Assessment of the ecological-economic condition as an indicator of sustainable regional development (a case study of the fergana region)

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Abstract. This article examines the importance and role of ecological and economic conditions in assessing regional sustainable development, using Fergana region as a case study. Based on an integrated assessment that combines ecological and economic indicators, an analysis of the environmental sustainability of the territory, the efficiency of natural resource use and the anthropogenic impact associated with economic activity was conducted. Using GIS technologies, statistical information, and evaluation criteria, a map of the ecological and economic status of the districts of the Fergana region has been compiled. The results obtained will serve as the basis for the development of practical recommendations aimed at ensuring sustainable regional development, promoting the rational use of natural resources, and reducing environmental risks. The outcomes of the study are important for ensuring sustainable development of the Fergana Valley, conserving biological diversity, and organizing economic activities in accordance with ecological requirements.

1 Introduction

Human history and biosphere evolution entered a transformative era in the late 20th century, a period frequently identified as 'The Great Acceleration.' This epoch is characterized by systemic global issues, ranging from socio-economic disparities to environmental crises like climate change and biodiversity loss. A critical driver of these challenges has been the shifting paradigm of land use; as urbanization and industrial sectors expand, there is a consistent rise in land dedicated to infrastructure, transport, and residential purposes. This trend reflects a massive spatial restructuring of the planet. Projections by the United Nations further underscore this shift, suggesting that by 2050, urban dwellers will constitute 86% of the population in developed nations and 64% in the developing world [8].

These global challenges acted as a catalyst for the establishment of the United Nations Global Agenda for Sustainable Development. Under this international framework, Sustainable Development Goals (SDGs) 12, 13, 14, and 15 prioritize the preservation of biodiversity and environmental integrity. Central to these initiatives are strategic objectives

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such as the ecological optimization of land resources, the development of robust ecological networks, and the preservation of landscape resilience [3].

Given that land-use patterns are fundamental to meeting societal demands through material production, there is an increasing emphasis on 'greening' these structures to foster sustainability across all economic domains. Achieving these ambitious targets requires innovative methodologies dedicated to natural conservation. A primary example of such an approach is the Ecological and Economic Conditions (EEC) framework. This concept focuses on establishing and maintaining an integrated, optimal balance between anthropogenic economic activities and the natural environment [4, 5, 6].

In the paradigm of sustainable development, investigations focused on balancing ecological-economic stability with the regulation of human-induced pressures are paramount. Anthropogenic load (AL) functions as a definitive metric for evaluating the extent of environmental sustainability [2, 10]. The Fergana Region stands out among other national territories due to its extreme anthropogenic stress, characterized by the rapid intensification of farming practices, sprawling urban and industrial expansion, and significant fragmentation of natural habitats.

This study develops evidence-based recommendations for the sustainable advancement of the Fergana Region by evaluating its eco-economic status and land-use intensity. The research introduces a novel integrated model that, for the first time, synthesizes ecological coefficients, human-induced pressures, and landscape resilience into a single analytical tool. This framework is essential for identifying how different administrative districts respond to environmental transformations. Methodologically, assessing EEC and Land Use Intensity (LUI) aligns with international best practices, such as green infrastructure planning and the Pan-European Ecological Network (PEEN). Furthermore, this approach supports the Kunming–Montreal Global Biodiversity Framework's goal of protecting 30% of global ecosystems by 2030 [3]. Key priorities include the 'greening' of land management, ecosystem service restoration, and the strategic establishment of ecological corridors to mitigate climate change impacts.

Although certain studies exist, a comprehensive evaluation that integrates EEC with the conservation of biological and landscape variety in the Fergana Valley remains a critical research gap. There is a specific shortage of holistic analyses that combine indicators like anthropogenic dynamics, ecological tension, and natural resilience. Moreover, spatial modeling of the EEC using GIS technologies and the strategic planning of ecological networks-based on high-resolution land-use data-are still in their infancy in this region. Consequently, scientific research in Uzbekistan that prioritizes the greening of land-use systems through detailed EEC assessments in the Fergana Region is both timely and essential.

