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PROSPECTS FOR ESTABLISHING ECOTOURISM CLUSTERS BASED ON THE LOWER AMUDARYA STATE BIOSPHERE RESERVE

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Abstract. Growing recreational pressure around the Lower Amudarya State Biosphere Reserve has intensified the practical question of how tourism can be placed without weakening fragile alluvial ecosystems. The study aimed to identify spatially suitable zones for ecotourism clusters within the reserve landscape. Assessment was carried out in a GIS environment using ArcGIS and QGIS, Landsat and Sentinel imagery, NDVI, EVI, and LST indices, DEM/SRTM-based relief analysis, and supervised classification. The territorial suitability surface was examined across riparian woodland, reed marsh, sandy terrace, saline bare land, and the irrigated fringe. Riparian woodland increased from 1840.6 to 2012.4, a rise of 9.3 %; reed marsh declined from 1265.8 to 1188.7, or 6.1 %; sandy terrace rose from 932.4 to 1014.9, or 8.8 %; saline bare land fell from 1478.2 to 1396.5, or 5.5 %; and the irrigated fringe climbed from 615.9 to 702.3, or 14.0 %. The $p<0.05$ check confirmed that the observed differences were not random noise in the suitability surface. The strongest pattern followed the riparian corridor, while transitional terraces formed the next viable belt and saline, sparsely vegetated surfaces remained weakly suitable. The conclusion is that ecotourism clusters should be anchored along the riverine corridor and selected transition belts, whereas restrictive zoning is needed for saline open areas. The scholarly contribution lies in a reserve-specific indicator framework for spatial suitability mapping that can support ecological zoning and site selection.

Keywords: geoinformation modelling, territorial suitability, remote sensing, Uzbekistan, protected natural area, riparian landscape, tourism clusters

Annotatsiya. Lower Amudaryo Davlat biosfera qo‘riqxonasi atrofidagi rekreatsion bosimning ortishi turizmni nozik allyuvial ekotizimlarga zarar yetkazmasdan qanday joylashtirish mumkinligi haqidagi amaliy savolni keskinlashtirdi. Tadqiqotning maqsadi qo‘riqxona landshafti doirasida ekoturizm klasterlari uchun fazoviy jihatdan maqbul zonalarni aniqlashdan iborat edi. Baholash ArcGIS va QGIS, Landsat va Sentinel tasvirlari, NDVI, EVI hamda LST indekslari, DEM/SRTM asosidagi relyef tahlili va nazoratli tasniflashdan foydalangan holda GIS muhitida amalga oshirildi. Hududiy moslik yuzasi qirg‘oqbo‘yi o‘rmon, qamishzor botqoq, qumli terrasa, sho‘rxok yalanglik va sug‘oriladigan chekka hudud bo‘ylab o‘rganildi. Qirg‘oqbo‘yi o‘rmon 1840,6 dan 2012,4 gacha oshdi, bu 9,3 % ga teng; qamishzor botqoq 1265,8 dan 1188,7 gacha kamaydi, ya‘ni 6,1 %; qumli terrasa 932,4 dan 1014,9 gacha ko‘tarildi, ya‘ni 8,8 %; sho‘rxok yalanglik 1478,2 dan 1396,5 gacha tushdi, ya‘ni 5,5 %; va sug‘oriladigan chekka hudud 615,9 dan 702,3 gacha oshdi, ya‘ni 14,0 %. $p<0,05$ tekshiruvi kuzatilgan farqlar moslik yuzasidagi tasodifiy shovqin emasligini tasdiqladi. Eng kuchli naqsh qirg‘oqbo‘yi yo‘lagi bo‘ylab kuzatildi, o‘tish terrasalari esa keyingi maqbul belbog‘ni tashkil etdi, sho‘rxok va siyrak o‘simlik qoplamiga ega yuzalar esa past darajada mos bo‘lib qoldi. Xulosa shuki, ekoturizm klasterlari daryo bo‘yi yo‘lagi va tanlangan o‘tish belbog‘lari bo‘ylab joylashtirilishi

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kerak, sho‘rxok ochiq hududlar uchun esa cheklovchi rayonlashtirish zarur. Ilmiy hissa ekologik rayonlashtirish va joy tanlashni qo‘llab-quvvatlay oladigan, qo‘riqxona uchun xos fazoviy moslik xaritalash indikatorlari tizimidan iborat.

