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Optimization of Natural and Economic Systems within the Land and Property Complex in the City of Kurgan in Accordance with the Study of Environmental Risks Using Topic Mapping Technologies

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Abstract

The negative impact of natural, technology-related and artificial risks on the components of the urban landscape causes irreversible processes of its development, leads to disruption of the existing city ecosystem, and leads to a deterioration of health among the urban population. The main sources of environmental risks are industrial facilities, transport and other communication corridors that do not protect the urban environment during their operation. Along with anthropogenic and technology-related risks for cities, natural risks remain relevant: underflooding, inundation, swamping, mudflow and etc. Therefore, a comprehensive assessment of environmental risks remains relevant, which allows the adjustments to the organization of land use, the urban fabric, its improvement, thereby the provision of its environmentally sustainable development.

Keywords. Environmental risk, system, classification, natural, anthropogenic and technogenic risks, urban area, urban landscape, potential environmental hazard, concept of sustainable development, integral assessment, analysis, landscape-ecological approach, risk reduction and prevention, natural ecological framework, modeling of a sustainable urban area, risk management.

1. INTRODUCTION

The most important conditions that determine the strategy of human interaction with the natural environment include knowledge of its features, the resistance of landscapes to natural and technology-related hazards, as well as knowledge of the environmental risks nature [1].

The society slowly comes to the comprehension of dangers as the result of a negligent treatment in relation to the natural environment, which is characteristic of urbanized (urban) territories, that have characteristics of multifunctional land, pronounced mosaic structure, high density of building, transport and communication networks, insufficient landscape gardening, flood flow and etc. [9, 10].

With the adoption of the concept of sustainable development of territories in the XX century, the analysis and prevention of environmental risks become particularly important. The Russian scientists have made an invaluable contribution to the implementation of the main tasks for the formation of environmentally sustainable land use, rational organization of urban land use, as well as classification and management of environmental risks: V. V. Artemenko, Yu. M. Bahramov, S. N. Volkov, E. B. Dopiro, N. B. Ermasova, A. L. Zhelyaskov, A. G. Isachenko, V. V. Kozin, Z. F. Kochergina, G. M. Lappo, S. A. Medvedev, F. N. Milkov, N. N. Mikhailov, Z. G. Mirzekhanova, M. A. Podkovyrova, N. F. Reimers, Yu. M. Rogatnev, M. A. Rogov, V. N. Rusakov, A. V. Sevostyanov, S. G. Kharchenko, N. V. Khokhlov, A. G. Schmal, and others

The purpose of the research is to form the urban land use for the most sustainable environmental development on the basis of a comprehensive analysis in respect to natural, technology-related and artificial risks. We determined the territory of the Kurgan's municipality and its urbanized landscape as the object of research. The subject of the research is a method of complex analysis and comprehensive assessment of natural, technology-related and artificial risks, as well as a landscape-ecological approach that provides risk reduction, prevention and management.

2. METHODOLOGY

The authors of the article suggest the following research methodology:

1. Research of theoretical and methodological provisions of the city environmental risk assessment
2. Study of the origin and degree of influence in respect to natural, technology-related and artificial risks on the state of the urban environment, components of the urban landscape.
3. The comprehensive analysis and assessment of natural, technology-related and artificial risks specific to the territory of the Kurgan city.
4. Identification of potential environmental hazards from the influence of environmental risks within the development of the city territory.
5. Research of landscape-ecological approach that provides reduction, prevention and management of environmental risks.

6. The modeling of the city ecological framework as the basis for the formation of environmentally friendly and sustainable development of urban land use.

2.1. Theoretical and methodological provisions the city environmental risk assessment

The term "risk" in modern science is most often refers to the danger. The emerging trend includes the risk identification as the probability of possible damage. An example of this is the approach of S. G. Kharchenko to the definition of environmental risk, in which: "Risk is the probability that a particular substance or situation will be classified as dangerous under certain conditions." Risk is a combination of three factors: the probability of an adverse situation; uncertainty in the assessment of both the probability and magnitude of consequences; and the consequences of an adverse situation [6].

