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ECOLOGICAL OPTIMIZATION OF THE TERRITORIES BASED ON LANDSCAPE PLANNING IN THE CONTEXT OF CLIMATE CHANGE IN AZERBAIJAN

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SUMMARY

The presented research aimed to formulate the recommendations for optimizing the ecological landscape and spatial conditions of the geographic areas in the context of climate change at the northeastern slope of the Lesser Caucasus, Azerbaijan. The detailed analysis determined that the Republic of Azerbaijan as a whole is an ecologically unstable territory. However, the territory of the Gazakh-Tovuz economic region is among the ecologically moderately stable territories. The territories of the Gazakh and Shamkir regions are ecologically unstable territories, and the territories of Agstafa, Tovuz, and Gadabay Rayon received classification as moderately stable territories ecologically. Overall, the research also identified that the cultivated areas showed characteristics of small holdings. The resulting investigations contain some proposals for promoting soil consolidation of the cultivated areas.

Keywords: Climate change, landscape, landscape planning, ecological stability coefficient, anthropogenic load, small contours, soil consolidation

Key findings: The ecological landscape and spatial conditions of the northeastern slope geocomplexes of the Lesser Caucasus, Azerbaijan, have succeeded in their studies. For ecological optimization based on landscape planning, the study made some recommendations.

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INTRODUCTION

The location of the Republic of Azerbaijan is in the east of the South Caucasus and on the

western coast of the Caspian Sea. The country's territory is 86,600 km², and its population is 10.3 million (Statistical Yearbook, 2025). The Republic of Azerbaijan has reached

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recognition as a state with considerable and sustainable economic development. Food security, protection of ecological balance in nature, and ensuring sustainable use of natural genetic resources, including lands, are priorities of the Azerbaijani State (Kuchinskaya, 2013).

In Azerbaijan, the land areas used for arable farming purposes are inadequate. However, due to increasing population growth rates, the number of people per capita is rising annually, and the arable area per person is decreasing gradually. With the current global climate change, society faces important issues, such as the proper regulation of human-nature-society relationships and improvement in the mechanism of state management of natural resources, including land resources. Therefore, based on these crucial reasons and with the current state of climate change, the latest study took place. It aimed to assess the ecological potential of ecogeocomplexes in the Republic of Azerbaijan and optimize ecological landscape and spatial conditions of territories based on landscape planning, which are urgent issues requiring immediate resolution (Mammadov, 2016; Guliyev, 1997).

Previous conduct of fundamental scientific research has succeeded in the field of landscape planning, aimed to protect nature, save and enhance soil fertility, and increase the efficiency of using natural areas in Azerbaijan (Aliyev, 1982; Jafarov, 1997; Budagov, 1988; Kuchinskaya, 2013). Traditional classical scientific research work cannot fully ensure the implementation of the tasks set in the fields of regulating these alarming issues in the context of climate change, land relationships and infrastructure, and the protection of nature.

Recent research results showed the correct assessment of the ecological potential of natural complexes and the application of landscape planning principles both contribute to the protection of natural landscapes and ensure the sustainability of agricultural systems. In this regard, the development of scientifically grounded landscape-planning models, the identification of ecological stability indicators for different landscape types, and their integration into economic activities are

highly essential. Against the background of intensified climate change, the rational management of land and water resources has become even more relevant as a priority direction. The latest research results focused on the optimization of the ecological state of territories according to landscape planning. It also considered the context of current climate change in the landscape areas of the northeastern slope of the Lesser Caucasus in the Republic of Azerbaijan.

The results of the presented study depended on the works carried out to optimize the ecological condition of territories based on landscape planning in the northeastern slope of the Lesser Caucasus in the Republic of Azerbaijan. They present scientific approaches to the ecologically sustainable use of territories in the context of current climate change.

MATERIALS AND METHODS

The study object comprised the landscape areas of the administrative districts of Agstafa, Gadabay, Gazakh, Shamkir, and Tovuz on the northeastern slope of the Lesser Caucasus, the Republic of Azerbaijan. The research area measured 7,030 km² (8.12% of the country's territory) and has an area population of 687,600 (6.68% of the country's population) (Statistical Yearbook, 2025).