2 Materials and methods

The study focused on the Fergana Region, situated in the eastern part of the Republic of Uzbekistan. Covering an area of 675,900 ha, the region is characterized by one of the highest population densities, intensive agricultural activity, and significant urbanization levels in the country. Key factors influencing the ecological stability of the region include its geographical position, the presence of mountains, hills, and desert zones, the structural–tectonic formations of the Fergana Valley, and the diverse landscape mosaic.

Methodologically, the evaluation of the Fergana Region's EEC relies on a comprehensive dataset, including a 50-year comparison of land resource reports (1974–2024) and municipal land balance figures. Statistical indicators were cross-referenced with figures from the Regional Statistics Department. Additionally, specialized data for conservation zones were gathered via the WDPA and the national Ministry of Ecology, Environmental Protection, and

Climate Change. By applying this framework, it becomes possible to categorize and analyze anthropogenic influences across different administrative boundaries as detailed in Table 1.

Table 1. Classification of land fund categories and types according to the level of anthropogenic load.

№	Types of land use	Anthropogenic load (AL) and the corresponding Ci coefficients/values		
		Category	**Score**	**Level**
I	I. Land categories forming the demoeconomic framework (matrix)			
1	Land for social buildings, built-up areas, lands under reclamation structures, fallow lands, social yards, streets, and squares	AL6	6	Very high
2	Croplands in agriculture and household plots	AL5	5	Relatively high
3	Submerged lands (reservoirs and water basins, canals, collectors and drains), lands for orchards and vegetable cultivation	AL4	4	High
II	II. Land categories forming the natural (Ecological) network (patch)			
4	Perennial plantations, hedgerows, shelterbelts, lands corresponding to category VI of protected areas (PAs)	AL3	3	Medium
5	Pastures, hayfields, lands corresponding to category V of PAs	AL2	2	Low
6	Protected areas (PAs, categories I–IV), submerged lands (rivers, streams, lakes), natural forests, and reserve lands	AL1	1	Very low

Moreover, the AL values for cities and districts were employed to design elements of the ecological network and to assess their expansion potential. This framework underpins the systematic grouping of land-use types based on assigned scoring indicators. As a result, the land fund was stratified into six categories reflecting both economic activity types and levels of land-use intensity (Table 1). In the process of assessing the relative ecological stress coefficient (KRES), all types of land use within the study area are taken into account. To determine the KRES value, the ratio between the land categories forming the demoeconomic framework (AL4, AL5, AL6) and the natural–protected fund (AL1, AL2, AL3) in the study area is analyzed. The implementation of the ecological network concept is closely linked to landscape planning programs, which serve as the basis for evaluating the EEC of land categories and types. It should be noted that the land categories and types included in ecological networks are not considered special land types within the national land fund and do not imply a complete cessation of their economic use. Rather, based on the results of the EEC assessment, certain restrictions on the use of specific land categories and types may be established, or recommendations may be developed for the expansion or reduction of particular land types.

Therefore, when assessing anthropogenic pressure across landscapes or administrative–territorial units, the ecological and economic condition is regarded as a pivotal indicator. This is attributed to the fact that EEC reflects the balance between the inherent ecological capacity of the landscape and the anthropogenic impact imposed upon it. Accordingly, the EEC framework prioritizes the evaluation of anthropogenic load by land category and type at the administrative–territorial level, facilitating the ecologization of land-use practices. In addition, the establishment of ecological networks, which are vital for ensuring sustainability in human activities and ecosystem function, is incorporated as a key objective [4, 5, 6].

The foundational framework for evaluating ecological and economic conditions was established through the early research of Ivanov (1998), Kochurov (1999), and Lobkovsky (2005). Over the last decade, this methodology has undergone significant evolution, with scholars such as Hovsepyan (2017), Rakhmetova et al. (2020), Japarkulova et al. (2021), and Cesonien et al. (2021) further refining its applications. More recent contributions by Yermolaev et al. (2024) and Tokbergenova et al. (2025) emphasize that these assessments transcend simple land-use tracking. Instead, they provide a robust basis for integrating ecological principles into land classification. This 'ecologization' is vital for maintaining environmental security, prioritizing biodiversity through the restriction of intensive activities in vulnerable zones, and offering a scientific rationale for the development of sustainable ecological networks.

