr} taxons.

Plotting diversity curves for EGM_{atr} taxons is possible in two variants: in total for all EGM_{atr} taxons and in total for EGM taxons not containing the negative geological process, that is excluding EGM_{atr} taxons free of the negative geological processes.

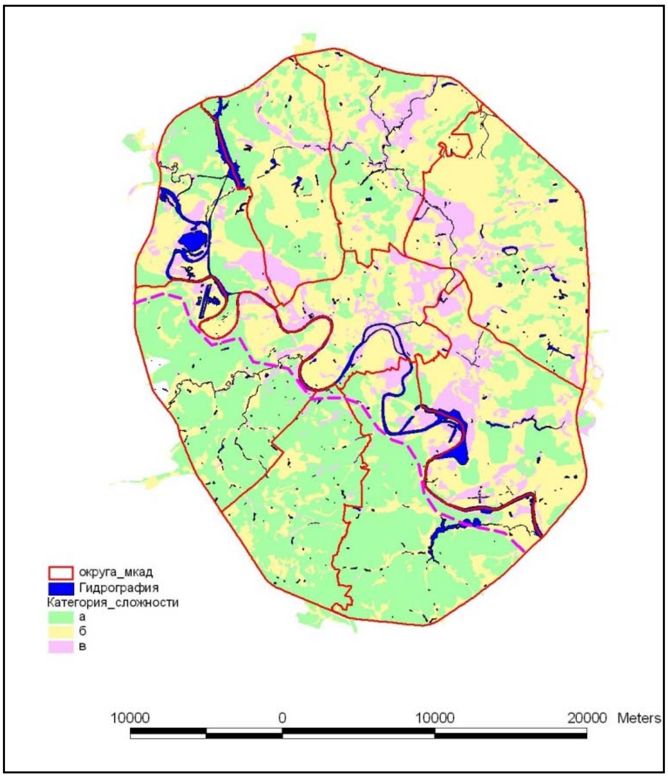

Fig. 2. Schematic map of engineering geological complexity (fragment of the city of Moscow territory inside Moscow Ring Road (MKAD) with boundary between uplift (A) and subsidence (B) megamassifs (dotted crimson line).

RESULTS

At the city level. Schematic map of engineering geological complexity based on distribution of complexity of the engineering-geological conditions (fragment of the city of Moscow territory inside MKAD) is shown in **Fig. 2**. Results of statistical indicators calculation with breakdown by complexity of the engineering-geological conditions by administrative districts in the city of Moscow territory (inside MKAD) are shown in **Table 2**.

To obtain quantitative assessment of the engineering geological complexity distribution in the city of Moscow territory, proportion was calculated for areas occupied by categories (low, average, high) of the engineering geological complexity within the limits of the administrative districts; statistical estimates of the results are shown in **Table 2**.

Diagram of the engineering geological complexity distribution by the administrative districts in the city of Moscow territory (inside MKAD) makes it possible to single out the administrative districts with low complexity of the engineering-geological conditions (**Fig. 3**). Analysis of the spatial distribution allows to note that a lower category of the engineering geological conditions (EGC) is characteristic for territories of South and Southwest administrative districts (cadaster numbers 77:06, 77:05, 77:07). Boundary of the territory with the lowest EGC complexity coincides with boundary between megamassifs of the engineering geological zoning map dividing structural uplift and subsidence.

Table 2. Preliminary data of the territory classification system by degree of engineering geological complexity

Combined degree of engineering geological complexity	Proportion of the occupied territory by degree of EGU complexity, %		
	a	b	c
Low	≥ 80	< 20	0
Average	≤ 80	> 20	≤ 20
High	< 20	< 80	> 20

