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ENVIRONMENTAL ASSESSMENT OF URBAN LANDSCAPES OF MINSK

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Abstract

The research presents the approach of assessment of state of the environment for big city using methods of landscape ecology. The assessment has been made for the capital of Republic of Belarus, Minsk city. The methodology of integrated environmental assessment of urban landscapes which take into account natural environment and specific urban use has been developed. Urban landscapes were used as an evaluation units for this research. For the territory of Minsk 26 types of urban landscapes were identified which were combined into 9 groups with relatively homogeneous elements of natural and anthropogenic spatial structure of the city. The assessment includes the following stages: factor analysis of natural (air, soil and topographic features urban area) and anthropogenic (location of industrial facilities, specifics of urban planning) components of urban landscapes; and integrated assessment. The results of the assessment describe the territory of Minsk by satisfactory conditions. The main residential areas of the city locate on the territories with favorable and satisfactory environmental conditions. Further planning of urban infrastructure in the city requires more detailed assessments and monitoring.

Key words: *urban landscape, integrated environmental assessment, ecological status, Minsk*

INTRODUCTION

The world is getting urbanized. Currently the most of 50% of the world population live in urban area and this amount is growing. Only during the XX century, this figure increased by 5 times. Urbanization is accompanied by growth of large cities with number of population in 1 million people and more. Among all cities of Belarus, the problems of spatial spreading and population growth are the most urgent. Over the past decade, the territory of Minsk increased to 348.85 km², and the annual growth of population is by about 20 thousand people and currently the total number of population is 1.915 million (General plan of city of Minsk with surrounding territories 2010, Minsk City Committee 2010, National Statistical Committee of the Republic of Belarus 2013).

Minsk has been and remains the largest industrial center of the country, where most of enterprises are located with more than 30% of industrial

production of the republic. At the same time the city is characterized by a huge car fleet, comprising more than 600 thousand units of cars (NATIONAL STATISTICAL COMMITTEE OF THE REPUBLIC OF BELARUS 2013). Concentration of population, industry and transport located on a limited space inevitably leads to a change in environmental conditions in the city, the transformation which affects how the specifics natural conditions, and also particularly its spatial plan.

METHODOLOGY OF RESEARCH

The territory of Minsk within existing borders is an object of the research. Minsk is the capital of the Republic of Belarus, dynamically developing city in the country, which is its most important socio-cultural and industrial center. More than 20% of the population of the Republic live in Minsk, and, in the last half-century the population increased more than three times, and currently the average population density exceeds 6.100 inhabitants/km² (NATIONAL STATISTICAL COMMITTEE OF THE REPUBLIC OF BELARUS 2013).

Based on the analysis of the main trends in the study of the ecological state of the urban environment, the methodology of integrated environmental assessment of urban landscapes has been developed which take into account the natural environment and specific urban use. Selection of the evaluation unit is a difficult issue in the assessment of the ecological state of the city. Administrative district used as evaluation unit gives a distorted picture, as the borders of administrative areas are highlighted without natural features of the area. And at the current radial separation territory of Minsk on administrative areas is impossible, since the differences in the ecological status of the core and the periphery of the city will be leveled. Therefore, to study the ecological state of the city of Minsk urban landscapes grouped into several sets have been selected as an evaluation unit.

Urban landscapes are landscapes, which was formed as a result of the transformation of urban areas characterized by a homogeneous natural basis and a certain type of urban use (FALOLEEVA 2004). It includes natural and anthropogenic components. Natural components contain features of the natural landscape reflected in its type, including the genesis, topography, location within the boundaries of catchment. Anthropogenic components includes the set and spatial structure of morphotypes. Morphological types are considered as elements of natural and anthropogenic systems of the city and represent areas with relatively homogeneous land use and mechanisms of functioning (FALOLEEVA 2004). Currently within the Minsk three groups of morphotypes identified based on type of land use and specific features: 1) residential and public areas; 2) industrial, transport and storage areas; 3) green spaces and open spaces (KOLONTAI 2003). For the territory of Minsk 26 types of urban landscapes were identified. Their titles reflects the natural features and the specific morphotype. For example: urban landscape of moraine plains and hills with a set of high-and middle-stage residential and public buildings with large industrial, transport and warehouse areas (FALOLEEVA 2004).

