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PARTICULAR ASPECTS OF GEO-ECOLOGICAL ASSESSMENT IN GEO-ECO-SOCIO-ECONOMIC APPROACH TO THE DEVELOPMENT OF NORTHERN TERRITORIES¹

In today's context, the preservation of territory's ecosystem, when it becomes involved in the economic turnover, requires preemptive geo-ecological assessment aimed at identifying the extent of its sustainability to expected anthropogenic impact. The analysis of the existing methodological approaches to geo-ecological assessment allows to conclude that they are often standardized and can be equally applied to the various types of territories. The goal of this research study is to develop a methodological approach to the geo-ecological assessment of a territory, which allows to consider the specific character of the northern territories in the Ural region.

This article proposes a new methodological approach to geo-ecological assessment that takes into account the specific character of the northern territories in the Ural region and is based on assessing the saturation of the natural resource potential of the territory and the intensity of its restoration after the anthropogenic impact. The approach relies on the principle of scoring assessment of a territory, which can be explained by the large surface areas of the assessed territory and by the fact that these assessments are proposed to take place at the pre-project stage of the development of the territory.

Such approach allows to consider the specific aspects of the ecosystem of the territory, namely, its ability for self-restoration and self-cleaning during and after the economic development which, in turn, allows to make a general selection of the area of economic activity while minimizing the damage caused by violating the ecosystem of the territory and preserving its resource potential.

This article is intended for the specialists and students dealing with the issues of geo-ecological assessment of a territory.

Keywords: geo-ecological assessment, northern territories, anthropogenic impact, sustainability of territories, ecosystems, bio-resources, regionalization of territories

Introduction

The current stage of the development of relations within the “Society—Nature” system has predetermined the necessity to link them with the ecologic-economic models of economic development. This area is examined within a sustainable development model, which is characterized by setting multi-purpose management tasks, implies the equal importance of social, environmental, and economic targets and allows to maximize the economic gains only in case of mandatory compliance with the public social standards and environmental constraints, which predetermine the preservation of ecologic balance.

The geo-ecological approach allows to ensure favorable conditions for vital activity. In its essence, it is targeted to study the “relationship of geosystems with the diversified material environment and individual processes, phenomena of this environment for the sustainable development of the society.”

Ensuring a balanced development of the “Society—Nature” system requires a detailed geo-ecological assessment of the territory in terms of its sustainability to projected anthropogenic impacts. In geo-ecological studies, it is necessary to perform such assessments at all stages of elaboration and implementation of economic activities [1], which is particularly relevant at the pre-project stage. This indicates the ecologization of socio-economic approach, while the assessment of geo-ecological stability by using the cost indicators demonstrates the economization of geo-ecological approach. The observed convergence of socio-economic and geo-ecological approaches led today to the formation of a new approach to the development of the natural potential of the territory, such as the geo-eco-socio-economic approach [2, 3].

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The geo-ecological assessment of the territory is the process of systematic analysis and assessment of ecologic and related social and other implications of proposed activity, as well as the consideration of results, obtained in such analysis, before adopting the decision on carrying out this activity [4].

The geo-ecological assessments reflect the results of the interaction between nature and society. The object of geo-ecological studies is complex multicomponent natural geosystems and nature-technogenic systems, which include not only natural links but also the links of such type as “Human – Natural System – Human.”

Methods

The geo-ecological studies involve the use of techniques from various branches of science, such as the geology, mining, geography, biology, ecology, and economics. On the one hand, this contributes to a comprehensive examination of the objects of study, and on the other hand, it allows us to find non-standard solutions to geo-ecological problems. The geo-ecology uses the comparative, systemic, time-based approaches, which have been previously transformed by geography and ecology, and perceives the reality as a heterogeneous integrity. However, the traditional (e.g. geological) methods, that are effective in many cases require substantial rework in the study of such complex objects, as technogenic and technogenic-transformed soils. As a result, there is a need for rational complexation of various methods depending on the nature of problems that are being addressed, natural characteristics and specifics of technogenic changes: modeling, regionalization, system analysis, etc.

