Geoecological analysis and optimization of the protected areas network in the Fergana Valley

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Abstract. This paper examines a geoecological approach to the analysis and optimization of the network of protected natural areas (PNAs) using the administrative districts of the Fergana Valley of Uzbekistan as a case study. The effectiveness of the regional ecological framework is assessed through indicators such as the Coefficient of Conservation of Natural Geosystems (CCNG) and the Coefficient of Provision with Conservation Objects (CPCO). The study identifies structural imbalances in the existing PNA categories, characterized by a deficit of strictly protected areas and lack of connectivity between conservation sites. Particular attention is given to the expansion of the network through the establishment of geological reserves and natural monuments, which serve as a foundation for both landscape preservation and practical natural science education. The findings offer priority areas for establishing new PNAs and can be integrated into the state planning system for environmental protection.

1 Introduction

The global decline in biological and landscape diversity (BLD) poses a direct threat to ecological stability and the resource security of humanity. In response to these challenges, the international community, including United Nations institutions, has set an ambitious goal to grant protected status to at least 30% of the Earth's terrestrial surface by 2030. The development of protected natural area systems is recognized as the most effective tool for counteracting landscape degradation, particularly in regions experiencing high anthropogenic pressure. Despite global initiatives (notably the Aichi Strategic Goals and the decisions of the 14th Conference of the Parties to the Convention on Biological Diversity), the rate of loss of unique natural complexes remains high [7, 5, 3]. For the Republic of Uzbekistan, the fulfillment of international obligations is integrated into the National Strategy for the Conservation of Biological and Landscape Diversity for 2019–2028. This document provides not only for the expansion of PNA areas but also for their mandatory state registration within cadastral systems to ensure an effective legal protection regime.

The current stage in the development of the PNA network requires a transition from the fragmented protection of individual species to the systematic formation of an ecological framework. An important complement to the biological vector should be the conservation of

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geological heritage. The establishment of specialized geological reserves and natural monuments makes it possible not only to protect unique geological outcrops and stratigraphic reference sections, but also to create a scientific and practical foundation for consolidating theoretical geological knowledge under field conditions. This article presents methodological approaches and practical results of assessing the representativeness of the protected natural area (PNA) network and the conservation potential of territories within the Fergana Valley, aimed at improving the structure of environmental governance in the region.

2 Research methods

The formation of an effective strategy for expanding the ecological network of protected natural areas (PNAs) requires a comprehensive analysis integrating both bioecological and socio-economic indicators [3]. This study provides a critical analysis of the criteria and methodological approaches proposed by leading experts and researchers for evaluating the effectiveness of nature conservation systems.

In addition, contemporary studies by L. Miklós (2019), D. M. Theobald (2022), and Xinyue Fan (2023) were analyzed, emphasizing the adaptation of global protected area management standards to the regional specificity of landscapes. The theoretical framework developed by these researchers makes it possible to consider PNAs not as isolated reserves, but as dynamic geosystems characterized by internal resilience and spatial connectivity. It is precisely this systemic approach that serves as the methodological key to identifying unique geological natural monuments and integrating them into the educational and conservation potential of the Fergana Valley. Despite the existence of global standards (IUCN, Convention on Biological Diversity), the regional characteristics of the Fergana Valley necessitate the adaptation of existing approaches.

Traditional criteria often fail to account for landscape representativeness and the geological uniqueness of the region, which reduces the effectiveness of the ecological network [4, 1]. The area occupied by PNAs serves as an indicator of the level of conservation of wildlife, biological and landscape diversity, gene pools, cultural heritage, and recreational resources of the region, and also guarantees long-term ecological stability [6].

According to the concept proposed by Graeme S. Cumming and Craig R. Allen (2017), protected natural areas should be regarded as dynamic social–ecological systems. This approach enables the integration of nature conservation objectives into the framework of regional development, ensuring the resilience of landscapes to external anthropogenic pressures. In this study, the assessment of the PNA system is based on two key components:

Territorial structure: PNAs are considered as a dynamic system comprising core areas, ecological corridors, and buffer zones.

Geosystem value: Analysis of unique landscapes through indices of reference value, conservation status, and landscape representativeness.