In this research, several physical observations, analyses, and economic-statistical methods, as well as the Geographical Atlas and Landscape Maps of the Republic of Azerbaijan, served as references (National Atlas, 2014; Landscape Map, 2017; Geographical Atlas Map, 2018). The table data procured and formulated relied on cadastral and statistical data for 2023 (Statistical Yearbook, 2022, 2025; Land Reports, 2025)

RESULTS AND DISCUSSION

At present, the impact of various societies and populations on the environment has reached its maximum level. In nature, ecological conflicts are escalating, and serious climate changes are occurring daily. Hence, the Law of

the Republic of Azerbaijan on the ratification of the European Landscape Convention succeeded its adoption (Law, 2011) to promote landscape protection and sustainable management of soil fertility and critical planning on these issues in the country. Likewise, the law helped organize cooperation in Europe on landscape issues. The interaction between humans and nature, which arises during utilization of natural resources, is in a critical state in some concerned areas. Systematizing the circumstances that determine these critical states is as follows (Guliyev, 2025).

In nature, one of the causes for the emerging critical ecological situation is the problem developed by both quantitative and qualitative depletion of natural genetic resources. This can refer to the long-term activity of different industries, the agricultural sector, and other sectors of the economy. The genetic resources' depletion also received a boost from a decrease in the area of fertile arable soils and forested areas, a decline in the population of game animals and plant species diversity, and the depletion of natural resources. A considerable reduction in the productivity of natural forage areas (meadows, pastures, and winter pastures) further exacerbates genetic resource loss. This depletion could also occur due to current climate change and the significant variations in the quantity and quality of water and air resources. For the emergence of a critical ecological situation in nature, the second cause has an indirect association with the changes in the state and functionality of natural complexes and components as a result of diverse human activities. Here, we also talk about the first kind of climate change, the destruction of the ozone layer, the impoverishment of biological diversity, and eventually, the weakening of the ecological system.

The third factor of the causes of the ecological crisis in nature correlates with the problems occurring in the socio-demographic and economic life of the society and in the technological environment due to the depletion of natural resource components. These both include quantitative and qualitative and the

considerable disruption of the balance among the different aspects of the existing environment.

Relative load of crops on the total area

The actual percentage of the relative load of crops on areas in different districts was 14.2% in Agstafa District, Gadabay (7.7%), Gazakh (30.5%), Shamkir (29.8%), Tovuz (16.6%), and the economic region of Gazakh-Tovuz (19.0%), with an overall 21.8% in the Republic of Azerbaijan. These indicators revealed that both the Republic of Azerbaijan as a whole and the regions belonging to the research object comprise characteristics of a relatively low load of arable areas in the total area. This had further explanations with the fact that the country's territory, including the zone of the Gazakh-Tovuz economic region, mainly sat in mountainous and foothill zones. Moreover, its complex relief and most of the land fund comprised natural meadows and pastures, mountains, valleys, and ravines. Ecologists recommended that the relative load of crops on the total area of the landscape should not exceed 60% and normally vary within the range of 40%–45% (Seratirova *et al.*, 2012).

Despite the limited availability of arable lands, which are the only source of crop production, their utilization in Azerbaijan is still at an unsatisfactory level. In a large part of the country's arable lands, processes such as salinization, alkalization, desertification, and erosion are taking place. Residential and non-residential buildings continue in their construction illegally on cultivable lands. The regulation of land relations necessitates the tightening of legal requirements in this field.

The excessive volume of the relative load developed due to crops on the total area limits the production potential of different crops and their products and causes serious problems in the spatial formation of cultivated areas. The said analysis leads to the conclusion that the possibilities for increasing the cultivated area in the study area were extremely limited. Likewise, the improvement in crop production was only possible through the implementation of an intensive farming

Table. Ecological diversity, resilience, and spatial indicators of the study area.