There are various methodological approaches to geo-ecological assessment of territories. Some methodological approaches are based on the concept of geosystems' sustainability, defined as a system's property to return to its original state after the end of exposure that took it out of such state [5], as well as landscape's sustainability property defined as the ability to maintain the structure of population and functioning or to restore after anthropogenic impact [4].

The sustainability of ecosystem is its ability to retain its structure and functional characteristics when exposed to external factors [6]. Therefore, by knowing the limits of sustainability of a geosystem, we can substantiate and establish the maximum loads for its initial state, which would allow its subsequent restoration, and to perform ecologic regulation and ecologic-geographic forecasting of territory's development.

The sustainability of geosystems can be assessed by the following factors:

- Probability of preserving the object within a certain period;
- Stability of maintaining its state over time;
- Ability to restore the previous state after a disturbance;
- Ability to adapt to changing conditions;
- Ability for a long-term accumulation of substances without causing harm;
- Ability to easily skip pollutants;
- Ability to retain the production functions in a socio-economic system.

There are four types of sustainability: physical, geochemical, biological, and integral. The main idea of this approach is to conduct an integral assessment of the geo-ecological state of the natural geological environment [7–9]. According to this approach, the algorithm of geo-ecological assessment includes a number of steps:

1. Selecting the set of criteria and indicators. Typically, the main objects of assessment are the lithogenous base, landscapes, soils, bottom sediments, subsurface water, surface water and near-surface atmosphere. For each of them, we select ten most important indicators that describe their state.

2. Categorizing the geo-ecological state, which is usually based on the four-rank assessment structure developed for ecosystems by B. V. Vinogradov. This involves the identification of four levels of ecologic violations: standard, risk, crisis and disaster, which correspond to such classes, as Favorable, Conditionally Favorable, Unfavorable, and Highly Unfavorable ecologic state;

3. Selecting mapped and assessment taxons by using the “basinal” approach;

4. Developing the scale of scoring assessment and assessment technology, defining the values of ingredients in the scores. Each criterion was assessed on a 10-point scale, according to the classes of the ecologic state. This includes the intensity of each indicator in terms of its value and its distribution over the surface area of the sections. For example, if none of the elements on the site exceeds the unit of Maximum Allowable Concentrations (MAC), then assessed site will be assigned 1 point (standard)

for this criterion. If the element exceeds the MAC, it will be assessed for matching any group of ecologic classes: 2–4 (Risk), 5–7 (Crisis), 8–10 (Disaster). The minimum score will be assigned in case of the single-point distribution (up to 10 % of the surface area); average score, for local distribution (10–30 %), maximum score, for areal distribution (> 30 %). These assessments are used to calculate the mapped integral indicator based on the sum of scores across all criteria in the assessed sites. Next, we use the integral indicator of the state of natural and geological environment to establish the ranking by 4 grades of ecologic state classes based on statistical distribution and actual data.

5. Final regionalization of the territory by the ecologic state of its natural geological environment.

Another fundamental approach to geo-ecological assessments of the territory is based on the concept of territory's stability, by which we mean the ability of geosystem to function without changing its own structure and remain in balance for a long period of time [10].

Geo-ecological stability is a state of natural and nature-technogenic systems that allows their insignificant restructuring by anthropogenic impact [11]. This assessment is different from spatio-temporal differentiation and can be expressed by the quantitative values of natural resource potential of geosystems at the time of their geo-ecological assessments. In this case, the geo-ecological stability is assessed when initial natural resource potential decreases as a result of the technogenic impact, and its value is determined as the difference between the values of natural resource potential assessment and damage with regard to the surface area of the eco-system [10]. The resulting value will characterize the level of stability at a specific point of time and serve as a measure describing the state of various components of natural and nature-technogenic systems, which will allow in the future to determine the area of expected change and provide objective recommendations for maintaining or restoring the stability by regulating the economic activities and implementing the relevant environmental protection measures aimed at minimizing or compensating the damage.

This approach can be applied to the territories of various scale. The rank of geosystems is determined by the goals, objectives and spatial criterion of the research study. The final results of geo-ecological assessments are reflected in the map, which is based on comprehensive natural regionalization, including physical and geographical or engineering and geological regionalization (for urban areas) that takes into account the current land-use structure and functional zoning of the territory. The geosystems with a higher rank and relatively minor development of territory serve as a background for habitats with a high degree of anthropogenic impact. The studies conducted at a smaller scale involve collecting the detailed information at such levels as the Landscape, Group of Natural Boundaries, Complex Natural Boundary, etc.