Under conditions of intensive subsoil exploitation in the Fergana Valley, such sites should be granted the status of reference geocomplexes, ensuring not only the conservation of biological and landscape diversity, but also serving as a practical basis for the training of geological specialists.

To analyze the representativeness of the PNA network, a coverage indicator (PNAC) was applied, which, in accordance with Uzbekistan's national targets up to 2028, should approach 17%:

$$\mathrm{PNA}_{CL} = \frac{S_{PNA(\text{I-IV})}}{S_{A}} \times 100\% \tag{1}$$

where PNACL is the coverage level; SPNA(I–IV) represents the area indicators corresponding to Categories I–IV of protected natural areas within administrative units (districts, regions) or natural geographical regions (NGRs); SA is the total area of administrative units or natural geographical regions.

For a comprehensive analysis of the structural and functional integrity of the PNA network of the Fergana Valley, a geosystem parameterization method was applied using two interrelated indices: the Coefficient of Conservation of Natural Geosystems (CCNG) and the Coefficient of Provision with Conservation Objects (CPCO).

2.1 Integral assessment of the conservation of natural geosystems (CCNG).

Unlike standard methodologies that consider only the total area of protected lands, this coefficient makes it possible to differentiate territories according to the degree of anthropogenic transformation. The calculation was carried out based on up-to-date land balance data for the administrative districts of the Fergana Valley for 2024 (Table 1). The use of administrative-territorial units as the basis for assessment is justified by the fact that operational land management and decisions on allocating plots for new conservation-designated sites are implemented at the district level [9]. The mathematical model is expressed as follows:

$$CCNG = (2Sland + 1.75Sforest + 1.5Swater + Spasture) / Stotal \quad (2)$$

where: Sland - area of natural landscapes; Sforest - area of forest fund lands; Swater - area of water fund lands; Spasture - area of pastures and hayfields; Stotal - total area of the physical-geographical region or administrative unit.

The application of the increasing coefficient “2” for the S_land category is обусловлено the exceptional importance of these lands as the cores of the ecological framework. We propose including in this category not only biological reserves, but also geological natural monuments and reserves. The establishment of such sites in the Fergana Valley will not only stabilize the ecological situation, but will also form a practical foundation for training future geological specialists, transforming theoretical knowledge of the Earth’s crust structure into a visual educational resource.

Table 1. The main categories and types of the land fund included in the ecological network.

№	**Types of land use**	**Importance for maintaining biological and landscape diversity**
I	**Land categories forming the demo-economic framework**	
1	Settlement lands; industrial, energy, transport, communication, defense, infrastructure, and other designated lands	Not applicable
2	Agricultural lands	Very low
3	Water fund lands (reservoirs, canals, collectors, and other uses)	Low
II	**Land categories forming the natural framework**	
4	Restricted forest belts along riverbanks, lakes, reservoirs, and other water bodies; green zones around cities and industrial centers	Relatively high
5	Forests of nut-producing zones; pastures and hayfields; protective forest plantations; lands belonging to categories V–VI of protected natural areas	High
6	Lands of conservation, health, recreational, and historical-cultural purpose (lands belonging to categories I–IV of PNAs); natural landscapes; water fund lands (rivers, streams, lakes); especially valuable forests and reserve lands	Very high

Source: recommended by the authors.

In the updated structure of the table, special emphasis is placed on Item 6, highlighting natural landscapes as the "cores of the ecological framework". The inclusion of geological natural monuments in this category is scientifically justified by the fact that the lithogenic foundation (relief and geological structure) forms the basis of biological diversity. The exceptionally high significance of these lands is обусловлено their role as reference zones. The conservation of such areas in the Fergana Valley makes it possible to: ensure the stability of biospheric processes; preserve unique geological sections for scientific research; create a foundation for practice-oriented education (student field training), where sites function as visual teaching aids.

2.2 Coefficient of provision of the territory with conservation objects (CPCO).

This indicator is used for the quantitative and qualitative analysis of the level of development of the protected natural area network at regional and local scales. Unlike simple statistical indicators, the CPCO accounts for the functional significance and protection status of different categories of territories. The information base for the calculations included data from the State Register of Protected Natural Areas of the Republic of Uzbekistan, as well as information from territorial departments of the Ministry of Ecology, Environmental Protection, and Climate Change.