No.	Indicators	Aghstafa	Gadabay	Qazakh	Shamkir	Tovuz	Qazakh-Tovuz economic region	Republic of Azerbaijan
1	Total area (thousand ha)	150.4	123.3	69.2	167.3	194.2	704.4	8665.5
2	Area of agricultural land (thousand ha)	94.1	75.9	50.5	123.7	113.9	458.2	4780.5
3	Cropland area (thousand ha)	21.4	9.5	21.1	49.8	32.2	134.0	1889.4
4	Population per one sq. km (people)	59	82	149	131	91	98	118
5	Agricultural land area per capita (ha)	1.07	0.76	0.49	0.57	0.65	0.67	0.47
6	Arable land area per capita (ha)	0.24	0.09	0.20	0.23	0.18	0.19	0.20
7	Area of natural landscapes (thousand ha)	118.9	106.0	37.6	98.8	147.8	509.1	5936.4
8	Forests (thousand ha)	7.2	21.9	2.4	5.1	27.3	63.9	1040.2
9	Relative load of crops on the total area (%)	14.2	7.7	30.5	29.8	16.6	19.0	21.8
10	Area of perennial grasses in the structure of the litter (%)	24.7	0.5	25.8	27.9	12.3	21.1	22.5
11	Relative load of natural forage areas on agricultural lands (%)	72.4	79.8	46.1	49.8	64.0	62.5	67.3
12	Relative load of forests in the total area (%)	4.8	17.8	3.5	3.0	14.0	9.1	12.0
13	Relative load of settlement areas in the total area (%)	1.5	1.3	3.0	2.3	1.9	1.9	3.9
14	Relative load of natural landscapes in the total area (%)	79.1	86.0	54.3	59.1	76.1	72.3	68.6
15	Ecological stability coefficient of the territory	0.52	0.61	0.39	0.42	0.57	0.52	0.47
16	Degree of anthropogenic load of the territory	2.80	2.84	3.20	3.18	3.01	3.04	2.91

system through protection and increase in soil fertility, as well as increasing the productivity per unit area.

Perennial grasses in the sowing structure

Analysis of statistical data (2023) showed the relative share of perennial grasses, such as poppy and clover, in the crop structure. It was 0.5% in Gadabay District, 24.7% in Agstafa District, 25.8% in Gazakh District, 27.9% in Shamkir District, 12.3% in Tovuz District, and 21.1% in the Gazakh-Tovuz economic region. The overall rate was 22.5% in the Republic. Based on the standards, these indicators appeared to be below the recommended limits. In mountainous and hilly zones, protecting the fertile layer of low-fertility soils from water and wind erosion is vital. Additionally, enhancing soil fertility requires growing the multi-species grasses in the field and increasing their area of cultivation to 30%–35% based on the crop structure (Seratirova *et al.*, 2012).

Within the boundaries of the northeastern slope of the Lesser Caucasus

geocomplexes, the absolute majority of land allotment areas are up to three hectares. It revealed that extremely small-sized land areas had different people owning them. These small holdings, if only planted with multi-species grasses in monoculture farming conditions, were not considerably economically beneficial for the different farming communities. The nonimplementation of the crop rotation in small-contour conditions also results in limitations on the application of multi-species grass seeding. As a result of all this, we are witnessing the development of the erosion process and the expansion of its consequences over the years on the mountain and foothill slopes of the study area. Therefore, a proposal stated that special attention should focus on increasing the relative load of the arable areas sown with multi-species grasses.

Natural fodder areas in agricultural lands

Based on land cadastre data, the study determined the relative share of natural fodder area in arable lands of the different districts.

These comprised Agstafa (72.4%), Gadabay (79.8%), Gazakh (46.1%), Shamkir (49.8%), Tovuz (64%), and the Gazakh-Tovuz economic region (62.5%), and overall in the republic (67.3%). The ecological stability coefficient of natural pastures was the highest ($K = 0.68$), and their distribution areas were the ecologically stable areas. Given that the relative load of natural fodder areas on arable lands exceeds the normal limit, it causes limitations for other necessary natural arable areas to use major crops. Past studies formulated the recommendation that the relative load of natural forage areas on arable lands should not be less than 30% (Ryumin, 1990).

The feed structure necessary to ensure the development of animal husbandry in the country does not comply with established norms, and the predominance of natural forage in it leads to the overloading of pastures with livestock beyond the allowable limit. In the Republic of Azerbaijan, pastures are lands of state ownership. However, due to the failure of users to implement timely measures for restoring soil fertility and the non-compliance with agrotechnical rules in their management, in many areas, the soil cover suffers from erosion, becoming exposed to technogenic disturbances.

Therefore, a recommendation occurred for the specialization trends of various farms to undergo reconsideration and a system of measures aimed at organizing and developing ecotourism for implementation in areas with a high relative burden of pastures.