All urban landscapes by location combined into 9 groups (central, southern, southeast, east, northeast, north, northwest, west, south-west), which have a relatively homogeneous elements of natural and anthropogenic spatial structure of the city. These groups of urban landscapes were used as a unit for further analysis and evaluation of its ecological status.

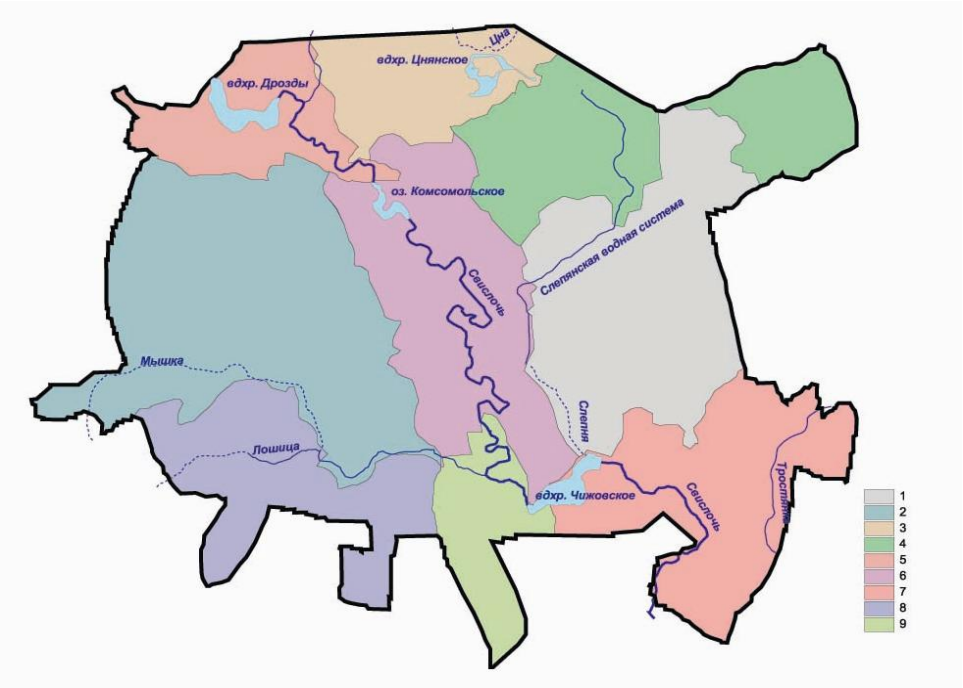

Fig: 1. Spatial distribution of groups of urban landscapes on the territory of Minsk Groups: 1 – east; 2 – west; 3 – north; 4 – northeast; 5 – northwest; 6 – central; 7 – southeast; 8 – south-west; 9 – southern.

Since urban landscape is a complicated natural- anthropogenic geosystem consisting of natural and anthropogenic subsystems, therefore the assessment of its ecological status requires an assessment of each of the components of the particular subsystems. The research includes the following stages: (1) factor analysis of natural (air, soil and topographic features urban area) and anthropogenic (location of industrial facilities, specifics of urban planning) components within urban landscapes; and (2) integrated assessment of data.

To assess the ecological status of the air the integrated index of pollution of the atmosphere (IPA) has been used. It is calculated as the sum of normalized by the mean daily maximum permissible concentration (MPCss) average contents of various substances. To ensure comparability of the results of calculations IPA is calculated for the first five on the concentration of pollutants. For Minsk these pollutants are inorganic dust, NMVOC (xylene and ethyl acetate), carbon monoxide, sulfur and nitrogen oxides, which are calculated by the formula:

$$IPA = \sum_{i=1}^{5} \left(\frac{C_i}{MPC_{c.c.i}} \right)^{q_i} \qquad (1)$$

where *i* – impurity; C_i – the concentration of the impurity; $MPC_{c.c.i}$ – corresponding mean daily maximum permissible concentration of the i-th impurity; q_i – constant, with values 1,7; 1,3; 1,0; 0,9 respectively for I, II, III, IV classes of substances.