The risk can only exist if we identify the source of the danger, or if there is a possibility of an adverse situation. One determines the danger by the possibility of a phenomenon that can provoke the negative consequences appearance of a certain type under certain conditions. In a simple version, risk consists of two components, the first component considers the event's probability, and the second – the probable consequences. In other words, we can determine the risk as a two-dimensional value which consists of the accident's possibility and the volume of consequences (losses) as the result of this incident [7, 8].

Currently, there is a variety risk classification on the basis of various statistical and dynamic parameters that reveal the nature of risks in different ways. The research on risk classifications belongs to such scientists as M. A. Rogov, N. B. Ermasova, Yu. M. Bahramov and others The complexity of risk classification occurs in connection with their diversity and the emergence of new risks' types in the process of economic, technological, social, environmental conditions and the development of the comprehension in respect to the modern world. The risk classification system contains classes, types, types and subspecies of the risk [3]. The large cities have such key characteristics as technology-related risks associated with the excessive concentration of transport and industrial enterprises on relatively small territories; the creation of anthropogenic landscapes that violate the state of ecological balance.

The classification of environmental risks in accordance with the source of impact consists of three classes: natural and environmental risks, artificial-natural risks and artificial (technology-related) risks [2, 5]. We divide the environmental risks into four types by the recipients of the impact: the risk to ecosystems, human health, loss of natural resource potential, and the risk of degradation or destruction of the landscape as a whole.

The removal of environmental problems largely depends on: timely detection of hazards, both of technology-related and natural character; assessment and forecast of the environmental risk degree that directly influence the possible damage to the natural environment and determine the amount and costs of territory environmental rehabilitation. The reason for this is that the ignorance or insufficient study of the possible consequences in regard to artificial impact on the environment, the underestimation of ecological risk often result in a quick environmental response and the unreasonably high costs in relation to reparation of damage to the natural environment. These environmental risks assessments within the territory of cities allow you to make adjustments to the organization of land use, the urban fabric in order to secure its environmentally safe development.

The risk management bases on comparison of the costs and the conceptual model design of the city is the main task of the environmental risk assessment. This requires the acquisition of comprehensive information:

- on natural and technology-related environmental concerns (physical, chemical, geophysical, geodynamic, geochemical);
- about the distribution of factors within the selected test area and beyond;
- in the habitats and distribution of indication species that are under the environmental risk;
- about exposure pathways;
- on the response reactions of organisms to influencing factors.

As a result of this information analysis, one designs the model in the form of environmental risk factors map: qualitative identification of hazards, the risk zone boundaries identification, exposure pathway assessment in respect to the source of the risk, risk characteristics, risk management [5, 14].

2.2. Methodological provisions for ranking assessment of the city's territory by the environmental risk's degree of severity

The risk management aims at grounds for a decision necessary to eliminate or minimize the risk and bases on a comparative characteristic of possible damages to the natural and territorial complex, the population and the possible implementation costs of various management solutions in order to reduce the risk. In order to achieve this purpose, the city territory ranks in accordance to the severity of environmental risks [12]. In practice, one uses the following categories of environmental risk severity: very low (lower risk limit) and low degree of environmental risk severity (LERS), which correspond to a state of the environment where the risk is practically absent. In addition, among the categories of the environmental risk severity are the extreme and catastrophic degree of environmental risk severity (the upper limit of risk), which on can compare to an emergency and an environmental disaster.

If one identifies the gradations of the environmental risk severity degree by the separate indicators of various natural environments (natural resources), human health, one should consider the nonlinear nature of its (degree of severity) changes. For each of the ranking indicators for the environmental risk severity of a particular natural component (soil cover, atmospheric air, surface water), one operates the topic mapping of their spatial distribution with a settlement explanatory note. By spatial cositing of map charts within individual significant indicators of the environmental risk degree and with GIS-technologies one designs map charts on the environmental risk degree for the separate environmental components. For each contour obtained as a result of map chart spatial cositing, one calculates the severity indicator of the environmental risk degree in respect to a separate component of the environment and/or the environment as a whole by the formula:

$$\text{СВЭР} = \Pi_{\text{Д}_i} + \sum_{i=1}^{n}(\Pi_{\text{ДП}_i})/(\sum_{I=1}^{n}(\Pi_{\text{ДП}_i}) + n) \qquad (1)$$

where LERS is the value of the environmental risk severity degree in respect to separate environmental components or the environment as a whole;

