Geospatial assessment of sustainable ecotourism potential in the Naryn Region, Kyrgyz Republic

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Abstract. Sustainable ecotourism has emerged as an important strategy for balancing environmental conservation and regional socio-economic development, particularly in ecologically sensitive mountain regions. The Naryn Region of the Kyrgyz Republic possesses substantial ecotourism potential due to its high-altitude landscapes, rich biodiversity, alpine ecosystems, and cultural heritage. However, spatially explicit assessments of ecotourism suitability in Central Asian mountain environments remain limited. This study aims to identify and evaluate suitable areas for sustainable ecotourism development in the Naryn Region using a Geographic Information System (GIS)-based weighted overlay approach integrated with Earth observation and remote sensing data. Seven thematic criteria were incorporated into the spatial analysis, including elevation, land use and land cover (LULC), proximity to water bodies, transportation accessibility, protected areas, human settlements, and cultural heritage sites. Open-access geospatial datasets derived from Sentinel-2 imagery, SRTM digital elevation models (30 m), HydroSHEDS, OpenStreetMap, and field-based GPS observations were processed and standardized within a multi-criteria decision analysis framework in ArcGIS Pro. Criterion weights were assigned according to their relative importance for ecotourism suitability in mountainous environments. The resulting suitability map was classified into five categories ranging from very low to very high suitability. Moderate suitability areas dominate the region, covering approximately 51.49% of the total area, followed by high suitability zones (43.50%), while very high suitability areas account for 1.52%. Areas with high ecotourism potential are primarily concentrated near water bodies, protected areas, transportation networks, and cultural heritage locations. The findings demonstrate the effectiveness of GIS-based spatial modelling for identifying ecotourism development opportunities and provide a practical decision-support framework for sustainable tourism planning and environmental management in fragile mountain ecosystems.

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1 Introduction

Mountain tourism is widely recognized as a rapidly growing segment of global tourism, involving travel to mountainous and highland areas for recreation, adventure, and nature-based experiences. It is closely associated with unique physical landscapes, biodiversity, and cultural heritage, which make mountain regions highly attractive for tourism development. Mountains are considered particularly important tourism destinations due to their aesthetic value, cultural and spiritual significance, and their role as spaces for emotional experiences in non-urban environments [1]. Mountain tourism is generally defined as travel to hilly or mountainous areas for leisure or adventure-seeking activities [2].

Within this context, ecotourism has emerged as a key component of sustainable tourism development, grounded in the principles of environmental conservation, socio-cultural integrity, and economic sustainability [3, 4]. It is based on sustainable development theory, which emphasizes meeting present needs without compromising the ability of future generations to meet their own needs, as well as on alternative tourism approaches developed in response to conventional tourism models. In the literature, ecotourism is commonly defined as nature-based tourism that includes recreational, educational, cultural, and adventure-oriented activities such as wildlife observation, camping, and exploratory travel [5]. It emphasizes responsible use of natural resources, biodiversity conservation, environmental education, and active participation by local communities in tourism development and benefit-sharing processes [6]. Although ecotourism is widely recognized as a sustainable development strategy for environmentally sensitive mountain regions, its effectiveness depends on spatially informed planning and community acceptance [7]. However, it remains a multidimensional and context-dependent concept with varying interpretations across studies.

Despite the growing body of literature on mountain tourism and ecotourism, spatially explicit studies remain limited in Central Asia, particularly in the Kyrgyz Republic. Most existing research focuses on well-established mountain regions such as the Himalayas, the Alps, and the Andes, while the ecotourism potential of the Tien Shan mountain system remains insufficiently explored. This highlights the need for integrated spatial approaches that combine environmental, physical, and socio-economic factors to support sustainable tourism planning in fragile mountain environments [8, 9].

In this context, GIS and remote sensing technologies have become essential tools for spatial analysis and decision-making in tourism planning. Multi-criteria decision analysis, including the weighted overlay method, is widely applied to evaluate tourism suitability by integrating multiple spatial variables such as elevation, land use, accessibility, population density, and proximity to natural and cultural resources [9]. Recent studies demonstrate the effectiveness of GIS-based multi-criteria decision analysis approaches in identifying suitable zones for ecotourism development in mountainous regions [8, 10].