The geo-ecological regionalization is conducted at the average weighted levels of stability established for geosystems, while the recommendations on preservation (restoration) of stability are elaborated individually for zones of impact and geosystems that contain such zones.

As a result, based on conducted studies, we can conclude that all existing methodical approaches to geo-ecological assessment of the territory are based on the concept of inflicted or assumed damage assessed on the basis of MAC established for considered elements by taking into account the intensity of each indicator and the value of its distribution across the surface area of considered sites.

The geo-ecological assessments of northern territories that have not been involved in the economic turnover required to develop a new methodological approach to their assessment and identify the admissibility of locating the economic objects on these territories. The proposed approach includes the particular characteristics of the ecosystems of northern territories.

According to the goals and objectives of research study on geo-ecological assessment of northern territories in order to select the area of their development, as part of geo-eco-socio-economic approach, we proposed a new methodological approach to geo-ecological assessment of the territory's stability to expected anthropogenic impact based on assessing the saturation of natural resource potential of the territory and the intensity of its restoration after the anthropogenic impact.

In our view, it will be the most appropriate to apply this approach by using the scoring assessment of the territory, which can be explained by the large surface areas of assessed territory, as well as by the fact that this assessment is performed at the pre-project stage of development of the territory and depends on the choice of economic activity.

As part of the proposed methodological approach to the assessment of the sustainability of the territories to anthropogenic impact, we propose to make the assessment based on the criterion of

biological sustainability of the territory to anthropogenic impact for such components, as the bio-resources of the territory and its land resources.

As the object of the geo-ecological assessment conducted in order to identify the potential sustainability to expected an anthropogenic impact, we considered the territory of Berezovsky Municipal District of Khanty-Mansi Autonomous Area—Yugra, which belongs to the territory of the Polar Urals. The typical characteristics of this district include the depleted number of species and small density of animal population, which is related not only to the harsh climate, but also to the scarcity of feedstocks.

It should be emphasized that the characteristics of this territory include the floral and coenotic diversity; low tolerance to anthropogenic stress and low restoration potential, extreme climatic conditions of the organic matter synthesis, high importance of feeding, food and medicinal plants, as well as a special role played by the vegetation in the stabilization and formation of soils.

The leading integral parameters that determine the instability of eco-system in this territory can include the following:

- Low diversity of species and its sharp decline from the South to North as a result of decreasing amount of climatic heat, which also determines a sharp increase in evolutionary, ecologic and practical importance of each species;
- High degree of dominance displayed by the most active species, destruction of or decrease in the numbers of populations, which leads to significant restructuring of the eco-system as a whole;
- Prevalence (especially in harshest high-latitudinal band) of the group of organisms with signs of primitive and archaic nature, and specific and narrowed adaptive capacity;
- Existence of exceptional synergy in the impact of natural and anthropogenic changes to the environment, which can cause a cascading effect and multiply the implications across the surface area;
- Openness of disturbed ecosystems and new anthropogenic habitats to invasions of alien species [12].

The expanding technogenic impact poses a real threat of the loss of unique natural complexes, reduction in the species and phyto-coenotic diversity, increase in the speed of degradation of vegetation and further decline of resource potential within a given territory.

Results

As a result of the study the authors propose the following algorithm for geo-ecological assessment of the territory of Berezovsky District based on the comprehensive criterion of sustainability to anthropogenic impact:

1. In order to assess the sustainability of territory's eco-system and the extent of its transformation as a result to natural and anthropogenic factors, we used the indicators that characterize the processes of formation of organic matter and its annual production assessed through the indicator of biomass and its productivity (or phytomass). These indicators are assessed through the indicator of phytomass stock (tons/hectare) and phytomass production (tons/hectare per year).