The application of this coefficient makes it possible not only to assess the current situation, but also to mathematically substantiate the expansion of the PNA network in areas with a deficit of conservation objects. The index is calculated using the following formula:

$$CPCO = (2SI + 1.5SII + (1 + 0.01n)\ SIII + 0.5SIV) / Stotal \tag{3}$$

Where the following weight values are applied: SI - strict reserves (state nature reserves, biosphere reserves, complex reserves); SII - territories with regulated use regimes (national and natural parks, forest fund lands, and fishery zones); SIII - natural monuments of national significance. Within the framework of this study, particular attention is paid to geological natural monuments (stratotypes, unique landforms), whose value is adjusted using coefficient n (number of objects); SIV - natural monuments of local significance; Stotal - total area of the assessed territory.

The integration of geological objects into this formula highlights their role in conserving landscape diversity. The establishment of geological reserves and natural monuments in the Fergana Valley is considered not only as a measure for conserving subsoil resources, but also as the creation of an innovative educational environment. Such territories facilitate the transformation of theoretical geological knowledge into practical skills through field research and educational training. To systematize the obtained data and rank the administrative districts of the Fergana Valley according to their level of ecological protection, the results of the CCNG and CPCO calculations were classified using a five-level hierarchical scale (Table2).

Table 2. Classification of conservation and provision levels of protected natural areas.

Value range	Qualitative assessment	Recommendations for PNA network development
0 – 0,50	Very low	Critical deficit of PNAs. Urgent allocation of ecological framework cores required.
0,51 – 1,0	Low	Dominance of anthropogenic landscapes. Establishment of small PNA forms (natural monuments) is required
1,1 – 2,0	Medium	Satisfactory condition. Creation of ecological corridors is recommended.

Continuation of Table 2.

Value range	**Qualitative assessment**	**Recommendations for PNA network development**
2,1 – 3,0	High	High representativeness potential. Maintenance of the existing protection regime
Above 3,0	Very high	Reference geosystems. Possibility of establishing state nature reserves, biosphere reserves, or complex reserves.

This methodology makes it possible not only to state the current condition of landscapes, but also to scientifically substantiate the localization of geological natural monuments and state nature reserves. In areas characterized by "very low" and "low" indicators (typical of the central lowland parts of the Fergana Valley), the identification and protection of even small geological objects (unique residual landforms, paleontological layers) becomes a priority task.

The integration of geological attractions into the regional PNA network addresses a dual objective:

Ecological: preservation of the lithogenic foundation of landscapes and prevention of their degradation;

Educational: use of geological reserves as "living laboratories" for the practical consolidation of students' theoretical knowledge, which is critically important for the formation of professional competencies of future specialists in Earth sciences.

3 Results and discussion

The strategy for optimizing the network of protected natural areas (PNAs) should be based on a two-level approach: a landscape-based approach to ensure natural and geographical representativeness, and an administrative approach for the practical implementation of conservation measures by governmental authorities. Such duality makes it possible to integrate ecological imperatives into the system of territorial planning and the state cadastre [8, 10].

In the Development Strategy of New Uzbekistan for 2022–2026, important objectives are defined in the fields of ecology and environmental protection, improvement of environmental conditions in cities and districts, and implementation of the nationwide project "Green Land." Within the framework of the "Green Land" project, particular attention is given to the expansion of forestry across the republic. The presence of forest belts in all regions ensures the integrity of ecological corridors at the national scale (Table 2).

According to the above analysis, the lowest indicators in terms of PNA area and category composition are observed in the Andijan, Fergana, and Namangan regions. In Fergana region, five natural monuments have been established ("Yazyavan Deserts" - 1,735.19 ha; "Central Fergana" - 142.5 ha; "Akbarabad Sands" - 39.5 ha; "Zilkha Sands" - 22.2 ha; "Bostonbuva Sands"), all having reserve status. The PNA network of Namangan region consists of one natural park (Pop NP - 10,000 ha) and two natural monuments ("Chust" - 96 ha; "Mingbulok" - 1,000 ha). In Andijan region, conservation efforts are limited to the establishment of local-level botanical natural monuments. Existing PNAs largely correspond to the Kuramin and Central Fergana natural geographical regions (NGRs).