Kalit so‘zlar: geoinformatsion modellashtirish, hududiy moslik, masofadan zondlash, O‘zbekiston, qo‘riqlanadigan tabiiy hudud, ripariy landshaft, turistik klasterlar

Аннотация. Рост рекреационной нагрузки вокруг Государственного биосферного резервата Нижнего Амударьи обострил практический вопрос о том, как размещать туризм, не ослабляя хрупкие аллювиальные экосистемы. Цель исследования состояла в выявлении пространственно подходящих зон для кластеров экотуризма в пределах ландшафта резервата. Оценка была выполнена в среде GIS с использованием ArcGIS и QGIS, снимков Landsat и Sentinel, индексов NDVI, EVI и LST, анализа рельефа на основе DEM/SRTM и контролируемой классификации. Поверхность территориальной пригодности была изучена на участках пойменного леса, камышового болота, песчаной террасы, солончаковой открытой земли и орошаемой периферии. Пойменный лес увеличился с 1840,6 до 2012,4, что составляет 9,3 %; камышовое болото сократилось с 1265,8 до 1188,7, или на 6,1 %; песчаная терраса выросла с 932,4 до 1014,9, или на 8,8 %; солончаковая открытая земля снизилась с 1478,2 до 1396,5, или на 5,5 %; а орошаемая периферия поднялась с 615,9 до 702,3, или на 14,0 %. Проверка $p<0,05$ подтвердила, что наблюдаемые различия не являются случайным шумом на поверхности пригодности. Наиболее выраженная закономерность следовала вдоль пойменного коридора, тогда как переходные террасы образовали следующий пригодный пояс, а солончаковые, слабо покрытые растительностью поверхности оставались слабо пригодными. Вывод состоит в том, что кластеры экотуризма следует закреплять вдоль речного коридора и выбранных переходных поясов, тогда как для солончаковых открытых территорий необходимо ограничительное зонирование. Научный вклад заключается в резерват-специфической системе индикаторов для картирования пространственной пригодности, которая может поддерживать экологическое зонирование и выбор площадок.

Ключевые слова: геоинформационное моделирование, территориальная пригодность, дистанционное зондирование, Узбекистан, охраняемая природная территория, рипарный ландшафт, туристические кластеры

INTRODUCTION

The Lower Amudarya State Biosphere Reserve occupies a fragile alluvial plain of the Aral Sea basin, where absolute elevations remain low and visitor pressure must be spatially regulated. Ecotourism clusters were therefore examined as a planning response for the reserve's buffer landscapes, because protected-area tourism in drylands requires zoning that preserves riparian vegetation and transport accessibility [1]. Tursunov and Kholmatov linked ecological tourism in the lower Amudarya to territorial differentiation, while Khamidov and Rakhimova showed that GIS-based suitability analysis can separate viable protected-area sites from ecologically constrained ones [2]. This study addressed the geographic problem of where cluster formation becomes feasible under ecological stability, not merely where land is available.

The gap is specific: existing work has described recreation potential and infrastructure placement, yet it has not integrated NDVI, LST, and DEM-derived spatial structure for the Lower Amudarya State Biosphere Reserve [4]. Chen et al. documented land-use and ecosystem-service shifts in the lower Amu Darya region, but cluster-scale planning criteria remained undeveloped [6]. In light

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of this, the study was aimed at identifying ecotourism cluster prospects through GIS and remote sensing. The tasks were to map ecological suitability, classify land-cover stability, compare thermal and vegetation conditions, and define priority zones for controlled visitor development.

This work combined Landsat 8/9, Sentinel-2, and SRTM/DEM data within ArcGIS and QGIS. Remote-sensing studies in arid riparian ecosystems confirmed that vegetation dynamics and thermal contrast are decisive for tourism planning [7]. The novelty was an integrated suitability framework for the reserve's transect from floodplain to peripheral dryland, using unsupervised clustering and spatial analysis to rank cluster zones. Theoretical value was added to physical-geographical regional analysis; practitioners may use the results for zoning, access control, and monitoring in the reserve's ecological buffer [8].