Overall, the Arctic vegetation plays an important role in soil formation, stabilization of substrates, as well as in the regulation of temperature and water regimes. The mountain vegetation has a great importance as it is involved in the processes of weathering. The bacteria, algae, fungi are involved in the weathering of rocks. By destroying the surface layer, the lichens accumulate the fine soils. The formation of mortified sod containing rich microflora is also of great importance. The processes, involving the formation of soil and closed vegetation across overgrown stone fields, are closely intertwined and benefit to each other.

The intensity of erosion processes depends on the nature of substratum and topography. The protective properties of vegetation are associated with the capacity of moss and lichen cover, the extent of development in the root systems of vascular plants and turfness of the soil. In the mountains, the general loss of solid mineral substance is up to 14 g/m² per year, which corresponds to the destruction speed of 0.39 mm per year. In the mountain forest zone, where the vegetation covers large areas, the loss drops to 0.075 mm of soil layer, but in the case of damage to the integrity of the vegetation on the mountain slopes, it rises to 0.81 mm per year. By participating in the processes of weathering, the plants contribute to the formation of a certain amount of solid mineral substance, at the same time, the vegetation retains a significant amount of such substance and involves it in the process of formation of the mountain tundra soils.

The important information for assessing the production processes within the territory is provided by such indicator as the phytomass accumulation time. This indicator represents the result of dividing the amount of accumulated phytomass by the production, i.e. it shows, in how many years this type of eco-system can accumulate its typical phytomass at the existing speed of its annual growth.

When assessing the sustainability of ecosystems in terms of their phytomass, the objects (areas) have been grouped by such characteristics as the phytomass stock (tons/hectare); annual phytomass production (tons/hectare per year); phytomass accumulation period (years). The territories have been ranked by the level of their importance depending on the period of phytomass restoration and depending on the degree of manifestation displayed by this indicator [13, 14]².

The scores are distributed by the levels as follows: the indicator describing the level of sustainability changes in the range from 0 to 1 with an increment of 0.25. Accordingly, the high level is assigned with a maximum score equal to 1, while the minimum level has the minimum score equal to 0.25.

The territory of Berezovsky District features a great diversity of eco-systems that have different indicators of production processes of phytomass stock (from less than 25 tons/hectare to more than 200 tons/hectare), and the production can vary by more than 2 times (from less than 4 tons/hectare to over 8 tons/hectare per year). The extreme environmental conditions lead to a lower rate of production processes and the sustainability of ecosystems. The production capacity is fairly high in the forests of various types and flood-plain eco-systems. The wetland eco-systems without tree vegetation are characterized by a lower value of production capacity, which is associated with a poor mineral nutrition of soil solutions that affects the synthesis of organic substances by plants. The phytomass accumulation time ranges from less than 10 years to over 30 years. As a result of the destruction of indigenous vegetation and replacement of natural complexes with new anthropogenically transformed ecosystems, the production capacity in some parts of the territory decreased by 20–50 % both in highly productive and low productive types of ecosystems [14].

The results of ranking the territory in order to determine the potential sustainability of its eco-system to the expected anthropogenic impact depending on the phytomass restoration period in the context of Berezovsky District of Khanty-Mansi Autonomous Area are shown in Table 1 and Fig. 1.

Therefore, based on the ranking of the territory of Berezovsky District by the duration of phytomass accumulation, we can identify the following types of areas: highly sustainable, sustainable, low-sustainable and unsustainable to anthropogenic impact.

2. The methodological approach to assessing the sustainability of the territory to the future anthropogenic impact on its land resources resembles, in its principle, to the approach of assessing the sustainability of the territory's biota. As the assessment criterion, we use the indicator that describes the restoration period of the disturbed humus layer in the course of economic activity [14]. When ranking by this criterion, the territory was assigned with a low, medium or high level depending on the length of restoration period of the humus layer. Based on obtained scores, the territories have been ranked as sustainable, low-sustainable or unsustainable to anthropogenic impact.