To assess the contamination of soil the integrated index of soil pollution has been used (Zc):

$$Z_c = \sum_{i=1}^{n} K_i - (n-1) \tag{2}$$

where $K_i = C_i/C_F$ (C_i and C_F) – the actual concentration at a given point and the background concentration for soil type of i-th element, respectively); n – the number of considered elements at the point.

Terrain features in determining the assessment of ecological status of urban landscapes was calculated as follows: the maximum height accepted as the positive factor contributing to the self-cleaning of the area, and the minimum height as a negative factor contributing to the accumulation of pollutants.

The density of the emission of pollutants is calculated as the ratio of the volume of emissions (per year) from major stationary sources to the area of urban landscape.

Analysis of the scheme of functional zoning of the city showed that in different groups of urban landscapes different types of functional use are dominated. To assess the impact of the specificity of urban planning structure (urban infrastructure), as an important social factor, the coefficient of comfort Infrastructure (CCI) has been calculated, which takes into account the ratio of public space and landscape recreational areas for industrial and municipal storage spaces within the boundaries urban landscapes:

$$CCI = \frac{S_{general} + S_{landscape-recreational}}{S_{industry}} \tag{3}$$

where $S_{general}$ – share of public areas; $S_{landscape\text{-}recreational}$ – share of landscape and recreational areas, $S_{industry}$ – share of industrial and municipal storage areas.

Thus, an abundance of public landscape and recreational areas is seen as a positive feature, because it is at these territories objects are located that meet the diverse needs of the population: recreational and public, which include a number of needs (educational, medical, cultural, food, etc.). At the same time, the abundance of industrial and storage areas reduces the level of comfort for the living.

For data integration and geoecological assessment of urban landscapes, the absolute and relative values were translated into standard scores according to the formula:

$$p = \sum \frac{p_i - p_{\min}}{p_{\max} - p_{\min}} \tag{4}$$

where p – normalized value of the index in the range from 0.0 to 1.0; p_i – value of the i-th feature in a number of variation; p_{min} – the minimum value

of the sign in a number of variation; p_{max} – the maximum value of the sign in a number of variation.

Values of the indicators for each urban landscape creates a variation series, which defines the minimum and maximum values of the index. As a result of the mathematical processing for each urban landscape the normalized value obtained for the particular index ranging from 0 to 1, which are further summarized at complex evaluation.

The main tool for the calculation and visualization calculations are: ArcView 3.2a (with a set of extensions: Spatial analyst 2.0, Zonal stats), and Quantum GIS 1.7 (with a set of built-in extensions). Primary cartographic basis, and the basis for binding materials were obtained from the portal «Open Street Map Belarus». ArcView 3.2a used to assess the state of the environment block, and Quantum GIS for vectorization and conduct calculation of the coefficient of comfort infrastructure, on the basis of functional zoning scheme Minsk.

RESULTS

Relief of the territory plays a decisive role among the natural factors. The city of Minsk is located on the southeastern slope from north-west to southeast, and by the dismemberment of the urban area by valley of the river Svislach in the same direction (Fig. 2). In combination with the prevailing westerns directions of winds, features of relief create the favorable conditions for self-purification for most of the area of the city. The most polluted areas are areas located at the lowest hypsometric levels.