Municipal districts of the city of Moscow with a lower category of complexity of the engineering-geological conditions and lower engineering geological complexity (in alphabetical order) are located in the territory of the structural uplift block first singled out by V. I. Makarov (Updated tectonic structure and relief, P. 86-105. Moscow: Geology, 1997): Akademicheskiy, Biryulevo Vostochnoe and Zapadnoe, Gagarinskiy, Zyuzino, Konkovo, Kotlovka, Krylatskoe, Kuntsevo, Lomonosovskiy, Moskvorechye-Saburovo, Nagorniy, Obruchevskiy, Orekhovo-Borisovo Severnoe and Yuzhnoe, Ochakovo-Matveevskoe, Prospekt Vernadskogo, Ramenki, Tepliy Stan, Troparevo-Nikulino, Tsaritsyno, Cheremushki, Chertanovo Severnoe, Tsentralnoe and Yuzhnoe, Yasenevo. Comparison of the modal split of the geological hazard in the city of Moscow territory inside MKAD and in the

Table 2. Statistical estimates of complexity of the engineering geological conditions by the administrative districts of the city of Moscow

Indicators	Statistical indicators of distribution				
Proportion of the territory by degree of EGC complexity, %	Min. Value	Max. Value	Rang	Average Value	Standard deviation
_A	13.00	77.00	64.00	42.89	23.36
_B	21.00	67.00	46.00	44.22	17.06
_C	3.00	28.00	25.00	13.00	7.92
Number of EGMatr types/km2	0.06	0.27	0.21	0.12	0.07

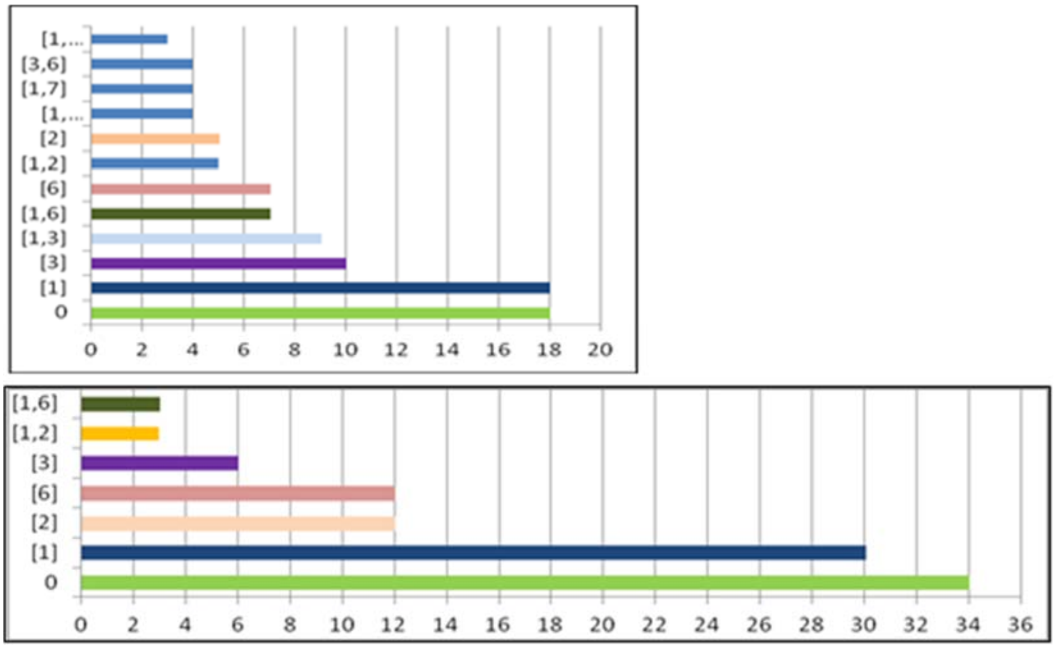

Fig. 4. Diagram of comparison of the modal split of the geological hazard in the city of Moscow territory inside MKAD (above) and in the landscape complex territory of the structural uplift (below). X axis – proportion of the occupied area to the total area of the territory in question, Y axis – process codes.