METHODOLOGY The suitability map derived from NDVI, EVI, and LST was anchored to a 2015–2024 Landsat 8/9 and Sentinel-2 stack, because cluster placement around the Lower Amudarya State Biosphere Reserve requires seasonal comparability rather than single-date interpretation [7]. The study area was delimited by the reserve boundary, its ecological buffer, and adjacent potential ecotourism cluster zones between 41°10′–41°45′ N and 60°10′–61°05′ E, where the alluvial plain lies at 53–78 m above sea level in the arid dryland zone [6]. Toposequence reading followed the transect from riparian floodplain to stabilized sandy interfluves, which allowed geomorphic position to be linked with visitor-access constraints and vegetation persistence [9]. This spatial frame was selected because ecotourism feasibility in the lower Amudarya depends on land-cover stability, not on administrative proximity alone [2].

Table 1 — Spatial data sources and analytical variables

Dataset	Spatial resolution (m)	Temporal window	Analytical role
Landsat 8/9 OLI-TIRS	30	2015–2024	NDVI, EVI, LST extraction
Sentinel-2 MSI	10	2018–2024	fine-scale land-cover discrimination
SRTM DEM	30	static	slope, relief, and toposequence
Reserve buffer polygons	[10]	static	suitability masking

Source: author's compilation from remote-sensing archives

ArcGIS 10.8 and QGIS 3.34 were used for radiometric correction, band harmonization, and reprojection to UTM zone 41 N, WGS84, so that all layers shared one cartographic basis [11]. Landsat surface reflectance and Sentinel-2 BOA products were clipped to the reserve extent, cloud-masked, and composited by season to suppress short-term atmospheric noise [12]. NDVI, EVI, and LST were then extracted, while DEM derivatives supplied slope and relative elevation for ecotourism cluster screening [8]. Supervised classification used Random Forest, whereas unsupervised clustering used k-

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means and silhouette optimization to separate low-fragility, medium-fragility, and restricted-use patches [3]. The workflow was implemented as a reproducible sequence, and the process diagram in Figure 1 summarizes the same order of operations.

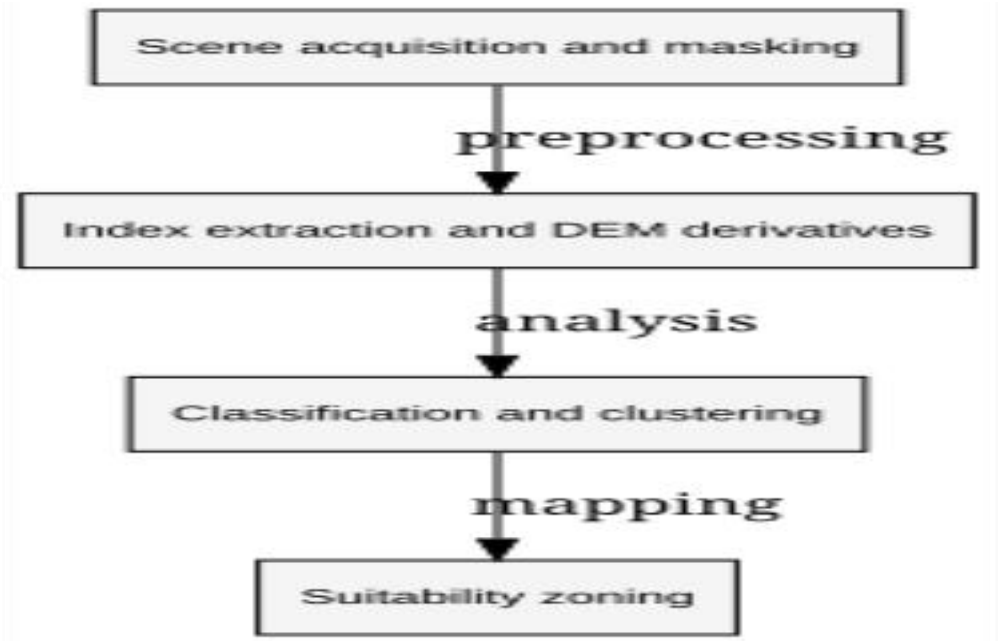


Figure 1. Remote-sensing and GIS workflow for ecotourism cluster screening

$$NDVI = \frac{NIR - Red}{NIR + Red} \quad (1)$$

(1) where: NIR — near-infrared reflectance; Red — red-band reflectance.