P_{di} - the score value of the dominant indicator in relation to the natural environment component or the environment as a whole (the dominant indicator is a ranking indicator that determines the maximum LERS for this contour);

P_{dpi} - the score value of the additional indicator in relation to the the natural environment component or the environment as a whole (additional indicator - a ranking indicator that is more low than the dominant one or equal to it-by hazard class and by LERS); n – the number of additional parameters.

The processes with the highest damage-forming for the territory of the Kurgan city include the underflooding due to both natural causes and changes in the river regime by hydraulic facilities. In turn, urban land is subject to processes of wind and water erosion, salinization and acidification of soils, which ultimately causes a soil fertility decrease (figure 1)

Map-chart

Legend

The indicator definition

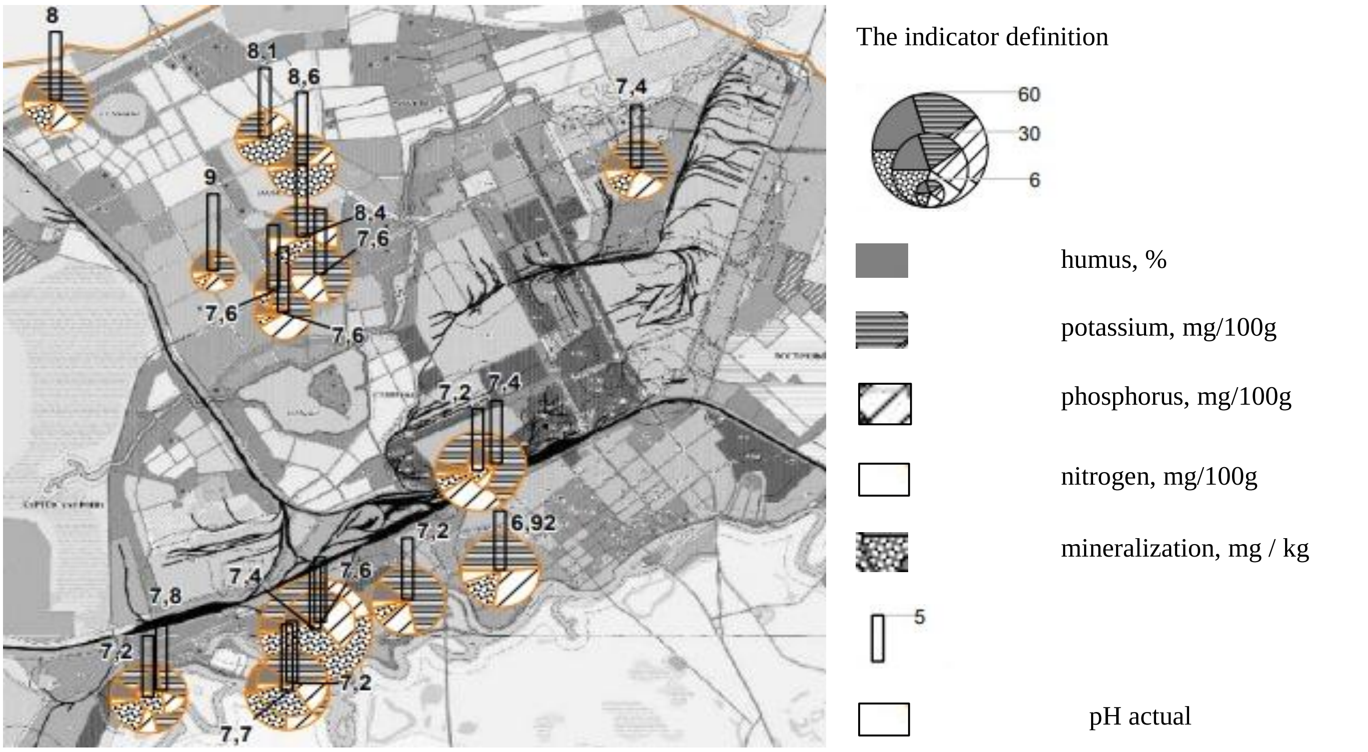

Figure 1. Map-chart of soil fertility within the territory of Kurgan city

The state analysis of urban land soils confirms the dynamics of their degradation and, as a result, a decrease in resource potential and a decrease in biodiversity.