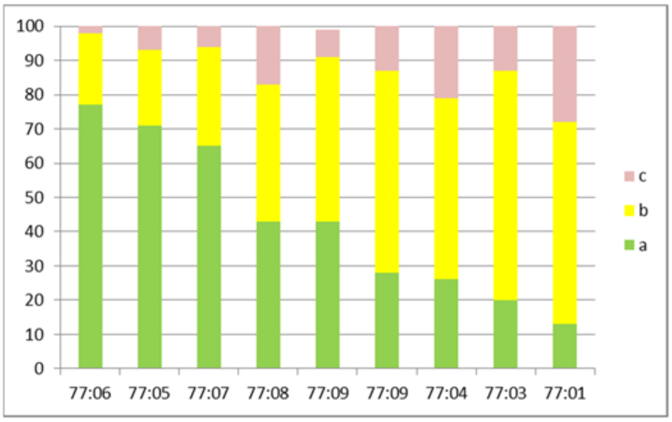

Fig. 3. Diagram of the engineering geological complexity distribution by the administrative districts in the city of Moscow territory (inside MKAD). X axis – administrative districts in the city of Moscow territory, Y axis – proportion of area occupied by a category of the engineering geological complexity adopted in the engineering geological zoning map.

landscape complex territory of the structural uplift is presented in **Fig. 4**. Analysis of distribution takes into account EGM_{atr} taxons with the occupied area up to 3% of the city of Moscow area within the limits of MKAD.

Results of assessment of EGM_{atr} taxons diversity together with proportion to megamassifs (uplift or subsidence) in the administrative districts territories are presented in **Table 3**.

At municipal level. Comparison of calculation results for indicators of the engineering-geological conditions complexity of cadastral districts in the city of Moscow territory (inside MKAD) is carried out by selecting lower and higher complexity of the engineering-geological conditions in **Table 4**. Analysis of the indicators distribution allows to note that higher complexity leads to increase in spread of indicators and density of EGM_{atr}. It is necessary to note that statistical indicators for municipal districts, by comparison with statistical indicators for administrative districts, are distinguished by scattered results; when comparing indicators, it should be taken into account that the average area of a cadastral district is 10 times smaller of the average area of an administrative district. When analyzing spatial distribution of the negative processes, important role belongs to character of their distribution over the territory – compactness (cluster character) of the hazardous processes which is critical for spatial planning to resolve issues of locating a new construction site. Examples of different distribution of the negative geological processes in the municipal territories are shown in **Fig. 5**. In Shchukino municipal district, the negative geological processes are distributed compactly, while in Pokrovskoe-Streshnevo, they are distributed at random.

Table 3. Assessment of EGM taxons diversity together with proportion to uplift and subsidence megablocks in the administrative districts territories of the city of Moscow inside MKAD

Admninstrative district	77:06	77:05	77:07	77:08	77:09	77:02	77:04	77:03	77:01
megablock	A	A	A	B	B	B	B	B	B
I_{Sim}	0.374	0.519	0.564	0.553	0.593	0.599	0.792	0.785	0.751
$K_{pl\ EGM}$	3.11	4.20	5.20	8.19	4.29	7.09	3.50	3.75	7.28
$K_{pl\ EGMatr}$	0.088	0.094	0.169	0.098	0.108	0.121	0.150	0.304	0.154

Note: A – uplift megamassifs, B – subsidence megamassifs [Updated tectonic structure and relief, P. 86-105. Moscow: Geology, 1997]:

Table 4. Comparison of the calculated statistical indicators by lower and higher complexity selections of the engineering geological conditions for cadastral districts of the city of Moscow territory inside MKAD

Statistical Indicators	Proportion of the territory by degree of EGM complexity, % selection of lower complexity			Proportion of the territory by degree of EGM complexity, % selection of higher complexity		
	A	B	C	A	B	C
Min. Value	80.00	5.84	0.00	0.00	12.62	3.52
Max. Value	94.00	20.09	1.82	84.00	71.16	65.86
Rang	14.00	15.75	1.82	84.00	58.54	62.34
Average value	88.38	11.15	0.57	11.17	50.78	37.94
Standard deviation	5.13	5.28	0.70	19.21	14.57	15.61

Formalization of the geoecological features in the regional model of spatial planning, along with creation of the taxonomic formula of geological hazard (Karfidova, 2018), is supplemented by assessment of diversity of distribution for the negative geological processes. Methods of using the diversity assessment allow to plot EGU diversity distribution curves with identification of a negative geological process and to compare diversity estimations between different administrative districts (**Fig. 6**).