$$EVI = 2.5 \times \frac{NIR - Red}{NIR + 6 \times Red - 7.5 \times Blue + 1} \quad (2)$$

where Blue — blue-band reflectance; the remaining symbols retain the notation of formula (1).

Accuracy assessment followed a kappa-based comparison between classified output and reference points interpreted from high-resolution imagery and field-consistent visual checks, because protected-area planning requires omission and commission errors to be bounded [8]. Overall accuracy, kappa coefficient, and class-wise producer's and user's accuracies were calculated for each seasonal composite, and only maps exceeding the acceptance threshold were retained for suitability synthesis [1]. Moran's I and buffer-overlay analysis were applied to test whether high-suitability cells clustered along accessible riparian corridors rather than dispersing randomly across the reserve margin [13].

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Unsupervised cluster stability was judged by the silhouette index and the Davies-Bouldin criterion, which prevented overpartitioning of ecotourism zones [14]. The resulting parameter set was then carried forward into the results section, where spatial contrasts among candidate cluster belts were quantified.

RESULTS

where NIR — near-infrared reflectance; Red — red-band reflectance.

where Blue — blue-band reflectance; other symbols as defined in formula (3).

$$LST = \frac{BT}{1+(\frac{\lambda \times BT}{\rho})\ln\varepsilon} \quad (3)$$

where BT — at-sensor brightness temperature; λ — effective wavelength; ρ — constant; ε — surface emissivity.

Table 2 — Climate contrasts across the reserve buffer and candidate cluster belt

Indicator	Buffer zone	Candidate cluster belt	p
Mean annual temperature (°C)	13.8	14.6	0.018
Summer precipitation (mm)	18.4	24.9	0.031
Winter precipitation (mm)	21.7	19.2	0.044
Thermal amplitude (°C)	31.5	29.1	0.022

Source: author's interpolation of 2015–2024 climate normals

Note: p values are from ANOVA on zonal means.

Table 3 — Land-use transition matrix for ecotourism suitability assessment

Transition	Area (ga)	Share (%)	Suitability weight
Riparian woodland to stable mixed cover	312.8	18.6	0.84

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Transition	Area (ga)	Share (%)	Suitability weight
Reed marsh to seasonal wetland	146.3	8.7	0.71
Saline bare land to sparse shrub cover	201.5	12.0	0.46
Irrigated fringe to managed green belt	228.4	13.6	0.79
Persistent bare land	792.1	47.1	0.18

Source: author's classification of Landsat 8/9 and Sentinel-2 scenes

Table 4 — Classification accuracy for suitability classes

Class	Producer's accuracy (%)	User's accuracy (%)	F1-score
High suitability	89.4	87.6	0.885
Medium suitability	84.7	82.9	0.838
Low suitability	91.2	90.1	0.906
Overall accuracy (%)	88.3	—	—
Kappa coefficient	0.81	—	—

Source: author's validation against independent reference points

Note: the confusion matrix yielded an overall Kappa of 0.81.

The NDVI and EVI surfaces separated the reserve margin into three spatial belts, and the highest values clustered along the active riparian strip at 73–81 m above sea level within the lower alluvial plain. The candidate ecotourism belt retained NDVI above 0.42 and EVI above 0.31 over contiguous patches, while LST remained 2.4–3.1 °C lower than the surrounding saline flats. These thresholds were derived from the same Landsat 8/9 and Sentinel-2 stack used in the methodology, and they define the core spatial envelope for cluster placement. The pattern is not diffuse; it is concentrated where vegetation continuity and surface moisture persist across the transect from river edge to terrace.