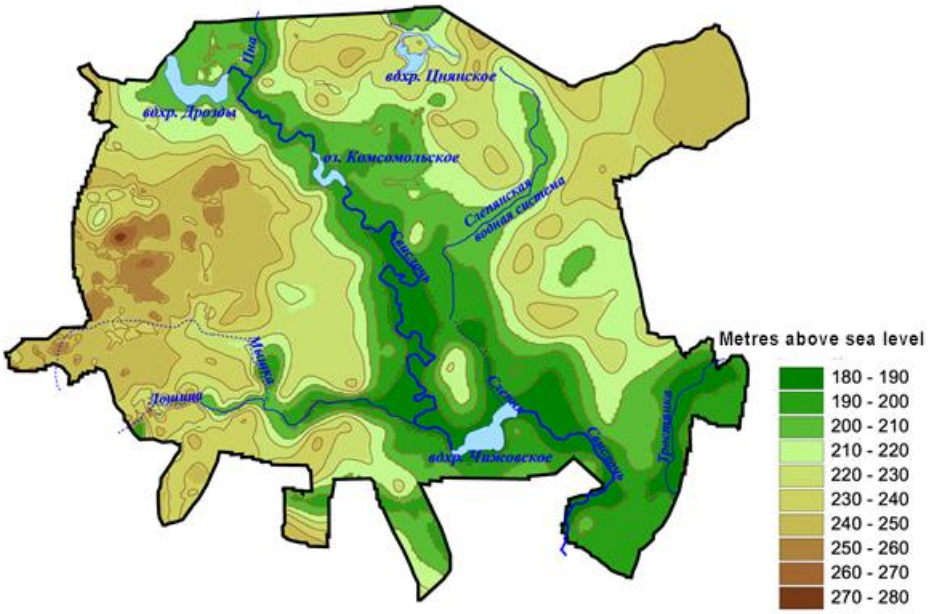

Fig. 2: Physical characteristics of relief in Minsk area

Industry of Minsk city and its transport have the most significant impact on the state of natural environment. Within the area of the city about 1300 enterprises are located. 80% of their volume of pollutants emissions accounts for 13 enterprises, concentrated mainly in the center and eastern part of the city (Fig. 3). Annually volume of emissions from stationary sources accounts about 40 тons, which is only 15% of the total emission of pollutants onto the atmosphere (STATE OF THE ENVIRONMENT AND NATURAL RESOURCES OF THE CITY IN MINSK 2011).

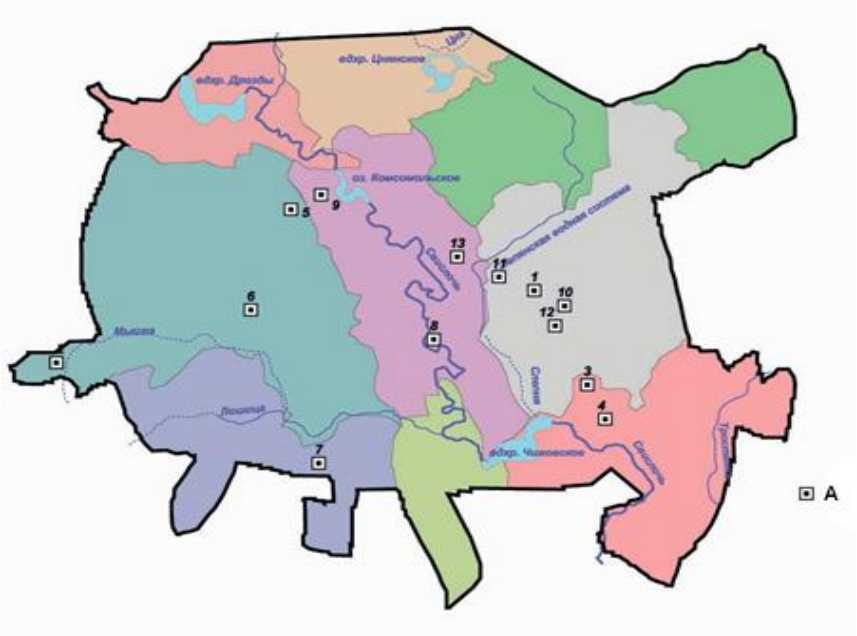

Fig 3: Location of the biggest enterprises in Minsk
A. Enterprises: 1 – Minsk traktor plant; 2 – Central Heating and Power Plant-4; 3 – Central Heating and Power Plant-3; 4 – Minsk Automobile Plant; 5 – Minsk Heating Equipment Plant; 6 – Minsk Plant of building materials; 7 – JSC «Keramin»; 8 – Minsk heat networks; 9 – PA «Atlant»; 10 – Minsk Motor Plant, 11 – Minsk Electrotechnical Plant; 12 – Minsk Bearing Plant; 13 – Minsk Plant of Gypsum and Gypsum products.