In distribution of geological hazard, analysis of modal split is interesting both by separate negative geological processes and by their combinations. Comparison of modal split of geological hazard in the city of Moscow territory inside MKAD and in the landscape complex territory of the structural uplifts is shown in Fig. 4, comparison of EGM_{atr} diversity curves – in Fig. 6.

X axis – EGM rank, Y axis – proportion of EGM area on a logarithmic scale (Lg10) within the limits of the administrative district. In square brackets – codes of hazardous processes according to the engineering geological zoning map.

Analysis of the taxonomic formula by modal split allows to note that in accordance with frequency of occurrence, the hazardous processes are positioned in the following order (descending order): 1) underflooding, 2) karst-suffosion, 3) complex process of underflooding and karst-suffosion, 4) complex process of underflooding and technogenic soils. Also, characteristic combinations in the taxonomic formula of hazard can be observed: if underflooding comes as the first process, then as the second process, more often, comes (in descending order) the complex process of underflooding and karst-suffosion, further – the complex process of underflooding and technogenic soils; if the complex process of underflooding and karst-suffosion comes first, then as the second process comes underflooding. Combination of the said processes can be explained by prevailing value of their common hydrogeological nature.

DISCUSSION

As emphasized in (R.S. de Groot et al, 2010): ”the quantitative relationship between biodiversity, ecosystem components and processes and services is still poorly understood”, but at the same time features of the abiotic properties of the ecosystem components (valuation of engineering geological conditions, negative geological processes) is lacking until now . The relevant Land Use and Development Rules adopted in the Russian Town-Planning Code make it possible to take into account the indicated features of the components of the ecological system in municipal services and urban planning. The principles and methods of developing environmental indicators in accordance with the sustainable development goals (SDG) presented in the review (Hak et al, 2016) were used in the proposed indicators of the diversity of engineering geological massifs. An analytical review of indicators in accordance with the sustainable development goals (Maxwell et al, 2015) draws attention to the necessary qualities of indicators: SMART (specific, measurable, ambitious, realistic, timebound). The proposed indicators are fully consistent with these recommendations. We agree with the authors (Santos at al, 2017), who introduce the concept of geological diversity as a variety of abiotic elements of nature, and mark the modern period of the methodological development of the approach. This approach is of particular relevance in the development of the territorial planning system and ensuring the sustainable development of the city. The research undertaken for this paper has generated some discussion points, which are listed below:

1) In city planning and spatial planning it is necessary to take into account not only natural hazardous process zones, but also engineering