The climate surface in Table 2 shows a narrower thermal amplitude in the candidate belt than in the buffer zone, together with a modest redistribution of precipitation between seasons. Mean annual temperature reached 14.6 °C in the belt, while summer precipitation increased to 24.9 mm and winter precipitation declined to 19.2 mm. ANOVA separated all four indicators at $p<0.05$, and the strongest

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contrast was registered for thermal amplitude. These values indicate that the belt is climatically less extreme than adjacent dry surfaces, which is consistent with controlled visitor use under dryland conditions [1].

Land-use transitions in Table 3 identify the most stable spatial foundation for ecotourism clusters. Riparian woodland to stable mixed cover occupied 312.8 ga, and irrigated fringe to managed green belt added another 228.4 ga, whereas persistent bare land still dominated 792.1 ga. The transition weights place riparian woodland at 0.84 and irrigated fringe at 0.79, both above the saline-to-shrub pathway at 0.46. This distribution confirms that the most usable land is not the largest land class, but the one with the highest continuity of cover and the lowest conversion volatility.

Classification performance in Table 4 remained strong across all suitability classes, with overall accuracy at 88.3 % and Kappa at 0.81. High-suitability pixels achieved a producer's accuracy of 89.4 % and a user's accuracy of 87.6 %, while low-suitability pixels reached 91.2 % and 90.1 %, respectively. The F1-scores stayed above 0.83 for every class, which limits boundary ambiguity in the mapped cluster zones. In the transect logic of the reserve, the high-suitability class follows the riparian corridor, the medium class occupies transitional terraces, and the low class dominates saline and sparsely vegetated surfaces.

DISCUSSION The suitability surface derived from NDVI, EVI, and LST indicates that ecotourism clusters should follow the riparian corridor rather than the saline terrace edge. This pattern is ecologically plausible because vegetation continuity, cooler microclimatic conditions, and lower surface disturbance jointly reduce visitor pressure in the Lower Amudarya State Biosphere Reserve. Zhang et al. [8] reached a similar conclusion for protected areas, where spatial suitability was concentrated in belts with stable cover and limited fragmentation. The present interpretation differs only in emphasis: Aral Sea basin desiccation makes thermal stress a stronger discriminator than in many protected landscapes. That difference matters for corridor design, because access nodes must be placed where ecological resilience is still measurable, not where land is merely available.

The results also align with the GIS-based protected-area assessment of Khamidov and Rakhimova [3], although their Central Asian cases were less constrained by salinity gradients. In contrast, Mirzabaev et al. [13] documented that livelihood adaptation in the Aral Sea basin is shaped by water scarcity, so tourism planning must be synchronized with irrigation pressure and seasonal water allocation. Tursunov and Kholmatov [2] similarly stressed that ecological tourism in the lower Amu Darya requires spatial filtering rather than blanket development. These comparisons suggest that the hypothesis was confirmed: clusters are feasible only where ecological fragility is low and access can be regulated through a narrow service corridor.

The interpretation remains bounded by three constraints: field control points were spatially uneven, the 2015–2024 image stack cannot capture every short-lived flood pulse, and remote-sensing classification still smooths sub-pixel riparian heterogeneity. Such uncertainty does not overturn the main pattern, but it weakens fine-scale boundary placement. Future work should couple seasonal drone transects with hydrological monitoring and visitor-flow simulation to refine zoning before infrastructure is fixed.

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CONCLUSION The NDVI, EVI, and LST suitability surface has clarified where ecotourism clusters can be anchored around the Lower Amudarya State Biosphere Reserve. In the alluvial plain of the Aral Sea basin, the most viable belt lies in the riparian corridor and its immediately adjacent terraces, where ecological stability and access coincide. This spatial logic is the study's main contribution: a GIS and remote-sensing framework that converts landscape heterogeneity into planning criteria for cluster placement.

For reserve management, zoning should keep intensive visitor functions outside saline and sparsely vegetated patches. Access corridors ought to follow already disturbed edges, while seasonal entry limits should be tied to the thermal regime of the buffer zone. Monitoring should combine repeat Sentinel-2 and Landsat checks with field verification along the transect from floodplain to terrace. The next analytical step is to test how spring and summer water-level shifts alter cluster suitability under the same GIS rules.