In the remaining NGRs, the main PNA categories (I–IV), which are essential for the conservation of biological and landscape diversity, have not been established. An analysis of PNAs by category composition, occupied area, and NGRs indicates that they do not meet the requirements of an ecological framework. Furthermore, protected natural areas are not interconnected by ecological corridors. The total coverage of all PNA categories amounts to 16.4% in Namangan region, 10.6% in Fergana region, and 10.2% in Andijan region.

However, state nature reserves, complex (landscape) reserves, and wildlife reserves have not been established in the Fergana Valley.

According to our analysis, the current coverage of PNA categories I–IV in Uzbekistan is 14.08%. However, the regional distribution of conservation sites is extremely uneven. While values in Tashkent region (37.5%) and the Republic of Karakalpakstan (22.2%) exceed the national average, the Fergana Valley exhibits a significant deficit of protected lands. Structural analysis of the PNA system revealed the following features:

Ecological network core (11.41%): The largest share is occupied by natural parks (9.48%), while the proportion of strict reserves (0.49%) and biosphere reserves (0.24%) remains critically insufficient for maintaining genetic diversity.

Regional disparities: State nature reserves are completely absent in the Andijan and Fergana regions. This gap in the wildlife protection system poses a threat to the degradation of reference landscapes.

Role of small-scale protection forms: Natural monuments of national significance are recorded in only five regions, including the Fergana and Namangan regions.

Within the context of improving the PNA network of the Fergana Valley, we propose shifting the focus toward the establishment of geological reserves and natural monuments. Given the high population density and intensive agricultural development of valley lands, allocating large territories for strict reserves is difficult. In this regard, the organization of localized but scientifically significant geological PNAs (sites of paleontological findings, stratigraphic sections, caves) represents an effective solution.

This approach addresses not only the task of conserving the landscape framework, but also the issue of practical geological education. Transforming unique geological objects into protected educational sites enables students to study the dynamics of natural processes on real objects that are legally protected from destruction due to economic activities. Thus, geological PNAs act as a connecting link between fundamental science and practical subsoil use.

Therefore, it is advisable to conduct a comprehensive assessment of PNA areas by administrative units and natural geographical regions until the target level of 17% is achieved. Particular attention should be paid to the optimal selection and organization of all PNA categories in these regions. The share of PNAs forming the core of the ecological framework by district amounts to 4.8% in Yazyavan district, 3.4% in Pop district, 1.3% in Mingbulok district, 0.3% in Koshtapa district, 0.1% in Chust district, 0.09% in Kuva district, 0.05% in Altyaryk district, and 0.02% in Buvayda district (Table 3).

Differences in the area occupied by all categories of protected natural areas (PNAs) are also substantial, exceeding 17% in the Markhamat, Oltinkol, Dangara, Besharyk, Uzbekistan, Yazyavan, Fergana, Jalaquduq, and Uychi districts. The highest values are observed in the Yangikurgan (92.7%) and Khojaabad (52.14%) districts. In these areas, a large proportion is occupied by water protection zones, zones of surface and groundwater formation, as well as fishery and hunting management areas. However, these PNA categories do not have a strict protection regime. The presented results indicate that improving the PNA system and its composition in the Fergana Valley is one of the most pressing issues. According to CPCO data, an average value was recorded in Pop district (1.60), while low values were identified in Mingbulok (0.60), Yazyavan (0.60), and Kushtepinsky (0.51) districts, which is explained by very low values in most other districts (Table 3).

Table3. The area of protected natural areas by districts and cities (2022).