The territory of the Berezovsky District belongs to the middle taiga subzone. A distinctive feature of soils and soil cover in this region is their increased hydromorphism and extremely strong swampiness. The swamps occupy about 50 % of the region. The permafrost does no longer influence the process of soil formation. Within the northern taiga, it goes down to a depth of 3–5 m. With the prevalence of poorly drained interfluves with their high waterlogging, the gley-like and gley soils became widely common in this area. Conventionally, the entire territory of the region can be divided into the soils of plains and soils of mountains. The soils of plains are represented by the following types of soils:

— Gley soils characterized by the presence of litter-peat horizon and gley horizon, humus type: low-power fulvic;

— Podzolic soils characterized by the presence of peaty litter with the capacity of 3–10 cm, and humus content of 1–4 %;

— Peat-like and peat-podzolic-gley soils characterized by the presence of peaty litter with the capacity of 10–50 cm, and humus content of 1–5 %;

— Podzolic illuvial-humus soils located in the lower elements of the relief on the periphery of swamp areas, these soils is quite rich in humus;

² Kompleksnaya otsenka zemel Khanty-Mansiyskogo avtonomnogo okruga. Beloyarskiy i Berezovskiy rayony. Otchet o NIR po teme №1.93 [The comprehensive assessment of the lands in Khanty-Mansi autonomous area: Beloyarsky and Berezovsky districts. Research report on the topic no. 1.93]. (1994). Ekaterinburg, 48.

Ranking of Territories Depending on the Phytomass Restoration Period after Anthropogenic Impact

Phytomass Restoration Period, years	Scores describing the level of sustainability to anthropogenic impact
Less than 10	1
10–20	0.75
20–30	0.5
Over 30	0.25

Rank of the territory of Berezovsky District for its sustainability to anthropogenic impact, by phytomass accumulation time