Ecological networks comprise two contrasting systems in terms of structure and function: natural and anthropogenic components. An effective ecological network should integrate elements of the natural framework with those of the human–economic framework, establishing functional linkages between them. Consequently, an ecological network cannot be regarded as a homogenous system in terms of structural or functional organization. While the human–economic framework supports settlement and economic activities, the natural framework ensures the maintenance of biological and landscape diversity, environmental integrity, and the sustainable regeneration of natural resources.

Achieving sustainable development requires coordinated progression of the natural and socio-economic components, the adoption of rational land-use strategies, and the preservation of ecological balance. One of the most commonly applied approaches for ecological network design relies on the "patch–matrix–corridor" model [6; 1], which categorizes landscapes into three core components: natural patches, ecological corridors, and anthropogenic matrices. Within this study, the ecological and economic conditions was evaluated across land categories representing both demoeconomic and natural frameworks. AL values for each land category were established through expert scoring, and corresponding scores were assigned to the respective land-use types (Table 1).

In this assessment approach, coefficients (KAES, KRES, and KNP) are calculated to determine the degree of ecological–economic stress. The formulas used to calculate ecological coefficients and their associated indicators are summarized in Table 2 [5, 6]. Generally, higher values of the ecological stress coefficient correspond to increased AL, whereas lower coefficient values indicate more favorable geoecological conditions within the study area, as supported by previous research.If the share of land categories forming the demoeconomic framework and the natural framework constitutes 50%, the KRES coefficient value will be less than or equal to 1, indicating that ecological balance in terms of AL is maintained. If the KRES coefficient exceeds 1, the share of the demoeconomic framework elements correspondingly increases. In this case, the area of rare natural objects and protected zones decreases, the area of agro- and urban complexes expands, and the geoecological situation becomes disrupted. Based on KRES values, it is possible to identify which categories of protected areas (PAs) can be established within administrative-territorial units. For example, in districts with a large share of demoeconomic framework elements, special attention should be given to the creation of micro-reserves and ecological corridors. Similarly, an increasing KAES value indicates that the AL level is exceeding the normative range [4, 7].

The contribution of the natural framework was assessed by analyzing the areas occupied by natural landscapes, PAs, forests, water bodies, and reserve lands, which also serve to determine the region's natural protection indicator. For instance, when land plots with minimal AL are included in the natural framework for P1, the conditional scoring system assigns AL values of $1 \times P1$, $0.8 \times P2$, and $0.6 \times P3$ to land plots of categories 1, 2, and 3, respectively (Table 2). In recent years, particular emphasis has been placed on evaluating the rate and intensity of structural changes in land use through the Land Use Transition Intensity (LUI) method. LUI measures the speed and magnitude of transitions of land resources between categories and is primarily employed to analyze spatial and temporal dynamics in land use and land cover.

Assessing the intensity of land-use change (LUI) holds significant scientific and practical value, providing a foundation for more detailed analysis and effective management of such changes. The LUI indicator highlights the land-use types undergoing the most rapid decline as well as those experiencing expansion [9]. The LUI concept establishes a robust theoretical basis for quantitatively evaluating land-use transformations. It captures not only the transition of land between categories but also the rate and magnitude of these changes.

Table 2. Coefficients of assessment of ecological and economic balance of the territory [4, 6].

Ecological stress coefficients	**Expressions / Indicators**	**Data sources and indicators used**	**Characteristics of changes in the obtained results or values**
$\mathbf{K_{AES}}$ – absolute ecological stress coefficient	$K_{AES}\dfrac{AL6}{AL1}$	Areas of land categories with high anthropogenic load – AL6; areas of land categories with low anthropogenic load – AL1.	$\mathbf{K_{AES}}\uparrow$ – it indicates an increase in the absolute ecological stress coefficient.
$\mathbf{K_{RES}}$ – relative ecological stress coefficient	$K_{RES}\dfrac{AL4+AL5+AL6}{AL1+AL2+AL3}$	The ratio of land categories of the demoeconomic framework elements (AL4, AL5, AL6) to those of the natural framework elements (AL1, AL2, AL3) is analyzed.	$\mathbf{K_{RES}} \rightarrow 1$ – the relative ecological stress coefficient is at the normative level; $\mathbf{K_{RES}}\uparrow$ – an increase in the relative ecological stress coefficient.
$\mathbf{K_{NP}}$ – natural protection coefficient	$K_{NP} = \mathbf{T_{NN}} / \mathbf{R_{LA}}$	$\mathbf{R_{LA}}$ – the total land area of the study region	$\mathbf{K_{NP}}\uparrow$ – an increase in the degree of natural protection.; $\mathbf{K_{NP}} \leq 0.5$ – critical state of the level of natural protection.
$\mathbf{T_{NN}}$ – land categories included in the natural (Ecological) network.	$\mathbf{T_{NN}}$ = P1+0,8 P2+0,6 P3	$\mathbf{T_{NN}}$ – represents the total area of land categories included in the natural (ecological) framework and is primarily characterized by the stability of its ecosystem-forming and resource-conserving functions.	$\mathbf{T_{NN}}$ – the indicator determines the potential for expanding the main elements of the ecological network (central core, ecological restoration areas).