The main sources of air pollution in the city are motor transport and industry: motor transport has a negative impact on the urban scale, and industry hat the negative impact locally in the area of its concentration. However, in accordance with the duration of influence, the motor transport is a mixed-cycle pollutant, since its peak activity decreases during the working day, and the energy constantly pollutes the air.

In accordance with the volume of emissions, discharges, and generated waste products, the most polluted area of the city is the Western region, see table 1.

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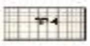
Table 1: Ecological status of the Kurgan city territory (on the basis of three territorial modules)

Module 1 (Western region of the city territory)	Module 1 (Central region of the city territory)	Module 3 (North-Eastern region of the city territory)
		
In accordance with the emissions of pollutants from stationary sources, the territory has the characteristics of the most polluted area, which constitutes 40% of all emissions.	34 % of this city part territory belongs to the the industrial zone.	It is the most" vulnerable " urban area. There is an excess of the ambient air standard by benz(a)pyrene.

Legend

industrial zone (PR 1)

storehouse and public utilities zone (PR 2)



mining zone (PR 4)

The city has such characteristics as energy scarcity, cross-border transfer of clean water pollutants along the Tobol river from the territory of the Republic of Kazakhstan such as: copper, zinc, iron, manganese, phenols, organic substances, biogenic elements. The Tobol river is under the influence of the industrial and municipal wastewater, half of which lacks water purification, which affects the chemical composition of the water. A comprehensive assessment of the the Tobol river pollution level within the Kurgan region is in table 2.

Table 2: Comprehensive assessment of the the Tobol river pollution level

The observation section lines	Specific combinatorial index of water pollution (SCIWP) for 2017		SCIWP for 2018	
	degree of quality	characteristics of water pollution	degree of quality	characteristics of water pollution
r. Tobol, c. Zverinogolovskoe	4B	«polluted»	4A	«polluted»
R. Tobol, Kurgan water storage basin	4A	«polluted»	4A	«polluted»
R. Tobol, p. Smolino	4A	«polluted»	4A	«polluted»
Tobol, c. Kostousova	4B	«polluted»	4B	«polluted»
R. Tobol, c. Belozerskoe	4B	«polluted»	4A	«polluted»

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The most common and significant artificial risk sources of Kurgan city include the next, see table 3.

Table 3: Sources of risks and consequences of their realization

Anthropogenic sources	Possible environmental risks	Consequences for ecosystems in cases of risks realization
Industrial facilities, as well as: industries with pipes,	Fires, accidents, as well as emergency emissions of pollutants.	Dust and chemical pollution of the atmosphere, chemical pollution of natural waters and soil, thermal pollution.
industries without pipes.		Chemical and mechanical pollution of natural waters and soil, thermal pollution.
Waste storage sites (SDW landfills and industrial waste products).	Fires, toxic, chemical and biologically dangerous substances in the ecosystem.	Land degradation, chemical and biological pollution of ecosystem components, thermal pollution.
Complexes of hydraulic facilities.	Emergency collapses of coast-protection structures, dam failures.	Underflooding of territories, destruction of communications.
Transport communications (bridges, grade separation structures, roads, railways, pipelines, HVTL, as well as electrical substation).	Fires, emergency collapses of structures, leakage of pollutants into the landscape.	Chemical, mechanical, thermal, noise and electromagnetic pollution of the ecological system components.

Under the Kurgan city ecological state study, we selected the following indicators for the environmental risks severity assessment for various components of the urban landscape: *atmospheric air*: the concentration of nitrogen dioxide, formaldehyde, Benz (a)pyrene; *surface waters*: the concentration of nitrite nitrogen, ammonium nitrogen, copper; *soils*: the concentration of cadmium, lead.