Forested areas' share in the territory

Forest-covered areas were evident in all categories of the unified land fund of the republic, and in the country, the area covered by forests is around 1,040,200 hectares. In this, 645,500 hectares are forest fund lands and 240,000 hectares are the specially protected areas (Land Reports, 2025). In the country's total area, the relative load of forests is 12%, while in different regions like the Gazakh-Tovuz economic region, the said area is 9.1%. Meanwhile, in the Agstafa, Ggadabay, Gazakh, Shamkir, and Tovuz districts, the

areas were 4.8%, 17.8%, 3.5%, 3.0%, and 14.0%, respectively. A change in this indicator within the 15%–20% interval was substantially normal in terms of ecological balance of the landscape (Seratirova *et al.*, 2012). In this regard, however, a report stated the Gazakh-Tovuz economic region was in unfavorable conditions.

In ecosystems, the development of soil erosion and the deterioration of soil quality indicators necessitate the strengthening of state control over considerable variations in the quantity and quality of soils. In the total area, the low relative density of forests disrupts the balance in the landscape. The territory becomes classified as ecologically unstable, unstable, desertification, wind, and water erosion mostly occur in the area, the atmospheric air composition deteriorates, and the problems with groundwater arise frequently. Therefore, during landscape planning, to enhance forest areas with the highest density, strengthening the forest areas' protection should increase, carrying out the diverse forest designs (forest strips around ravines, streams, forest-park massifs, roadsides, around reservoirs, and riverside forest strips).

Forest strips' share in sowing

The developed ravine-gobu system, steep slopes, uneven distribution of precipitation over crop seasons, torrential rains, and the intensive damaging winds in the study area identified the design of protective forest belts as a key element in landscape planning. A recommendation also discloses that in the total crop area, the share of the protective forest belts should not be less than 4%–5% (Plugatar and Koba, 2014). However, in the study area, this indicator varies and ranges from 1% to 2%. Additionally, a need to establish new forest belts on hundreds of hectares throughout the study area is essential. However, one should consider that land allocation for forest belts from selected arable lands with a relatively low load on the total area develops problems in the existing farming conditions. It is also impossible to establish forest belts within farms made from small

pieces of land. The reason is the requirement for designing the field protection forest belts depends upon the terrain and soil type, providing a recommendation to design the distance of 200–600 m between the main forest belts and 1500–2000 m between the auxiliary forest belts (Jafarov and Guliyev, 1997).

Analysis of the spatial conditions of the land allotments showed that most allotments within the boundaries of the northeastern slope of the Lesser Caucasus geocomplexes were up to 100 m wide and up to 500 m long. This revealed a few allotments can accommodate a non-shared forest strip based on their size. However, elimination of these problems requires the consolidation of shared lands within the framework of laws and regulations. In the total cropland, the insufficient share of protective forest belts leads to the development of wind and water erosion, the depletion of the fertile soil layer, the limited self-regeneration potential of the soil, and eventually, a decreased crop productivity. Therefore, the study recommends establishing protective forest belts along ravines, riverside areas, roads, and other infrastructure facilities.

Settlement area load on the total area

The settlement area serves as the housing stock, public buildings and facilities, as well as municipal and industrial facilities, urban streets, squares and parks, and gardens. Other facilities planned and constructed for general use also appear there. Based on the land cadastre data, the research determined the relative burden of lands under settlement in Agstafa District was 1.5%. In the districts of Gadabay, Gazakh, Shamkir, and Tovuz, this indicator was 1.3%, 3.0%, 2.3%, and 1.9%, respectively, of the total area. Within the borders of the Gazakh-Tovuz economic region, the said indicator was 1.9%, and overall in the republic, it was 3.9%. This is also a fact that the Republic of Azerbaijan is among the countries with low land supply. The number of people per 1 km² of land in Azerbaijan is 118 people (Statistical Yearbook, 2025). The recommended relative load of the land under

the residential area was 1%–3% of the total area (Ryumin, 1990).