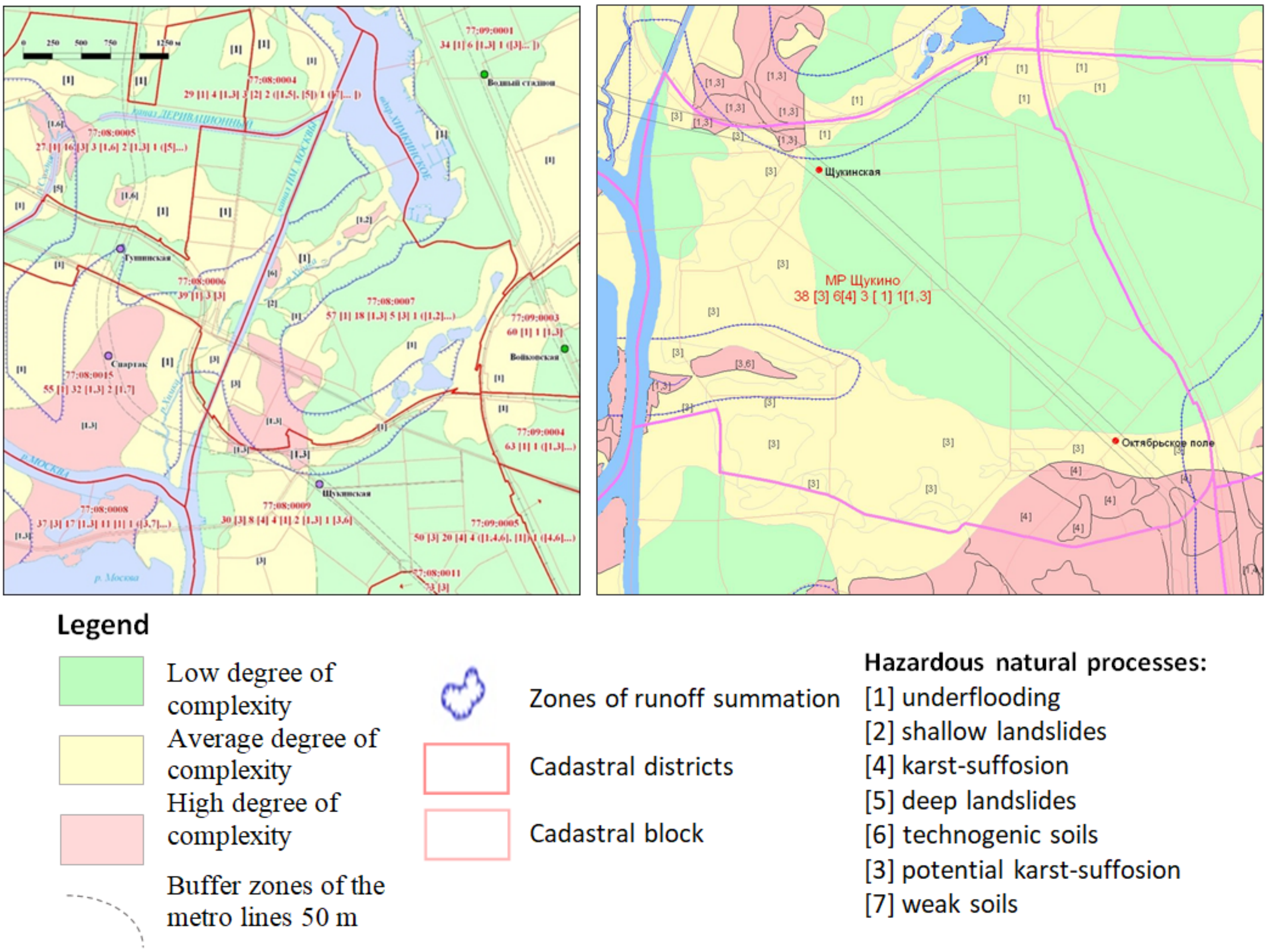

Fig. 5. Fragments of the engineering geological complexity map with taxonomic formula. On the left hand: cadastral districts of Pokrovskoe-Streshnevo municipal district of the city of Moscow. On the right hand: for Shchukino municipal district of the city of Moscow.