In accordance with the scale of the environmental risk severity (table 3), one underlines the separate assessment for each selected indicator of various environmental components (table 4).

Table 4: The assessment scales of the natural environment components on the territory of the Kurgan city

Natural component	Indicator	Low degree of environmental risk severity (LERS)				
		very low (I)	low (II)	average (III)	emergency (IV)	catastrophic (V)
Soils	cadmium concentration (mg / kg)	< 1	1-3	3-5	5-20	> 20
	lead concentration (mg / kg)	< 32	32-125	125-250	250-600	> 600
Surface waters	nitrite nitrogen concentration (mg / l)	< 3,3		3,3-16,5	16,5-33	> 33
	concentration of ammonium nitrogen (mg / l)	< 2		2-10	10-20	> 20
	copper concentration (mg / l)	< 1		1-5	5-10	> 10
Atmospheric air	the concentration of nitrogen dioxide (share of the ambient air standard)	< 1	1-3	3-5	5-7,5	> 7,5
	formaldehyde (in shares of ambient air standard)	< 1	1-2	2-5	5-7	> 7
	Benz (a)pyrene (shares of ambient air standard)	< 1	1-2	2-5	5-7	> 7

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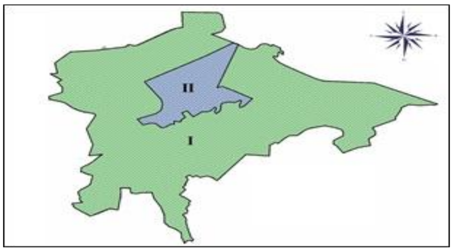
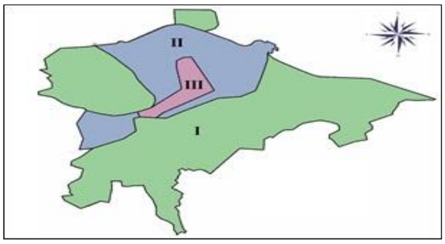
By all indicator values of the environmental risk degree in respect to a particular natural component (soil cover, atmospheric air, natural water), one have designed the map-charts that reflect their spatial distribution. Examples of map-charts are in figures 5-7.



a) map-chart of LERS risk for cadmium concentration



b) map-chart of LERS for lead concentration

Legend

very low LERS

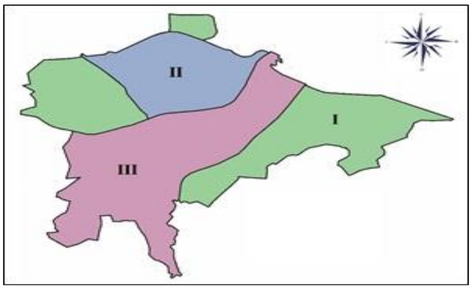
low LERS

the average LERS

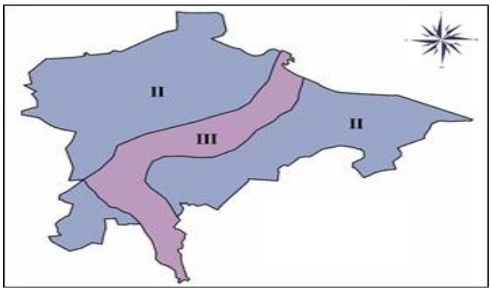
Figure 5 (a. b) - Spatial distribution of pollutants
(on example of cadmium and lead)

Lead is the most prevalent contaminant within the territory under study, the increased content of which in the city soils, as a rule, refers to an increased content of other elements. In accordance with the state of the soil cover, the main part of the urban area has a very low degree of the environmental risk. However, the central city part, which is residential, has an average degree of risk, which means that the natural environment cannot cope with the anthropogenic load.

The state of surface water is one of the most relevant problems of Kurgan city. In the urban waters, one often indicates nitrite nitrogen, copper and ammonium nitrogen in excess quantities.