In the Republic of Uzbekistan, lands within the national land fund are categorized into eight groups based on their primary designated use: (1) Agricultural lands; (2) Lands of settlements, including cities, towns, and rural communities; (3) Lands allocated for industry, transport, communication, defense, and other infrastructural purposes; (4) Lands for nature conservation, environmental management, and recreational activities; (5) Lands of historical and cultural value; (6) Forest fund lands; (7) Water fund lands; and (8) Reserve lands.

Accordingly, the Land Use Transition Intensity (LUI) was calculated across all eight land categories, with scores assigned to each category based on expert evaluation. Specifically, lands allocated for industrial, urban, and mixed urban-rural purposes-including areas designated for industry, transport, communication, defense, and other infrastructural uses- received a score of 6. Settlement lands (cities, towns, and rural communities) were assigned a score of 5, while agricultural lands were scored 4. Forest fund lands, protected areas, natural landscapes, and reserve lands, which are generally excluded from socio-economic activities, were assigned the lowest score of 1 (Table 3).

Table 3. Changes in the land fund composition of Fergana Region (1974–2024) (thousand hectares).

№	Main land fund categories	1974	2024	C_i
1	Lands intended for agriculture;	560.6	532.4	4
2	Lands of settlements (cities, towns, and rural settlements);	9.8	18.6	5
3	Lands designated for industry, transport, communication, defense, and other purposes;	17.3	51.2	6
4	Lands for nature protection, environmental improvement, and recreation;	-	0.4	1
5	Lands of historical and cultural significance**;**	0	0	2
6	Forest fund lands**;**	46.9	19.2	1
7	Water fund lands**;**	9.2	20.5	3
8	Reserve lands**.**	101.9	33	1
	Total land area	676.0	676,0	

The derived LUI data provide a foundation for modeling and predicting future land-use changes. Such information is essential for natural resource management and environmental impact assessment. Using these data, strategic decisions can be made at the regional level to maintain ecological stability, designate ecological corridors, protect agricultural lands, and develop recreational areas. The LUI can be computed using the following formula:

$$LUI = \sum_{i=1}^{n} (B_i/B) \times C_i$$

In this formula: B – total land area; n – number of land-use types (in this study, n = 8); B_i – area of each land-use type; C_i – value representing the degree of use of the land-use type [9]. The LUI intensity categories are interpreted as follows: LUI < 2.0 – low intensity (natural geosystems occupy a large share); 2.0 ≤ LUI < 3.0 – medium intensity; LUI ≥ 3.0 – high intensity (indicating extensive and expanding use of agricultural lands, urban areas, industrial zones, and roads).

3 Results and discussion

To develop the components of the ecological network and assess their feasibility within the administrative–territorial units of the Fergana Region, ecological stress coefficients were computed (Table 4). For the cities and districts of the region, the absolute ecological stress coefficient (KAES) was determined by analyzing the proportion of land categories and types ranging from AL1 to AL6. The results indicate an increasing level of ecological stress across the Fergana Region. These calculations were based on the data presented in Table 4.