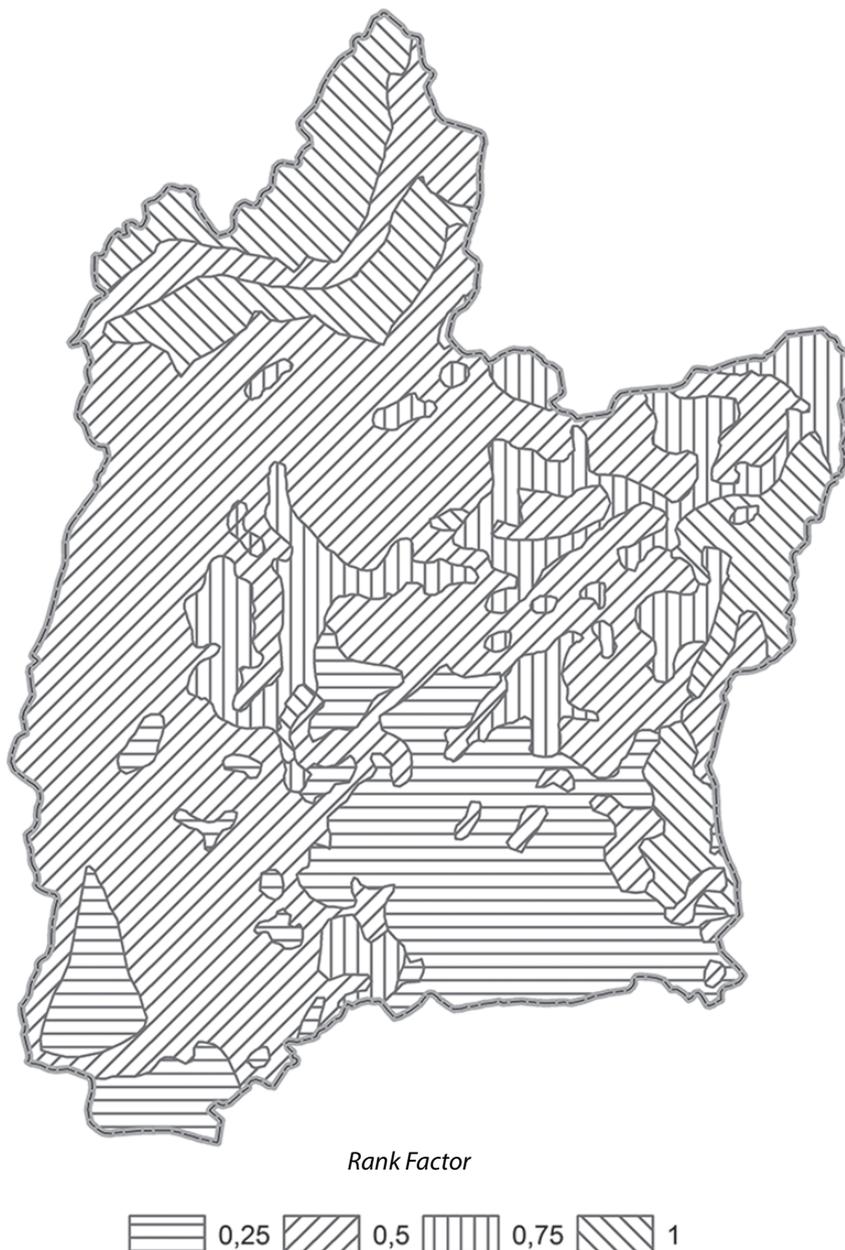


Fig. 1. *The results of ranking the territory of Berezovsky District by the degree of its sustainability to the expected anthropogenic impact depending on the phytomass restoration period*

— Light soils are represented by three types of soils, such as light soils, illuvial-ferruginous light soils, sod light soils. The soils are characterized by a lengthy seasonal frost. The litter-peat horizon has a low capacity of about 5 cm.

The mountain soils are underdeveloped and rubbly. Podzolized brown soils are common within the low-hill terrain and foothills of eastern slopes of the Urals. The coarse-humus brown soils are formed in the upper part of the forest belt in the mountain Urals. The gley-podzolic soils are characterized by the presence of surface-gley humus horizon.

Depending on the degree of their suitability for economic activities, the soils within the territory of Berezovsky District can be divided into such categories as suitable for tillage, suitable for haymaking, suitable for pastures or other agricultural lands, low-suitable for agricultural lands, and unsuitable for agricultural production³.

Table 2 and Fig. 2 show the results of ranking the territory of Berezovsky District by the criterion of the intensity of soils' self-cleaning from toxic pollutants.

Table 2

Ranking of Territories Depending on the Period of Soils' Self-Cleaning

Self-cleaning capacity of soils	Level of sustainability to anthropogenic impact, score
Above average with a weakening towards the lower horizons	Highly sustainable, 1
Average throughout the profile	Sustainable, 0.75
Very low in the upper part and inhibited in the lower part of the profile	Low-sustainable, 0.5
Very low throughout the profile	Unsustainable, 0.25

Rank of the territory of Berezovsky District for its sustainability to anthropogenic impact, by the capacity of soils to self-cleaning from oil and oil products