Therefore, this study aims to identify and map potential areas for sustainable ecotourism development in the Naryn Region of the Kyrgyz Republic using GIS-based weighted overlay analysis and Earth observation data. The study addresses the existing spatial research gap in Central Asian mountain regions by integrating environmental and socio-economic indicators within a unified spatial decision-making framework. The results are expected to support evidence-based planning and sustainable environmental management in fragile mountain ecosystems.

2 Data and methods

2.1 Study area

The Naryn Region is located in the central-eastern part of the Kyrgyz Republic within the Tian Shan mountain system and occupies approximately 23% of the national territory [11]. Geographically, the region extends between approximately 40°00′–42°30′ N latitude and 74°30′–77°30′ E longitude (Figure 1). Naryn is the largest administrative region in the country in terms of territorial extent and is distinguished by the predominance of high-mountain landscapes, including extensive alpine meadows, deep intermountain valleys, plateaus, and rugged terrain.

The region is characterized by a predominantly continental climate, with long and severe winters, short and relatively cool summers, and substantial climatic variability associated with altitudinal gradients. Elevation exerts a strong influence on temperature, precipitation patterns, vegetation distribution, and land-use practices, thereby shaping both environmental conditions and tourism potential across the region.

Socio-economically, the Naryn Region is among the least densely populated areas of the Kyrgyz Republic. Economic activities are primarily based on extensive pastoral livestock husbandry, while agricultural production remains spatially limited and concentrated within valley systems. At the same time, the region contains numerous natural and cultural assets, including high-altitude lakes, mountain pastures, protected areas, nomadic cultural landscapes, and historical heritage sites, which collectively contribute to its considerable ecotourism potential. Due to its combination of ecological sensitivity, relatively intact mountain ecosystems, and growing tourism opportunities, the Naryn Region represents an important case study for evaluating sustainable ecotourism development using geospatial approaches. Its environmental diversity and infrastructural limitations make the region particularly suitable for GIS-based suitability assessment and spatial decision-making analyses.

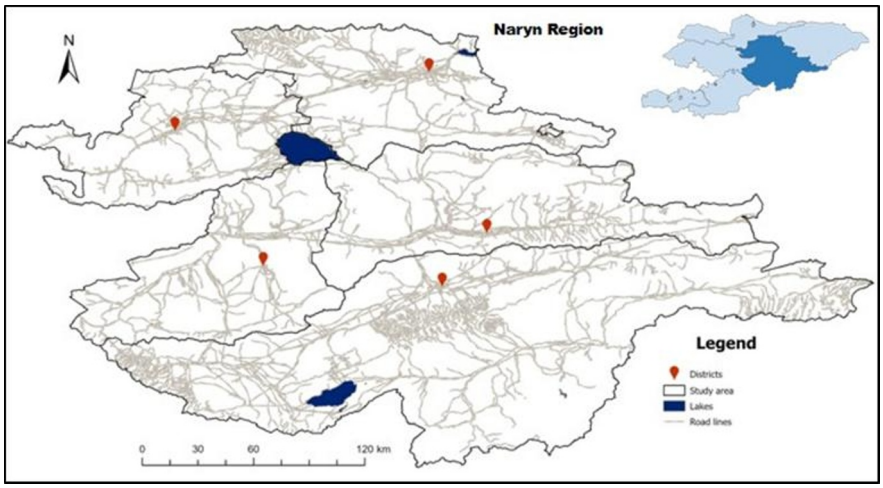

Fig. 1. Study area: Naryn Region, Kyrgyz Republic.

2.2 Data collection

This study integrates multiple geospatial datasets to assess ecotourism suitability in the Naryn Region, Kyrgyz Republic. The spatial database includes elevation, water bodies, LULC,

transportation accessibility, proximity to human settlements, protected areas, and cultural heritage sites. All datasets were obtained from open-access sources, including GADM, HydroSHEDS, Sentinel-2 imagery, SRTM DEM (30 m resolution), OpenStreetMap, and field-based GPS surveys of heritage locations. A summary of datasets is provided in Table 1.