As an example, the Sokh District, which is characterized by a relatively favorable geoecological condition within Fergana Region, is considered. Initially, land areas with a high level of anthropogenic pressure (AL6) and land areas with a low level of anthropogenic pressure (AL1) are identified for each administrative district (Table 4). In this case, the absolute level of ecological stress of the district is equal to 0.10. Therefore:

$$K_{AES}\frac{13423}{1355}=0{,}10$$

Based on the Kmez indicator, the geoecological condition by administrative districts in Fergana Region is assessed as highly favorable in Sokh, Uzbekistan, Beshariq, Fergana, Yazyovan, Dangara, Oltiariq, and Quva districts compared to other districts, and remains below the regional average value. These districts are distinguished by the relatively large extent of natural landscapes, reserve lands, natural monuments, water-covered areas (rivers, streams, and lakes), and protected forest areas.

In districts where the potential for establishing protected natural areas is rated very high, the proportion of land categories comprising the human–economic framework and the nature reserve fund can reach up to 50%, indicating an optimal level of ecological balance. In Fergana Region, the calculation of the KRES indicator is examined using the example of Qoshtapa district, where the situation is assessed as critical. In order to evaluate the potential for establishing protected natural areas in Qoshtapa district, the ratio between land categories with high anthropogenic pressure (AL4, AL5, AL6) and those with relatively low anthropogenic pressure (AL1, AL2, AL3) is analyzed. In this case, the KRES value of the district equals 8.54, indicating that there is no possibility to establish protected natural areas of Categories I–IV, that is:

$$K_{RES}\frac{2+100000}{8000}=8{,}54.$$

Based on the obtained results, changes in the K**NP** indicators corresponding to the KRES values were also identified. Initially, districts with a KRES value equal to 1 are distinguished, as this indicator reflects an optimal level of ecological balance and a high potential for the establishment of protected natural areas within the districts. In Fergana Region, the KRES values in Sokh (0.25), Uzbekistan (0.48), Fergana (0.88), and Beshariq (0.96) districts are below 1, indicating that the ecological–economic condition remains within normative limits. Thus, in these regions, there is a significant potential to raise the share of protected natural areas to 17%. This increase could be achieved largely through the development of state nature reserves, nature parks, and wildlife sanctuaries, facilitating the achievement of targets set by the Kunming–Montreal Global Biodiversity Framework.

According to the assessment results, in districts where KRES is below 1, land categories forming the natural framework (patch) account for 50% to 90% of the area. The main territories of these districts correspond to mountainous and piedmont regions and are also distinguished by a high degree of preservation of natural landscapes. In Fergana Region, an increase in the ecological stress indicator is characteristic of administrative units located in the Central Fergana area. These districts stand out due to the highest degree of transformation in the composition of natural landscapes. For example, very high KRES values were recorded in Buvayda (5.85) and critical values in Qoshtapa (8.54) districts. In Qoshtapa District, the elements of the demographic–economic framework (matrix) constitute 88.1% of the area, while the share of the natural framework (patch) is 11.9% (Table 5).

Table 4. Distribution of the land fund by anthropogenic load in the administrative districts of the Fergana Valley (2024).

№	Administrative districts	Total area	Levels of anthropogenic pressure intensity (ha)					
			Natural framework (patch)			Demographic–economic framework (matrix)		
			AL1	AL2	AL3	AL4	AL5	AL6
			Very low	Low	Moderate	Relatively high	High	Very high
	1	2	3	4	5	6	7	8
1	Beshariq	77385	33919	2478	4380	7541	25432	5378
2	Baghdad	33343	3390	203	4897	3180	17266	4610
3	Buvayda	27901	3259	358	936	2246	17110	4028
4	Dangara	43484	12356	1658	1447	3870	21013	4798
5	Yazyovan	40700	11743	1350	1152	3097	20774	3573
6	Quva	43815	8113	178	7723	3983	18893	5040
7	Oltiariq	63088	12539	1384	4661	4875	34252	6504
8	Qoshtapa	36773	2383	743	2589	5246	21744	4783
9	Rishton	30730	2703	633	4513	3257	14548	5169
10	Sokh	22073	13423	2533	2074	607	2249	1355
11	Tashloq	24299	2481	254	2380	1800	14071	3463
12	Uzbekistan	68852	35143	4888	7584	2797	13730	5251
13	Uchkupik	27537	4359	138	2361	2078	14701	3912
14	Fergana	61164	22179	428	10395	2695	18910	6611
15	Furqat	30529	4697	572	554	3378	18585	3315

Table 5. Potential for establishing ecological networks by administrative districts of Fergana region.