№	Administrative units	Total area, ha	Categories of protected natural areas (area, ha)**						Total area of protected natural areas, ha	IUCN coverage level*	Coverage level, %	C_{PCO}	C_{CNG}
			NP	SMP	WPZ	LFF	SWFZ & GWFZ	FZ					
	1	2	3	4	5	6	7	8	9	10	11	12	13
	For Namangan Region:												
1	Kasansay	52234				587			587	0,0	1,12	Very low	0,80
2	Mingbulak	74070		1000	1763,1	3993			6756,1	1,35	9,12	Low	0,24
3	Namangan	20506			1901,8	110		64	2075,8	0,0	10,12	Very low	0,18
4	Naryn	20715			1917,8	309			2226,8	0,0	10,74	Very low	0,14
5	Pap	290968	10000		4801	6524		375	21700	3,43	7,45	Medium	1,32
6	Turakurgan	27403			1895,6	260			2155,6	0,0	7,86	Very low	0,58
7	Uychi	30444			1902,40	352	5685		7939,4	0,0	26,07	Very low	0,24
8	Uchqurgan	29974			1328,40	384			1712,4	0,0	5,71	Very low	0,09
9	Chartak	37527				221	4192	170	4583	0,0	12,21	Very low	0,81
10	Chust	93749		96	250,3	331	22664,8	44822	68164,1	0,1	72,70	Very low	0,93
11	Yangikurgan	53174				284	4186	41	4511	0,0	8,48	Very low	0,95
12	Namangan city	13180				8			8	0,0	0,06		
	Total:	743944	10000	1096	15760,4	13363	36727,8	45472	122419,2	11096	122419,2		
		100	1,34	0,14	2,11	1,79	4,93	6,11	16,4 %	1.48%	16,4 %		
	For Andijan Region:												
1	Andijan	36915			869,10	240		383.4	1492,5	0,0	4,04	Very low	0,57
2	Asaka	28300				190			190	0,0	0,67	Very low	0,54
3	Baliqchi	33892			2032,90	285		650,4	2968,3	0,0	8,75	Very low	0,19
4	Buston	20047				424			424	0,0	2,11	Very low	0,04

5	Buloqboshi	18896				227			227	0,0	1,20	Very low	0,59
6	Jalaquduq	36865			666	160	8257,5	237,8	9321,3	0,0	25,28	Very low	0,50
7	Izboskan	28254			355,90	386		123,6	865,5	0,0	3,06	Very low	0,19
8	Kurgantepa	47524			779,50	556	1683	6182,2	9200,7	0,0	19,36	Very low	0,27
9	Marhamat	30536				98	4079		4177	0,0	13,67	Very low	0,57
10	Oltinkul	22170			971,40	120		307,4	1398,8	0,0	6,30	Very low	0,15
11	Pakhtaabad	25999			533,50	75		217	825,5	0,0	3,17	Very low	0,18
12	Ulugnor	35669			445,2	662		96,5	1203,7	0,0	3,37	Very low	0,15
13	Khojaabad	22886				39	11284		11323	0,0	49,47	Very low	0,81
14	Shahrihan	33458				92			92	0,0	0,27	Very low	0,22
15	Khanabad city	2338			133,20	125		140,4	398,6	0,0	17,04		
16	Andijan city	6554				188			188	0,0	2,86		
	Total:	430303	0,00	0,00	6836,2	3867	25303,5	8338,7	44300,4	0	44300,4		
		100	0,00	0,00	1,58	0,89	5,88	1,93	10,2 %	0%	10,2 %		
	For Fergana Region:												
1	Bagdad	42095		-	450,4	355	-	-	805,4	0,0	1,91	Very low	0,21
2	Besharik	78533		-	1874,6	2616	2195,9	4485.0	11171,5	0,0	14,22	Very low	0,80
3	Buvayda	32562		8,5	40,5	136	-	-	185	0,02	0,56	Very low	0,14
4	Dangara	45802		-	1480,1	4508	-	384	6372,1	0,0	13,91	Very low	0,45
5	Yozyovon	35937		1735,19	867,1	2407	-	2500	7594,5	4,82	21,13	Medium	0,54
6	Altyaryk	40090		22,22	1459,6	532		-	2013,82	0,05	5,02	Very low	0,40
7	Qoshtapa	39947		142,5	833,3	938	-	-	1913,8	0,35	4,79	Low	0,10
8	Rishton	42179			729,7	314	-	-	1043,75	0,0	2,47	Very low	0,21
9	Sokh	22073			-	168	-	-	168	0,0	0,76	Very low	1,26
10	Toshloq	28040			639,0	149	-	-	788,5	0,0	2,81	Very low	0,18