However, the main volume of emissions (226 tonnes) comes from for mobile sources of pollutions, mainly vehicles, the amount of which in 2011 exceeded 600 thousand cars. The qualitative composition of emissions from mobile sources is relatively constant and it is as follows: carbon monoxide (71.1%), hydrocarbons (17.9%), nitrogen oxides (8.4%), solid carbon (2.4%) and silica sulfur (0.2%) and 0.05 % of benzo(a)pyrene. While emissions from stationary sources are characterized by a wide range of elements, depending on the specific production of enterprise. Thus, high levels of air pollution are characterized for the major highways and interchanges of the city where IPA is 7-10.6 (GLAZACHEVA et al. 2011), which is confirmed by the results of this research. In accordance with the existing scale of air pollution: low pollution (IPA ≤ 5); increased (IPA 5–7); high (IPA 7–14); very high (IPA ≥ 14) (STATE OF THE ENVIRONMENT AND NATURAL RESOURCES OF THE CITY MINSK 2011), it is

obvious that the most favorable situation is created for the northern and north - western part of the city where there are no large industrial enterprises and not significant load of pollution from transport (Fig. 4). These areas are in accordance with the functional city zoning perform mainly recreational role. Southwestern and northeastern parts of the city are characterized by increased levels of atmospheric pollution due to a substantial load of pollution from transport and the influence of certain large industrial facilities. Low pollution on the western parts of the city is largely dependent on natural conditions especially on the specifics of the city orography (slope areas in the north- west to south- east) and the predominance of western and north – western directions of winds. These conditions contribute to removal of pollutants into adjacent territories. Zone of high level of air pollution is formed at the south-eastern, eastern and central parts of the city. This is explained by the several factors: a powerful industrial potential, high intense of traffic mobility, systematic occurrence of "heat island" in the center, resulting in a thermal choke and runoff of pollutants, as well as by natural conditions.

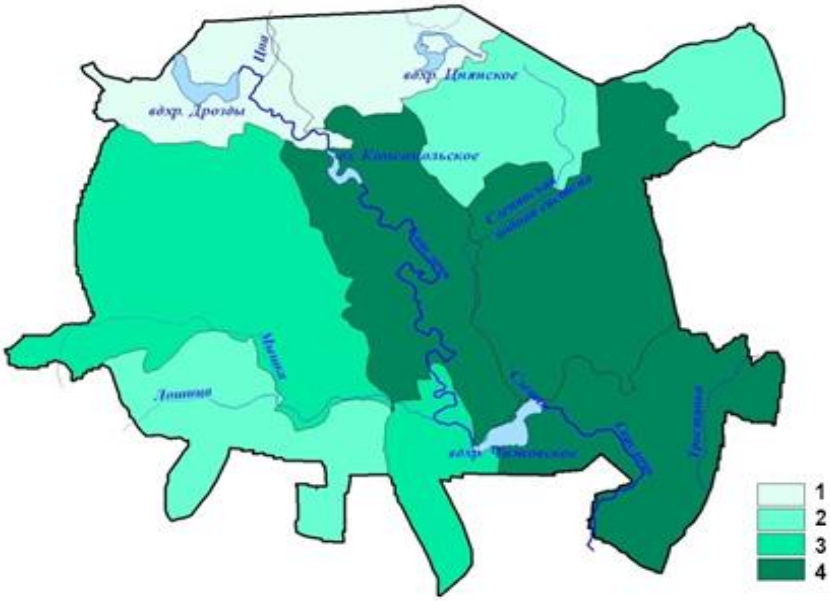

Fig. 4: Distribution of IPA for urban landscapes of Minsk
Level of IPA: 1 – low; 2 – increased; 3 – high; 4 – very high

Analysis of soil pollution in the city is resulted in conclusion that there are areas in Minsk with 5 levels of soil contamination (negligible, low, medium, higher and very high). Very high level of soil contamination (Zc > 16) is typical for central, eastern and southeastern parts of the city, especially in areas with a significant concentration of industrial capacity and lots of vehicles. The southern part of the city is characterized by better situation and the contamination of soil caused by individual industrial enterprises. The northern, north-western, western and south- western outskirts of the city are characterized by

insignificant and low levels of soil contamination which is caused by short time of urban development, less numbers of industrial areas, as well as terrain features and microclimate conditions.