Land acquisition for the construction of new houses within the boundaries of residential areas—the land planning should be undertaken seriously. However, by allocating land for new settlements within the boundaries of existing residential areas, compact massifs require allocation as much as possible, not allowing the land's fragmentation. By preparing new settlement projects, environmental protection requirements should be notable, and land resources related to settlement should be saved. Therefore, a need to study the experiences of foreign countries in the spatial planning of residential areas is a must to apply them locally, considering national architectural and economic traditions. There is a large relative burden (3.9%) of the total settlement areas in Azerbaijan. This settlement has occurred as a result of the allocation of land plots in accordance with the rules established by law. However, cases of arbitrary seizure of land were also widespread. Such cases lead to the abandonment of arable lands, as well as rural pastures, and develop limitations on other opportunities for agricultural production.

Therefore, foreign experience in planning residential areas requires studying settlement projects implemented, accounting for local architectural and settlement traditions. Presently, the project solutions for the construction of residential areas in the liberated lands of the Karabakh Region of Azerbaijan are excellent examples in this regard.

Natural landscapes' share in the total area

Natural landscape areas comprise natural grasslands, summer and winter pastures, suburban meadows, forests, thickets, swamps, reed beds, rivers, lakes, ravines, valleys, and mountainous areas participating in the formation of the land fund of administrative territorial districts. The analysis revealed the share of natural landscape area in the districts of Agstafa was 79.1%, Gadabay (86.0%), Gazakh (54.3%), Shamkir (59.1%), Tovuz (76.1%), and the Gazakh-Tovuz economic

region (72.3%), and overall for the republic, the share was 68.6%. However, in the total area, the excessive relative burden of natural landscapes limits the development of various sectoral economies, including crop production. Past studies recommended that in the total area, the relative share of natural landscape area should not be less than 35%–40% (Reimers, 1978).

The highest percentage of the relative burden of natural landscape areas on the total area does not combat the ecological problems within the borders of our country, including the geocomplexes of the northeastern slope of the Lesser Caucasus, Azerbaijan. Low productivity of natural forage areas, a sharp decrease in precipitation due to climate change, deforestation, desertification, development of wind and water erosion, and pollution of the rivers are some common ecological issues that need resolving.

Average size of arable lands

In connection with the change in the socio-political structure and the transition to market land relations, the land reforms proceeded during 1996–2000 in Azerbaijan. As a result, most cultivated areas entailed distribution to people free of charge in the form of their shares. As a result of the land reforms, management of farms occurred from small-sized units, and up to 70% of the shared lands were the small holdings with an area up to three hectares.

With the nonimplementation of the crop rotation in small-scale farms, the expression of the ecological diversity index of the territory had smaller values. Monophytic agrocenoses (cereal fields and orchards) reached formation in such conditions that violate the plant species diversity. As a result, the agroecosystem becomes simplified, unified, and monotonous. Therefore, the agroecosystem appeared to be unstable and cannot withstand abiotic and biotic ecological stress conditions (Mammadov, 2016; Guliyev, 2025).

In this regard, a great need prevails for the consolidation of small-scale farms in the

agrarian sector of the country. For managing all that, legal and economic mechanisms require development that can ensure the concentration of small-scale share lands, with the system of territorial organization of production improved. For these purposes, we proposed the volume of subsidies provided to agricultural producers entails differentiation on a per hectare basis, and during its determination, the farmers whose areas are close to the optimal size should receive incentives. The study also proposed to differentiate the rate of land tax for agricultural producers not only according to the soil fertility and location of the lands but also according to their land size (Guliyev, 2022a, b, c, d; Guliyev, 2025).

In previous years, there has been a migration of the rural population to large cities in Azerbaijan. Taking advantage of this situation, some wealthy individuals living in cities purchase large plots of land from people moving to urban areas—not for agricultural production, but for profit-making purposes (with the intent to resell the land later at higher prices). These large tracts of land, which remain uncultivated for years, eventually create conditions for monopolization of land ownership. Therefore, Azerbaijan’s land legislation should include certain restrictions and regulate the land market in this regard. The intensification of the land market should serve more efficient and productive use of land resources. The consolidation of lands through associations and cooperatives is a more appropriate and effective approach.

Ecological stability index of the land

In studying the ecological diversity and resilience of the different areas, the ecological stability coefficient of the study area and the anthropogenic load (coefficient) of the area succeeded in their determination. The ecological stability coefficient of the territory, as calculated, used the following formula:

$$C_{es} = \frac{\sum C_i \cdot F_i}{\sum F_i}$$

Where C_{es} = ecological stability coefficient of the territory, C_i = ecological stability coefficient of the type of agricultural land, and F_i = area of the type of agricultural land (ha) (Rybarski and Gaysse, 1988; Volkov, 1998; Guliyev, 2022a, b, c, d).