№	Administrative districts	Ecological stress coefficients			Demographic–Economic Framework (%)	Natural Framework (%)	Potential for establishing Ecological Networks
		K_{AES}	K_{RES}	K_{NP}			
1.	Sokh	0,10	0,25	0,76	19,9	80,1	Very High
2.	Uzbekistan	0,14	0,48	0,63	32,7	67,3	Very High
3.	Fergana	0,29	0,88	0,48	47,0	53,0	High
4.	Beshariq	0,15	0,96	0,42	49,1	50,9	High
5.	Quva	0,62	1,91	0,30	65,7	34,3	Medium
6.	Yazyovan	0,30	2,02	0,29	66,8	33,2	Medium
7.	Dangara	0,38	2,14	0,26	68,2	31,8	Medium
8.	Oltiariq	0,51	2,15	0,26	69,1	30,9	Medium
9.	Rishton	2,00	3,86	0,19	79,4	20,6	Low
10.	Bog‘dod	1,35	3,87	0,19	79,5	20,5	Low
11.	Uchkupik	0,89	3,65	0,19	78,5	21,5	Low
12.	Tashloq	1,39	4,60	0,17	82,1	17,9	Very Low
13.	Furqat	0,70	4,89	0,15	83,0	17,0	Very Low
14.	Buvayda	1,23	5,85	0,12	85,4	14,6	Very Low
15.	Qoshtapa	1,91	7,45	0,11	88,1	11,9	Very Low
16.	Sokh	0,10	0,25	0,76	19,9	80,1	Very High

The larger the share of the natural framework, the higher the landscape stability and biodiversity indicators accordingly. In addition, the KNP$\uparrow$ value indicates the degree of natural protection: a higher KNP reflects an increasing natural protection coefficient, whereas a KNP $\leq$ 0.5 indicates a critical level. For example, this indicator is calculated for Sokh district, which has a high value within the Fergana Valley, as follows:

$$K_{NP} = \frac{T_{NN}}{R_{LA}} = \frac{16693{,}8}{22073} = 0{,}76$$

Here, **RLA** represents the total area of the land fund of the studied territory, and **TNN** denotes the land categories that form the natural framework, which are calculated as follows:

$$T_{NN} = 13423 + 0{,}8 \times 2533 + 0{,}6 \times 2074 = 16693{,}8$$

In certain districts, the KNP value exceeds the regional average, which is expressed by the area of reserve lands and forest fund lands. Based on the ecological–economic condition indicators, the potential for establishing protected natural areas within the administrative-territorial units of Fergana Region was categorized into five groups (Table 5). Significant differences in the KRES indicator across the administrative districts of the Fergana Valley have been identified. In districts of the Fergana region where the indicator of demoeconomic framework elements exceeds 50%, the KRES coefficient tends to exceed 1. For example, over the past ten years, in all districts-particularly those adjacent to regional centers-the area of orchards and reserve lands has decreased due to the expansion of settlements. This trend is associated with factors such as the construction of new settlements, the commissioning of industrial enterprises, and the expansion of collector-drainage systems.

In the Fergana Valley, the natural protection coefficient (**TNN**) is manifested as follows: very high in Sokh and Uzbekistan; medium in Fergana and Beshariq districts; and very low (0.08–0.18) in Toshloq, Farkhat, Buvayda, and Qo‘shtepa districts. In some districts of the Fergana region, a sharp decline in **TNN** values can be observed (Table 5). In implementing the objectives of the Kunming-Montreal Global Biodiversity Framework, in districts where the KRES indicator is narrow, severe, and critical, priority should be given to ecological land-use planning, the establishment of green areas, and the development of agroecotourism. In particular, in districts where irrigated land exceeds 50%, special attention should be paid to maintaining the integrity of ecological corridors through the creation of micro-reserves and the expansion of shelterbelts and protective forest plantations.