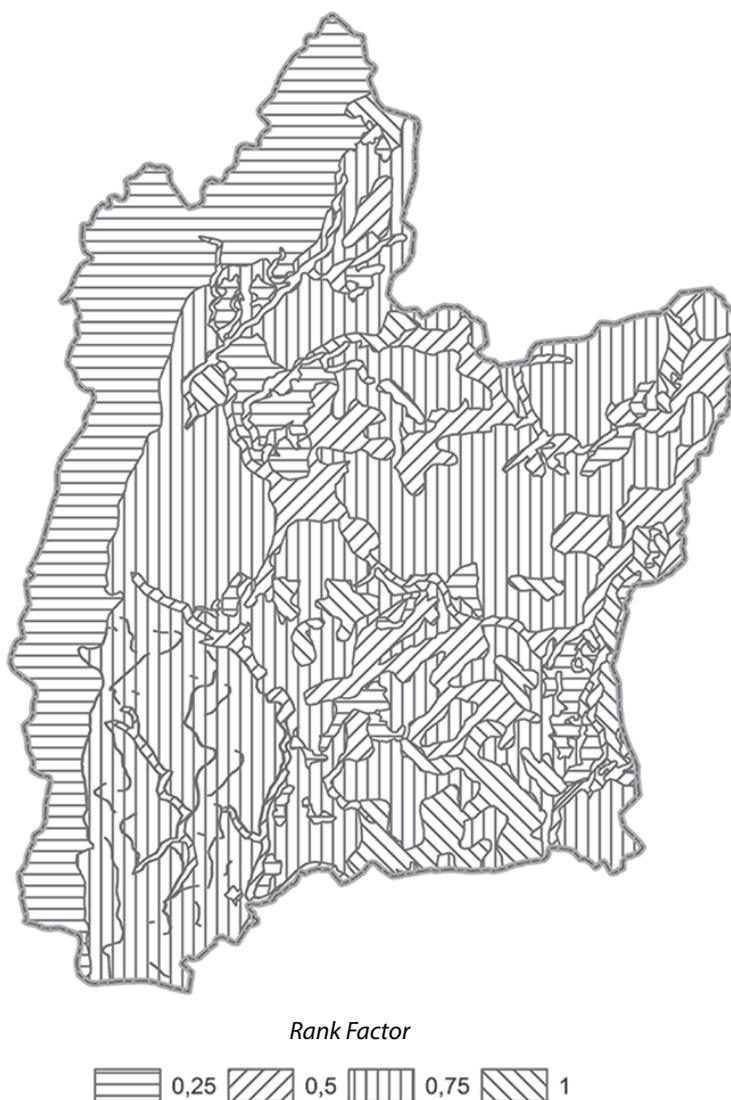


Fig. 2. The results of ranking the territory of Berezovsky District by the degree of its sustainability to the expected anthropogenic impact depending on the intensity of soils' self-cleaning

³ Комплексная оценка земель Ханты-Мансийского автономного округа. Белоярский и Бerezовский районы. Отчет о NIR по теме №1.93 [The comprehensive assessment of the lands in Khanty-Mansi autonomous area: Beloyarsky and Berezovsky districts. Research report on the topic no. 1.93]. (1994). Ekaterinburg, 48.

Therefore, based on the ranking of the territory of Berezovsky District by the criterion of the intensity of soils' self-cleaning, we can identify the following types of areas: highly sustainable, sustainable, low-sustainable and unsustainable to anthropogenic impact.

3. The level of sustainability to expected anthropogenic impact by the factor of terricole vertebrates and invertebrates is assessed by the same principles as the assessment of this criterion by the phytomass and land resources. As the base for assessment, we used the data on the biosphere value of terricole vertebrates and invertebrates [14].

For the conditions of Berezovsky District, the assessment was made depending on the habitat of terricole vertebrates and invertebrates based on the cost and biosphere value maps that reflect the wealth of living organisms in monetary terms. The average indicators of value are shown for 1 km².

The cost and the number of animals affected by the economic use of the territory allow to determine the economic damage. In addition to the economic (utilitarian) cost of the animals, we provided their biosphere value, because the terricole vertebrates and invertebrates are involved in maintaining the stability of biocenosis and soil fertility, and have the informational and recreational value.

Table 3

Ranking of Territories Depending on the Amount of Terricole Vertebrates and Invertebrates

The value of terricole vertebrates, million rubles/km ²	Level of sustainability to anthropogenic impact, score
0.2–0.5	Unsustainable, 0.25
11.1–18.7	Low-sustainable, 0.5
52.4–88.3	Sustainable, 0.75
203.4–459.1	Highly sustainable, 1