Features of constructions plays an important role in the formation of geo-environmental condition of urban landscapes, which are expressed through the specifics of functional zoning of city. The optimal balance of social, landscape, recreational and other areas forms necessary social infrastructure. 4 types of functional zones are approved by General Plan of Minsk (based on the dominant type, not less than 50% of the territory): residential, community, landscape and recreational, industrial and municipal storage (GENERAL PLAN OF THE CITY OF MINSK WITH SURROUNDING TERRITORIES 2010).

Joint structure of various functional areas within urban landscapes creates a special infrastructure. The presence of a significant proportion of public landscape and recreational areas characterizes the landscape from a favorable side, as it creates conditions for provision of social needs. A large proportion of the territory for landscape and recreational purpose is an important factor, as there areas have a number of ecological functions, as well as provision of recreational needs of the population. These areas occupy about 21% of the area of the city, which is quite a high rate for major cities. However, there is a shortage in the city landscape and recreational areas with high recreational improvement (their share is only 10%). Basically, landscape and recreational areas are confined to the valley of river Svislach and reservoirs created in its stream. The southwestern and western areas are characterized by low percentage in the structure of recreational areas. There is a lack of specialized parks in Minsk city (GENERAL PLAN OF THE CITY OF MINSK WITH SURROUNDING TERRITORIES 2010).

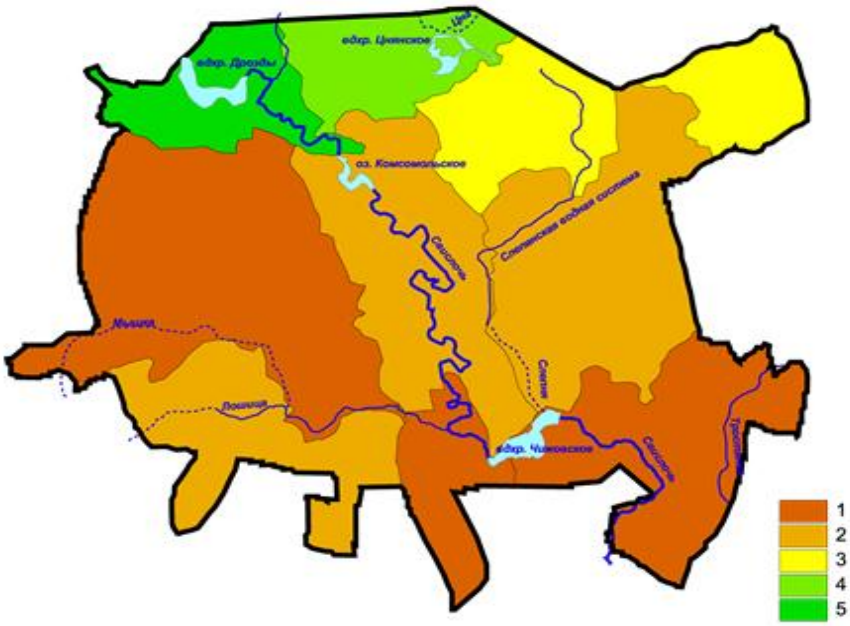

Fig. 5: Assessment of comfort of infrastructure
Level of the comfort of infrastructure: 1 – critical; 2 – unsatisfactory; 3 – satisfactory; 4 – relatively prosperous; 5 – favourable.

The coefficient of comfort infrastructure (CCI) was calculated and the scale for CCT was set up which includes 5 grades of comport levels: favorable (more than 4.0); relatively prosperous (2.14–3.99); satisfactory (1.60–2.13); unsatisfactory (0.72–0.15); critical (less than 0.71). The urban landscapes of the northwestern areas of Minsk city are characterized by highest levels of the coefficient of comport infrastructure (10.31) due to the dominance of the structure of the functional areas of landscape and recreational purposes and the almost lack of industrial areas (Fig. 5).