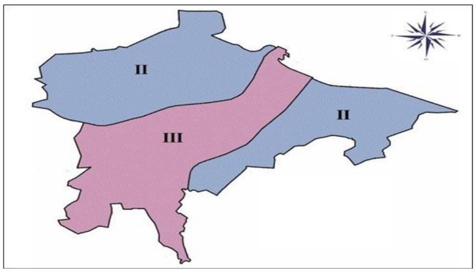
a) map-chart of LERS for nitrogen nitrite concentration



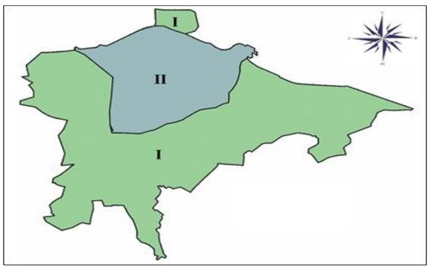
b) map-chart of LERS for copper concentration

Figure 6 (a, b) – map-chart for the degree of environmental severity risk in relation to surface water

Integrated map-charts of the LERS degree for the surface waters and characteristics of the city's air basin are in figure 7 (a, b).



a) Integrated map-chart of LERS surface water



b) Integrated map-chart of LERS air basin on the concentration of nitrogen dioxide

Figure 7 (a, b) – Integrated map-charts of the environmental risk degree for the surface water and air basin

At the final stage of the LERS study, one designed a map-chart of the environmental risk total degree for the territory of Kurgan city. In accordance with the obtained results, one found that, despite the fact that the values of LERS for various natural environments have characteristics of very low and average degree within the city, the total indicator spatial distribution of the environmental risk degree reflects their uniform nature and belongs to the third degree. This means that the ecological state of the urbanized landscape under study has slightly exceeded the maximum permitted concentration. The city is in a "boundary" state, for which a slight increase in anthropogenic load will lead to irreversible damage to the ecosystem and deterioration of the population health. In this regard, it is necessary to develop a set of measures for the preservation, restoration and development of the natural and territorial complex within the city. In accordance with the ecological component, the authors of the article recommend optimization of the natural and ecological framework in the city.

2.3. Scientific and methodological provisions for optimization of the natural and ecological framework in the city as the basis for its sustainable development

In case of optimization for the natural and ecological framework in the city, one proposes to use the author's methodology:

- state analysis of the natural framework elements in the city;
- ecological and functional zoning of the city territory;
- establishment of the actual ecological, socio-economic state of the existing ecological framework in the city;
- degree determination of the environmental situation in the city area;
- formation of the natural and ecological framework structure;
- provisions for the influence of the natural and ecological framework parameters on the ecological stability of the city territory [4, 9, 11, 13].

In case of the natural and ecological framework optimization, one uses the following principles: integrity, territorial interconnection, and preservation of natural processes. Within the analysis in respect to the existing structure of the natural and ecological framework, one should note that:

1. Specially protected natural reservations (SPNR) are in a fragmented state and do not constitute a coherent functioning system.

2. On the city territory there is a fragmentation of natural landscapes, violation of environmental relations, low ability of natural communities to self-repair. The existing natural landscapes do not constitute a full-fledged ecological framework, because its infrastructure has damage.

3. The natural ecological corridors of the Kurgan city include long natural-territorial complexes of rivers; stream courses, rivers; forest natural-territorial complexes of watersheds; ravine plantations; forest belts. The classic corridor in the city territory should take the riverbed of the river Chernaya, whose river head starts in the swamps of the Iletsko-Sosnovy Bor.

In order to form the city natural and ecological framework, one performed ecological and functional zoning of its territory (table 6).

Table 6: Structure of ecological and functional zones in the Kurgan city territory

Ecological and functional zone	Element of the ecological and functional zone	Main function
Medium-stabilizing (vulnerable) value – 7.2% of the total city area	Ravines, landfills, wasteland, industrial wasteland, quarries, areas with the scree.	The destruction of natural, natural and anthropogenic complexes as a result of erosion and geological processes.
Medium-forming value - 21% of the total city area	Landscape and recreational areas, Central Recreation and Leisure Park, city garden.	Genetic conservation of biodiversity; formation of microclimate; preservation of ecosystems (with natural and anthropogenic value), habitat of flora and fauna.
Environment-stabilizing value – 15.8% of the total city area of the	Victory Park, Play Park, Landscape Park, Central square, etc., embankment of the Tobol river, water protection coastal zones; protective (security) zones.	Restoration function.
Anthropogenic-techno-genetic value - 56% of the total city area	Residential and industrial territories, linear and nodal systems of civil engineering infrastructure.	Life support of the population.