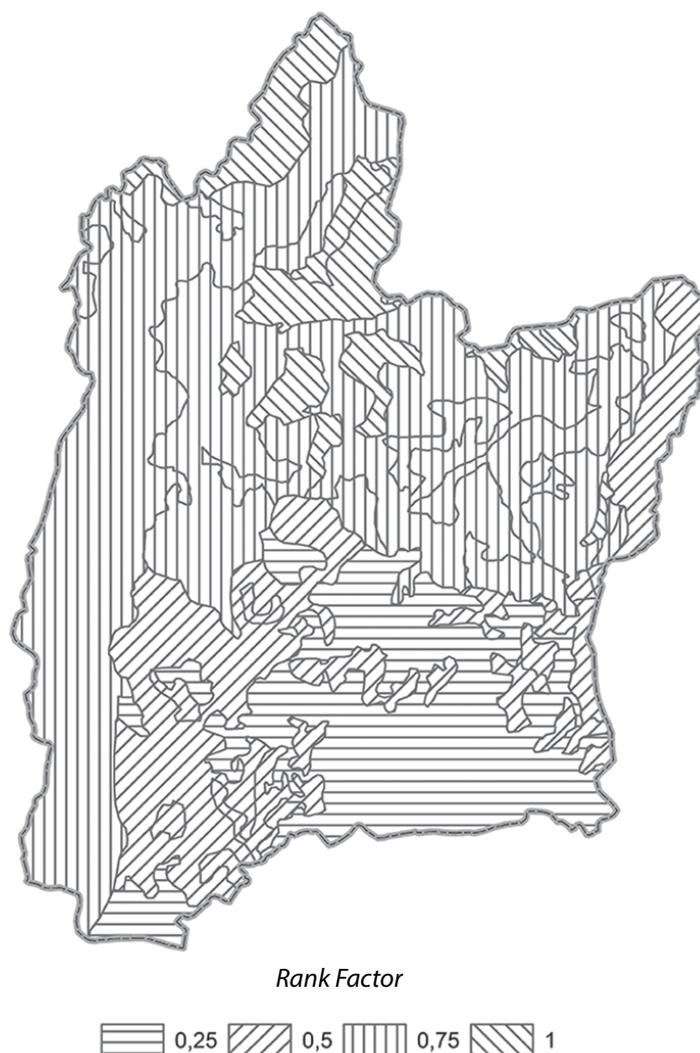


Fig. 3. The results of ranking the territory of Berezovsky District by the degree of its sustainability to the expected anthropogenic impact depending on the value of terricole vertebrates

The levels of total cost and biosphere value of terricole vertebrates and invertebrates on the maps reveal two subzonal belts: northern (primarily, northern taiga) and southern (primarily, medium and southern taiga) [14].

The above methodology served as the basis to provide the results of ranking the territory of Berezovsky District by the degree of sustainability to the future anthropogenic impact depending on the value of terricole vertebrates and invertebrates (Table 3, Fig. 3).

The resulting geo-ecological assessment of the sustainability of the territory of Berezovsky District to the potential anthropogenic impact was based on the weighted average score for the above groups of factors, such as the phytomass, terricole vertebrates and invertebrates, land resources. This served as a basis to identify four types of territories characterized by different degrees of sustainability.

The results of ranking are provided in Table 4 and Fig. 4.

The results of conducted studies on assessing the sustainability of the territory of Berezovsky District to anthropogenic impact on its territory can be conventionally divided into 4 groups:

Group 1 is characterized by high sustainability to anthropogenic impact, has a higher rate of reproduction of phytomass after the anthropogenic impact, significant capacity for self-cleaning from the oil and oil products and significant reserves of terricole vertebrates and invertebrates; its weighted average score is more than 0.75;

Table 4

Value of Rank Factors Characterizing the Sustainability of the Territory

Degree of sustainability of the territory and the limits of rank factor values	Surface area, km ²	Percentage of total surface area of the territory, %
Unsustainable < 0.25	2,880	3.2
Low-sustainable 0.25–0.5	16,740	18.6
Sustainable 0.5–0.75	61,200	68
Highly sustainable > 0.75	9,180	10.2



Rank Factor

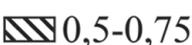
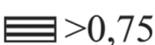
 < 0,25
  0,25-0,5
  0,5-0,75
  > 0,75

Fig. 4. The resulting map of ranking of the territory of Berezovsky District by the degree of sustainability to expected anthropogenic impact

Group 2 is assessed as sustainable to anthropogenic impact, has a lower rate of reproduction of phytomass compared to the Group 1, a lower capacity to self-cleaning from the oil and oil products; its weighted average score is 0.5–0.75;

Group 3 is assessed as low-sustainable, given the longer period of reproduction of its phytomass, low rates of self-cleaning from oil and oil products; its weighted average score is 0.25–0.5;

Group 4 is assessed as unsustainable to anthropogenic impact, because the period of reproduction of its phytomass exceeds 30 years, its capacity to self-cleaning is assessed as low throughout the profile, the amounts of stocks of terricole vertebrates are the lowest throughout the territory; its weighted average score is less than 0.25.

To sum up, the geo-eco-socio-economic approach provides for the strengthening of ecologic aspect and, in connection with that, we developed the methodological tools for geo-ecological assessment of the territory, which are based on assessing the sustainability of geosystems (eco-systems) to anthropogenic impacts, and allow to forecast and monitor the technogenic load, as well as to obtain the detailed information on potential ecologic implications when selecting an administrative decision based on multiple criteria.

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