Lower level (relatively prosperous) is present in the northern group of urban landscapes (3.58), where in the structure of the functional zones dominate landscape recreational and public areas. Satisfactory level of comport of infrastructure characterize northeastern urban landscapes, where compared to the north and northwestern landscapes, the volume of recreational zones is decreasing and the share of industrial and storage areas increased. The urban landscapes in southwestern, central and eastern part of Minsk city are characterized by unsatisfactory level of comfort of infrastructure. Critical level of comport of infrastructure describe western, southern and southeastern urban landscapes. This is primarily due to the abundance of industrial areas from 32 to 67%, and very small share of the public and recreational areas.

The results of factor assessment of urban landscapes were obtained in normalized scores and summarized in the final assessment score (Tab. 1).

Tab. 1: Assessment scores of environmental status for groups urban landscapes of Minsk area

Indicators (in normalized scores)	**Atmosphere air**	**Soil**	**Average height**	**Emission density**	**CCI**	**Total score**
Groups of urban landscapes	IPA	Zc				
Central	1	0.79	0.83	0.18	0.96	3.69
Northern	0	0.01	0.37	0	0.59	0.96
Northern eastern	0.35	0.26	0.22	0	0.81	1.54
Eastern	0.76	0.86	0.49	1	0.90	3.98
Southeastern	0.7	1	1	0.8	1.00	4.51
Southern	0.56	0.51	0.96	0	0.98	2.91
Southwestern	0.58	0.26	0.19	0.26	0.92	2.02
Western	0.49	0.33	0	0.84	0.96	2.62
Northern western	0.04	0	0.65	0	0.00	0.69

DISCUSSION TO THE FINAL RESULTS AND CONCLUSION

Grouping of received the final results into 5 levels has revealed urban landscapes with different ecological condition: favorable (less than 0.96), relatively favorable (0.96–2.02), satisfactory (2.03–2.91), unsatisfactory (2.92–3.98) and unfavorable (more than 3.98). Good ecological condition observed for the northwestern and northern groups of urban landscapes (Fig. 6). This area is characterized by the lack of large industrial facilities, the smallest contamination of soil and air. Largely favorable ecological situation is also due to the recent

development of these areas, specific features of the functional use of these areas (recreational role), as well as natural features of these territories.

Relatively favorable situation is typical for the southwestern and northeastern urban landscapes. These areas are characterized by small amount of large industrial enterprises in the city, however higher concentrations of heavy metals and IPA due primarily features of interposition of urban landscapes and industrial enterprises of the Minsk city and a significant negative impact of transport. Here are the major interchanges with major highways: P1, P23, M2, M3 (Brest, Slutsk, Moscow and Vitebsk highway). This region has also small squares of public landscape and recreational areas.

Western and southern urban landscapes are described by satisfactory ecological conditions due to existence of a number of large industrial facilities on these areas, with significant amounts of pollutant emissions and high impact of transport. The significant average height (maximum in the city) and atmospheric circulation features create favorable conditions contributing to the improvement of the ecological situation. However, these two groups are characterized by critical level of comfort, primarily due to the almost complete lack of public purpose areas, and landscape and recreation zones.