11	Uchkuprik	37226			-	188	3264,9	-	3452,9	0,0	9,27	Very low	0,22
12	Fergana	61270			473,2	143	12427	-	13043,75	0,0	21,28	Very low	0,85
13	Furqat	30433			424,5	971	-	-	1395,5	0,0	4,58	Very low	0,16
14	Uzbekistan	77011			-	726	13649	-	14375	0,0	18,66	Very low	1,09
15	Kuva	43678		39,5	2029,74	117	-	2400	4586,24	0,09	10,50	Very low	0,55
16	Fergana city	10520			45,6	173	-	-	224,12	0,00	2,13		
17	Kuvasay city	25467			394.1	88	4609,6	-	5091,7	0,0	19,99		
18	Margilan city	3888			34,4	35	-	-	69,4	0,0	1,78		
19	Kokand city	3710			-	-	-	-	0,07	0,0	0,001		
	Total	675900	0,00	1947,91	11849,1	14564	36146,4	9769	74295,05	1947,91	74295,05		
		100	0,00	0,29	1,69	2,079	5,1	1,39	10,6 %	0,29%	10,6 %		

** Protected areas of IUCN Categories I, II, III, and IV, as well as protected forests, are considered separately. **NP - Natural Parks; SMP - State Natural Monuments; WPZ -Water protection zones; LFF-Lands of the forest fund; SWFZ & GWFZ - Surface and groundwater formation zones; FZ - Fishery zones.*

In the Uzbek part of the Fergana Valley, CCNG values range from 0.04 to 1.32. The CCNG distribution is as follows: very high in Sokh, Pop, and Uzbekistan districts; high in Yangikurgan and Chust districts; and moderate in Fergana, Chortok, Khojaabad, Besharyk, and Kosonsoy districts (Fig. 1). In districts with very high and high CCNG values, there is potential for establishing PNAs of Categories I–IV. Considering the specific characteristics of the Fergana Valley, in districts with low and very low CCNG values it is recommended to establish new PNAs or expand existing ones by utilizing certain land categories with low economic efficiency and reserve lands.

This approach enables the creation of PNAs with a strict protection regime (natural monuments, micro-reserves, natural parks, state nature reserves) ranging in size from 10 ha to 10,000 ha or more. The analysis demonstrates that the coverage index of biological and landscape diversity does not reach an optimal level across administrative-territorial units and natural geographical regions [3]. Consequently, the necessity of a geoecological approach to the systematic formation of the existing PNA network in the Fergana Valley is substantiated, and proposals and recommendations for its improvement are developed.

4 Conclusion

Systemic Assessment and Identified Deficits. Despite the fact that the national PNA coverage indicator in Uzbekistan has exceeded 14%, a critical imbalance persists within the regions of the Fergana Valley. The analysis shows that the existing networks in the Andijan, Fergana, and Namangan regions lack sufficient representativeness. The main challenges include a severe deficit of strictly protected areas, fragmentation of the ecological framework, and the absence of functional connections (corridors) between conservation sites. The current coverage index does not ensure long-term geoecological stability of the region.

Micro-Reserve Strategy and Geological Heritage. To achieve the target value of 17% under conditions of high anthropogenic pressure in the Fergana Valley, the priority vector should be the creation of a network of small protected areas (micro-reserves) ranging from 10 to 500 ha. Special emphasis is placed on the establishment of geological reserves and natural monuments. In districts with a high conservation coefficient (CCNG), such as Sokh and Pop, the identification of unique stratotypes and tectonic outcrops will strengthen the PNA framework without the withdrawal of extensive agricultural lands. This approach not only preserves the landscape foundation but also creates an innovative educational platform where theoretical geological knowledge is reinforced through field-based training at protected natural reference sites.

Quantitative Targets and Cadastral Registration. Optimization of the PNA network requires expanding the protected area fund to at least 12% of the total area of each valley region. To achieve this, it is necessary to additionally allocate and register in the state cadastre 10.5% of land in Namangan region, 11.8% in Fergana region, and 12.0% in Andijan region. The prospective development plan should include the establishment of two state nature reserves, five national natural parks, and an expanded network of six reserves and five micro-reserves, including geological sites. Such a comprehensive approach will transform the PNA system from a narrowly biological model into a multifunctional geoecological system that meets the objectives of sustainable development and high-quality natural science education.

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