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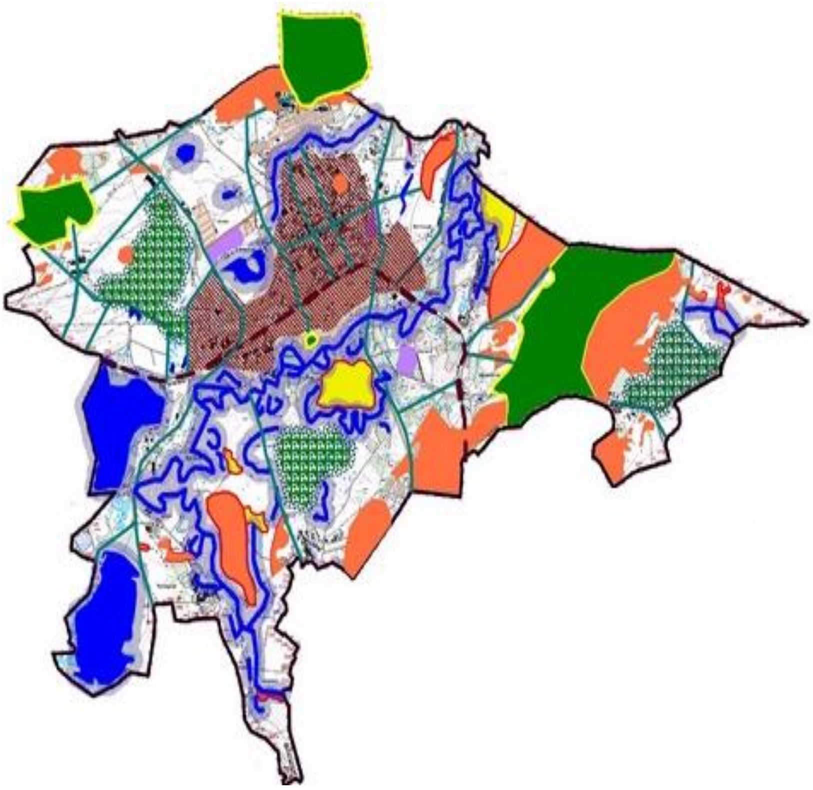
This type of zoning allowed us to clarify the structural elements of the natural and ecological framework in the city (table 7).

From the analysis of the city ecological framework structure, it follows that the landscape and environmental well-being is mainly under the influence of the sites, the area of which is 32.05% of the total city area.

Table 7: The characteristics of elements within the natural and ecological framework in the structure of Kurgan city

Functional elements of the city natural and ecological framework	Specific weight, %
Centers: specially protected areas-natural monuments "Iletsko-Ikovsky Bor", "Central Park of Leisure and Recreation", "Blue lakes", "Sosnovy Bor".	7.85
Sites: urban forests, shrubs, swamps, recreation areas, and interstitial zones.	32.05
Corridors: buffer, water protection coastal, green-protection zones along transport corridors, environmentally friendly ecotones.	3.5

The block scheme of the optimized natural and ecological framework within Kurgan city



Coefficient of landscape and ecological well-being of the urban area - 0.43

Legend

- Natural monuments
- Project forest belts
- Protective zone around the natural monuments
- Project parks
- Water objects
- Environmentally friendly ecotones
- Urban forests
- Water conservation zones
- Zone of natural landscapes
- Protective zone around the natural landscapes
- Protection zone along the railway
- Meadow
- Zone of intensive natural management

Figure 8: Natural and ecological framework of the Kurgan city

CONCLUSIONS AND RECOMMENDATIONS

The formation and functioning of the natural and ecological framework will reduce the severity of environmental risks within the city territory, ensure more sustainable environmental and socio-economic development.

One proposes the territorial model of this framework in order to use it as an information and analytical resource for forecasting and planning in respect to the rational organization of Kurgan city territory management [9, 10, 14, 15]

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