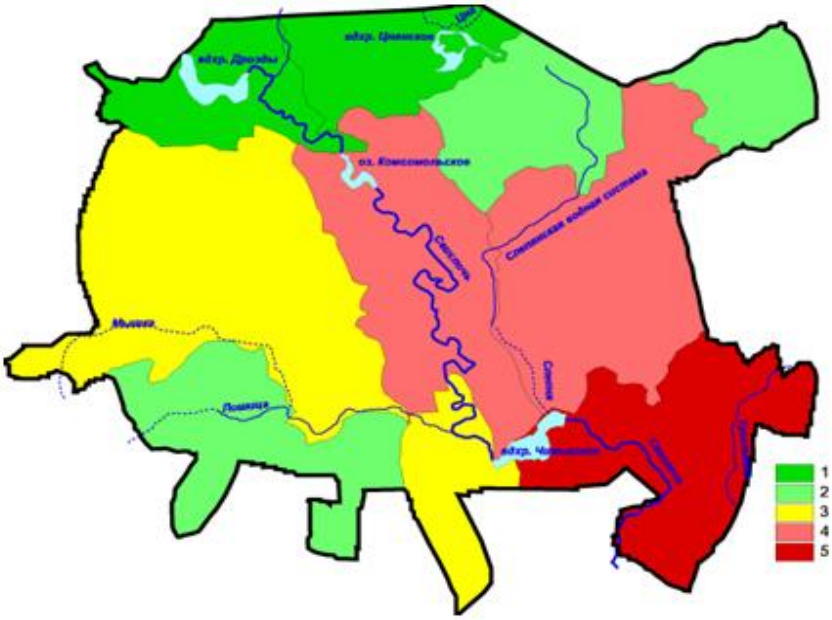

Fig. 6: Results of environmental assessment of urban landscapes of Minsk region
Levels: 1 – favorable; 2– relatively favorable; 3 –satisfactory; 4– unsatisfactory; 5 – unfavorable.

For the central and eastern group of urban landscapes generally unsatisfactory situation is typical. It is caused primarily by long-term city planning development of the territory, the presence of large industrial facilities, mostly old and occupied of a large areas, as well as the concentration of a large number of transport.

Unfavorable environmental condition observed in the southeastern group of urban landscapes. These are "industrial" areas of the Minsk city with the major sources of emissions. It is these areas are characterized by the highest levels of contamination of soil, a significant excess of MPC for NMVOC, CO, inorganic dust. Besides the natural conditions of the city contribute to accumulation of pollutants on these areas. There is also significant areas of concentrated industrial facilities (67%), respectively, and very low level of public and recreational areas.

In general, the territory of Minsk is described by satisfactory environmental conditions. The main residential areas of the city locate on the territories with favorable and satisfactory environmental conditions. The greatest industrial potential is concentrated in eastern and southeastern parts of the city. Orographic features and specificity of circulation of the atmosphere support the decrease of negative anthropogenic impact on the territory of the city. Thus, the deterioration of geoecological situation in Minsk from the northwest to southeast is not critical but requires monitoring and increased attention in further planning and development of urban infrastructure.

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SÚHRN

Environmentálne hodnotenie mestskej krajiny Minsku

Výskum prezentovaný v príspevku je orientovaný na posudzovanie stavu životného prostredia mestskej krajiny s využitím krajinnoekologických metodických postupov. Záujmovým územím je hlavné mesto Bieloruska – Minsk. Metodický postup reprezentuje syntetické environmentálne hodnotenie

využívajúce nástroje geografických informačných systémov a prácu s geodatabázami.

V Minsku bolo identifikovaných 26 krajinných typov, pričom klasifikačnými kritériami boli okrem iného morfologické ukazovatele. Napríklad: mestská krajina na moréne, kopce so súbormi vysokých a stredne vysokých bytových domov, priemyselnými, dopravnými a skladovými areálmi a pod. Tieto základné klasifikačné triedy boli reklasifikované v prostredí GIS do 9, kvázi homogénnych skupín, reprezentovaných priestorovými štruktúrami mesta prírodného a antropogénneho charakteru. Hodnotenie realizované v modelovom území zahŕňa faktorovú analýzu prírodných (ovzdušie, pôda, reliéf) a antropogénnych (napr.: umiestnenie priemyselných zariadení, špecifické charakteristiky urbánneho plánovania) zložiek, prvkov a charakteristík mestskej krajiny a syntetické hodnotenia.

Výsledky výskumu interpretované prostredníctvom máp deklarujú, že územie mesta Minsk má z hľadiska kvality životného prostredia uspokojivé podmienky. Hlavné zóny bývania sú v rámci mesta Minsk situované v území s priaznivými a uspokojivými podmienkami životného prostredia. Pre komplexné územné plánovanie rozvoja sídla je však potrebné vykonať ďalšie detailnejšie analýzy a syntetické hodnotenia.

Kľúčové slová: *mestská krajina, syntetické environmentálne hodnotenie, ekologická kvalita, Minsk*