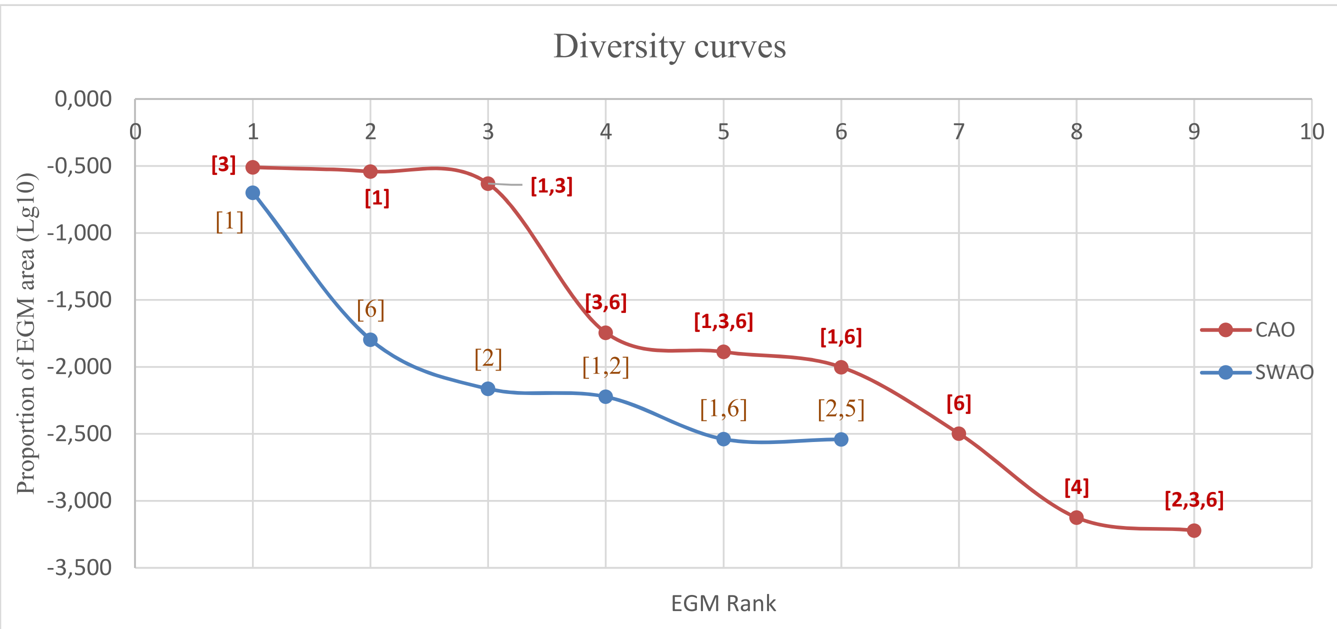

Fig. 6. Diagram of comparison of the EGM diversity curves in administrative districts: Southwest administrative district (SWAD) and Central administrative district (CAD) inside MKAD.

geological zoning, highlighting zones of varying complexity and the spread of negative geological processes.

2) Mapping the complexity of engineering geological conditions on the territory of the city is a necessary condition for the effective operation of urban services.

3) It is proposed to compile a taxonomic formula of geoecological (geoenvironmental) hazards in the information system of State Real Estate Cadaster for city divisions (in open access mode) and use in spatial planning for sustainable development of the city.

4) Estimates of diversity of negative geological processes for cadastral divisions are essential indicators for city and spatial planning, which reduces the uncertainty of city management.

5) The proposed approach allows a comparison of the geoecological features of urban divisions with each other and contributes to the development of the geoecological image of the city and its understanding.

The authors are aware that few large cities of the Russian Federation have a large scale map of engineering geological zoning similar to the map of Moscow, at the same time, the need to develop such maps for cities on the territory of which are negative geological processes is not in doubt in order to ensure their sustainable development. Necessary condition for development of the proposed method is interaction between the information system for urban planning and the information system of State real estate cadaster, at that, boundaries of cadastral division should be harmonized with boundaries of the municipal districts.

Formalization methods are proposed for use by the urban development complex for the purposes of city planning and spatial planning; later on, with development of methodological approaches in the environmental management block, the methods shall be used for assessment of the geoecological limitations.

CONCLUSIONS

Formalization methods for assessment of the engineering geological complexity of territory correspond to perfection of tasks of sustainable development of the city. Essential condition for implementation of the proposed methods is development of interaction between the information system for urban planning and the system of spatial planning. The methods are based on evolution of the open data concept, at that, the engineering geological complexity map is recommended for use as an open city information resource which shall allow to reduce uncertainty when developing the spatial planning schemes as part in the regional spatial planning model. Zones of the surface runoff influence and zones of the shallow metro lines influence were introduced into the engineering geological complexity map for the first time. Set of open data with the taxonomic formula of geological hazard provides the quantitative characteristic for spread of the negative geological processes and can serve the framework for evolution of the geoecological aspects of the regional spatial planning model. Analytical methods allowed to note that, in the territory of the structural uplift block of Moscow, categories of complexity of the engineering geological conditions and estimations of the geological hazard are lower than in the rest of the city territory. Also the municipal districts with low degree both of the geological hazard and indicator of diversity engineering geological massifs were determined. Analysis of the taxonomic formulas allows to reveal characteristic successions and combinations of types of the negative geological processes. On the whole, the proposed methods allow to shape the geoecological image of the city which shall supplement the existing ones and serve to the complete understanding of the city.

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