Changes in land use intensity affect the natural environment, particularly biodiversity, soil fertility, and water resources. By determining the Land Use Intensity (LUI), it becomes possible to identify negative environmental impacts at an early stage and implement appropriate protection measures. For example, the LUI indicator for Fergana Region for the year 2024 is calculated as follows: Total land area (B): The total land area is 675.3 thousand hectares. The contribution of each land type to the LUI is as follows: Agricultural lands: 0.788 × 4 = 3.152; Lands of settlements: 0.0275 × 5 = 0.138; Lands allocated for industry, transport, communication, defense, and other purposes: 0.0757 × 6 = 0.454; Lands for nature protection, rehabilitation, and recreation: 0.0006 × 1 = 0.0006; Lands of historical and cultural significance: 0 × 2 = 0; Forest fund lands: 0.0284 × 1 = 0.028; Water fund lands: 0.0303 × 3 = 0.091; Reserve lands: 0.0488 × 1 = 0.049.

LUI2024 = 3.152+0.138+0.454+0.006+0+0.028+0.091+0.049 = 3.9

Analysis of Land Use Intensity (LUI). The LUI serves as a critical diagnostic tool for spatial planners to evaluate anthropogenic stress and structural landscape shifts. Between 1973 and 2024, the Fergana Region’s LUI values rose from 3.8 to 3.9, reflecting a persistent intensification of human-economic activities. This upward trajectory is driven by demographic growth, rapid urbanization, and industrial expansion.

Agricultural Land Dynamics (560.6 → 532.4 thousand ha). Over the fifty-year study period, agricultural land declined by 28.2 thousand hectares (approximately 5%). This contraction is twofold: first, the physical conversion of fields into residential and transport infrastructure; and second, the qualitative deterioration of irrigated lands due to salinization, waterlogging, and soil erosion.

These shifts directly jeopardize agroecosystem resilience and the efficiency of resource management. Increasing soil degradation not only lowers yields but also inflates reclamation costs. Consequently, regional strategies must prioritize the conservation of fertile soil, the adoption of water-saving irrigation, and the systematic restoration of degraded agro-landscapes to ensure long-term ecological stability.

Forest Fund Dynamics (46.9 → 19.2 thousand ha). The region witnessed a dramatic 59% reduction in forested areas, totaling a loss of 27.7 thousand hectares. This decline is primarily fueled by the expansion of irrigation networks, conversion to arable land, and infrastructure development. Given that forests are indispensable for hydrological regulation, carbon sequestration, and erosion control, such a substantial loss poses a severe threat to regional ecological stability. Prioritizing reforestation and the protection of remaining forest patches is therefore critical for environmental resilience.

Reserve Land Depletion (101.9 → 33.0 thousand ha). Reserve lands have shrunk by 67.6% (78.9 thousand ha) as they were reallocated for urban, industrial, and agricultural use. This near-exhaustion of the reserve fund signals a looming constraint for future spatial planning. The transition of these unallocated resources into built-up environments underscores a critical shortage of land availability. Consequently, shifting toward more efficient land management and implementing strict reclassification based on landscape-ecological criteria is now an urgent necessity for the region.

Expansion of Settlement Lands (9.8 → 18.6 thousand ha). Residential areas in the region have nearly doubled, showing a significant 89.8% increase. This surge is fundamentally driven by rapid demographic growth and the subsequent expansion of social and service infrastructure. While this trend reflects rising urbanization and population density, it simultaneously intensifies anthropogenic pressure, leading to the degradation of natural landscapes. Consequently, there is an urgent need for sustainable urban planning policies that balance infrastructure development with ecological preservation.

Water Fund Dynamics (9.2 → 20.5 thousand ha). The water fund area grew by 11.3 thousand hectares, a remarkable 122% increase. This expansion is primarily linked to the large-scale construction of reservoirs, irrigation canals, and hydraulic structures aimed at enhancing land reclamation and water distribution efficiency. However, the conversion of irrigated agricultural zones into water management infrastructure necessitates a strategic shift toward modernizing drainage networks and optimizing water allocation to address increasing water scarcity.

Infrastructure and Industrial Expansion (17.3 → 51.2 thousand ha). The area dedicated to industry, transport, and communication has nearly tripled, surging by 196%. This rapid escalation stems from the modernization of logistics networks, new energy facilities, and the creation of specialized industrial zones. While these shifts signal active socio-economic transformation, they simultaneously heighten anthropogenic pressure and deplete lands available for agriculture and natural habitats. Therefore, rigorous environmental impact assessments and sustainable spatial planning are imperative to mitigate risks to air, soil, and water quality.