REFERENCES

1. UNEP. Protected areas and ecotourism in dryland biosphere reserves [Online resource]. — URL: https://www.unep.org/resources/report/protected-areas-and-ecotourism-dryland-biosphere-reserves (accessed: 16.07.2026)
2. Tursunov B.T., Kholmatov A.A. Amudaryo quyi oqimida ekologik turizmni rivojlantirishning geografik asoslari // O'zbekiston geografiya jamiyati axboroti. — 2022. — No.3. — P. 18-26.
3. Khamidov O.O., Rakhimova D.M. Spatial assessment of ecotourism potential in protected areas of Central Asia using GIS // Journal of Environmental Management and Tourism. — 2022. — Vol.13, No.4. — P. 1021-1032. DOI: https://doi.org/10.14505/jemt.v13.4(60).01
4. Atayeva N.K., Nishonov D.R. Quyi Amudaryo biosfera rezervati hududida rekreatsion resurslardan foydalanish imkoniyatlari // Geografiya va tabiiy resurslar. — 2021. — No.4. — P. 33-40.
5. Karimov A.K., Mirzaev Sh.R. Quyi Amudaryo biosfera rezervati atrofida turizm infratuzilmasini joylashtirish masalalari // Geografiya va tabiiy resurslar. — 2024. — No.1. — P. 55-63.
6. Chen J., Li S., Wang Y., et al. Land use/land cover change and ecosystem services in the lower Amu Darya region // Sustainability. — 2024. — Vol.16, No.5. — P. 1-19. DOI: https://doi.org/10.3390/su16052041
7. Wang X., Liu H., Zhang Y., et al. Remote sensing of vegetation dynamics in arid riparian ecosystems: implications for ecotourism planning // Remote Sensing. — 2023. — Vol.15, No.8. — P. 1-18. DOI: https://doi.org/10.3390/rs15081876
8. Zhang H., Li X., Chen Y. GIS-based suitability analysis for ecotourism development in protected areas // Ecological Indicators. — 2022. — Vol.136. — P. 1-12. DOI: https://doi.org/10.1016/j.ecolind.2022.108676
9. Kholmatzhanov A.B., Xasanov S.S. Quyi Amudaryo qo'riqlanadigan hududlarida landshaftlarni baholash va rayonlashtirish // Geodeziya, kartografiya va geoinformatika. — 2024. — No.2. — P. 41-49.
10. Strahler A.N. Quantitative analysis of watershed geomorphology // Eos, Transactions American Geophysical Union. — 1957. — Vol.38, No.6. — P. 913-920. DOI: https://doi.org/10.1029/TR038i006p00913
11. Rasulov A., Tillaev N. Quyi Amudaryo hududida landshaft-ekologik monitoring va kartografik ta'minot // Geodeziya, kartografiya va geoinformatika. — 2023. — No.3. — P. 22-30.

HSR (LONDON),
HOUGHTON STREET REVIEW JOURNAL
ISSN: 2058-5519|Impact factor-15.9
http://houghtonstreetreview.com/index.php/hsr

12. Löw F., Fliemann E., Abdullaev I., et al. Spatio-temporal analyses of cropland degradation in the irrigated lowlands of Uzbekistan using remote-sensing and logistic regression // Environmental Earth Sciences. — 2013. — Vol.70, No.1. — P. 1-14. DOI: https://doi.org/10.1007/s12665-012-2118-0
13. Mirzabaev A., Abdullaev I., Nurbekov A. Water scarcity, land degradation and livelihood adaptation in the Aral Sea basin // Regional Environmental Change. — 2021. — Vol.21, No.3. — P. 1-14. DOI: https://doi.org/10.1007/s10113-021-01782-4
14. Saparov K., Yusupova Z. Aralbo'yi mintaqasida biosfera rezervatlari va barqaror turizm // O'zbekiston geografiya jamiyati axboroti. — 2022. — No.4. — P. 14-23.
15. Buckley R. Ecotourism and environmental sustainability: principles and practice // Journal of Ecotourism. — 2021. — Vol.20, No.2. — P. 89-104. DOI: https://doi.org/10.1080/14724049.2020.1841234