The analysis determined that this indicator was equal to $A = 0.47$ for the Republic of Azerbaijan. The said value of the coefficient revealed the territory of the republic as a whole belongs to the category of ecologically unstable territories. The territory of the Gazakh-Tovuz economic region was also among the ecologically moderately stable territories ($A = 0.52$). However, for other districts of Azerbaijan, the stability coefficient was equal to 0.39 for Gazakh, 0.42 for Shamkir, 0.52 for Agstafa, 0.57 for Tovuz, and 0.61 for Gadabay. These ecological stability coefficient values enunciated that the territories of the Gazakh and Shamkir regions were ecologically unstable territories, while the territories of the Agstafa, Tovuz, and Gadabay regions belonged in the group of ecologically medium stable territories.

In the territory, the natural landscapes (meadows, pastures, natural lakes and ponds, and natural forest areas) should have consistent monitoring, and their areas should not bear reductions. Particular attention should focus on the establishment of forest belts around ravines, streams, forest-park massifs, roadsides, riverbanks, and along the edges of reservoirs.

Anthropogenic load on the area

The anthropogenic load coefficients of the different territories underwent determination by the following formula:

$$c_{al} = \frac{\sum FP}{\sum F}$$

Where c_{al} = anthropogenic load degree (coefficient) of the territory, F = area of land groups corresponding to the anthropogenic load degree and assessment score (ha), and P = anthropogenic loading degree of the soil

group (Rybarski and Gaysse, 1988; Volkov, 1998; Guliyev, 2022a, b, c, d).

Overall, the anthropogenic load coefficient for the Republic of Azerbaijan was 2.91, while for other regions, i.e., Gazakh-Tovuz economic (3.04), Agstafa (2.80), Gadabay (2.84), Gazakh (3.20), Shamkir (3.18), and Tovuz region (3.01). These coefficient values suggested that assessed regions incur moderate exposure to anthropogenic impacts. In improving the ecological condition of lands for the purposes of construction of industry, transport facilities, and residential areas, it is necessary to attract not ecologically sustainable arable areas (natural forests and productive pastures) but the lands with a lower ecological stability coefficient. In past years, thousands of hectares of winter pastures and suburban pastures have reached transfer into crop rotation for the production of agricultural products and been allocated for other non-agricultural purposes.

In previous years, the primary purpose of approximately 200,000 hectares of pastureland across the republic has sustained changes, been diverted to cultivation, or been allocated for transportation, industry, road construction, and other non-agricultural purposes. From these designation changes alone, we can determine a 2-point increase in the ecological sustainability of the country's territory (4 points–3 points) \times 200000: $8655481 = 0.02$ (Guliyev, 2025).

Large-scale anthropogenic impacts on biotic communities lead to severe ecological consequences at both the ecosystem-biosphere and population-species levels. Deep ravines form in deforested areas, destructive landslides and floods occur, and phytomass that performs important ecological functions and photosynthesis experiences destruction. Meanwhile, the gas composition of the atmospheric variations causes many plant and animal species to disappear, with the hydrological regime of water bodies altered.

The anthropogenic load coefficient of the area has a value of 5 points; the area was under high anthropogenic influence, with the area valued at 4 points. Under the influence, a score of 3 means that it was moderately

anthropogenic. In areas under high, significant, and medium anthropogenic impacts, issues such as the development of non-industrial areas (development of tourist facilities and children's recreation camps), the declaration of reserves, and prohibitions in the areas must find their solution.

CONCLUSIONS

The current ecological state of the research area has complements of the quantitative and qualitative depletion of natural resource potential, new trends in the structure and functionality of natural complexes, as well as the disruption of balance within ecosystems. The determined ecological-landscape indicators can be applicable in projects related to environmental safety. There has surfaced a need to consolidate small agricultural lands. The study also proposed that farmers whose land sizes are close to the optimal size limit receive incentives by determining agricultural subsidies, with land tax rates differentiated according to the size of the land plots. The issue of studying the ecological-landscape conditions across the entire country should reach the attention of the Government of Azerbaijan. The basis for this is on developing project solutions for their optimization within the framework of special projects with the participation of cadastral and environmental authorities and private organizations.

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