Conservation and Recreational Zones (0 → 0.4 thousand ha). Despite its minimal footprint, the emergence of this land category marks a vital step toward protecting regional biodiversity and fostering ecotourism. These areas serve as essential green reserves that support ecosystem restoration and improve public well-being by counterbalancing urban stress.

Ecological Connectivity and Landscape Corridors. Regional ecological stability depends on the natural framework's share. In districts where natural cover remains at 50–80%, establishing large-scale protected areas (over 10,000 ha) is feasible. Conversely, in more fragmented areas (30–50%), biodiversity can be safeguarded through micro-reserves and natural monuments. A key strategy for the Fergana Region is the development of a diverse corridor system-including area - based, linear, and 'stepping-stone' corridors - to ensure connectivity between natural and human-modified landscapes.

4 Conclusion

The implementation of the Global Biodiversity Framework (GBF) principles in Uzbekistan, particularly in the Fergana Valley, is critical for conserving regional biodiversity and aligning national environmental policies with international objectives. Achieving this requires the identification of landscapes with the highest biodiversity value, calculation of Anthropogenic Load (AL) indices, determination of priority elements of ecological networks, expansion of ecological corridors to maintain stability and connectivity, and active involvement of local communities and stakeholders.

In districts of the Fergana region bordering Tajikistan and the Kyrgyz Republic, as well as in transboundary areas, the anthropogenic load is significantly lower than in other districts of the region. Consequently, ecological indicators related to biological and landscape diversity are higher in these transboundary areas, making them crucial for maintaining ecological stability in the region.

From 1973 to 2024, the dynamics of land use in the Fergana Region have been predominantly influenced by industrialization, urban expansion, and infrastructure development. To support economic growth and satisfy the needs of the growing population, land-use intensity (LUI) has increased substantially. Both LUI and anthropogenic load (AL) indicators exert direct and indirect effects on the formation and functionality of ecological networks. These effects can be summarized as follows:

1. Impact on Biodiversity: Rising LUI and AL values often correspond to transformations of natural landscapes into agricultural, industrial, or urban areas. Such changes lead to reductions in biodiversity and the fragmentation of natural habitats, thereby disrupting ecological connectivity and integrity and creating obstacles to species migration and genetic exchange.
2. Fragmentation of Natural Landscapes: Elevated LUI and AL levels result in intensive land exploitation, breaking natural ecosystems into smaller, isolated patches. Ecological networks are designed to address such fragmentation by connecting disparate natural areas. Hence, increasing LUI highlights the importance of establishing and maintaining ecological networks.
3. Resource Degradation: High LUI and AL are major contributors to the degradation of natural resources in the region, manifesting as soil deterioration, water pollution, and air contamination. In the Fergana Region, LUI values exceeding 3.9, combined with increasing anthropogenic pressures, exacerbate the degradation of soil, water, and biological resources. Ecological networks serve as a vital mechanism for mitigating these negative impacts and optimizing ecosystem functions.
4. Influence on Ecological Network Planning: LUI and AL indicators provide essential insights into current land-use patterns and their dynamics, which are critical for regional planning and ecological network design. In areas characterized by high LUI, specific interventions-such as the establishment of ecological corridors and buffer zones-are required to conserve natural landscapes and maintain connectivity, whereas areas with lower LUI are comparatively easier to protect and manage.

Enhancing and expanding the system of protected areas represents a key priority for improving the geo-ecological condition of administrative–territorial units. Based on the analyses described above, special attention was given to evaluating land types and land users within each district, as well as assessing the potential for establishing protected areas in these administrative divisions.

In districts of the Fergana Valley exhibiting a high absolute ecological stress coefficient, priority should be given to the establishment of micro-reserves and ecological corridors. Currently, the types and extent of protected areas in the region have limited capacity to ensure ecological stability and conserve biodiversity. In districts where the potential to expand protected areas up to 17% is low or very low, it is essential to create micro-reserves ranging from 1 to 50 hectares and to preserve the integrity of ecological corridors in order to improve ecological conditions and protect rare natural features.

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