Table 1. Data sources and description.

№	Data and sources	
1	GADM	Boundary Map https://gadm.org
2	HydroSHEDS	HydroRIVERS and hydroLAKES https://www.hydrosheds.org
3	Roads	Kyrgyzstan roads (OpenStreetMap Export) https://data.humdata.org
4	Sentinel-2	ESA's Sentinel Hub https://apps.sentinel-hub.com/eo-browser/
5	DEM (SRTM) (30x30)	USGS Earth Explorer (https://earthexplorer.usgs.gov)
6	Protected Areas	IUCN Kyrgyzstan https://ucncontributionsfornature.org
7	Heritage Sites	Field work

The study applies a GIS-based multi-criteria decision analysis approach using ArcGIS Pro. A weighted overlay analysis was used to integrate multiple spatial criteria into a single ecotourism suitability index. Each thematic layer was standardized to a common scale and assigned a weight reflecting its relative importance for ecotourism development. The final suitability index was generated using the weighted overlay model (Figure 2).

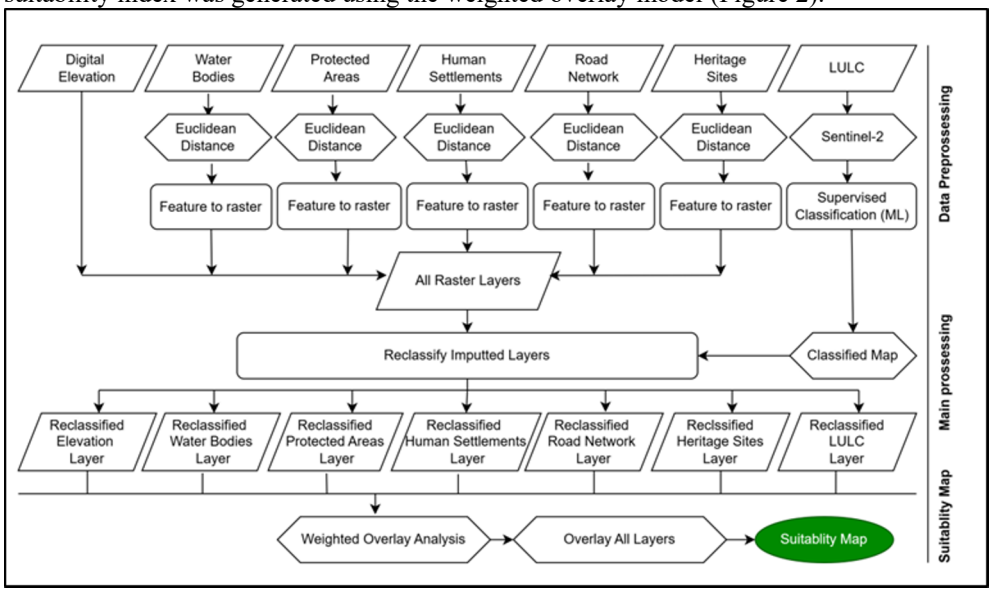

Fig. 2. Methodology for the ecotourism suitability mapping.

2.3 Spatial data preprocessing

Elevation data were obtained from the SRTM DEM (USGS) at 30 m resolution, with values ranging from 1118 to 5600 m. The dataset was reclassified into five categories for standardization. Based on its influence on ecotourism suitability, a weight of 18 was assigned.

Water Bodies significantly influence tourism location patterns due to their aesthetic and recreational value. Euclidean distance analysis was applied to derive proximity to rivers and lakes. The resulting raster was classified into five distance intervals: 0–8 km, 8–15 km, 15–25 km, 25–35 km, and >35 km. A weight of 15 was assigned.

LULC classification was performed using Sentinel-2 Level-2A imagery (2024) in ArcGIS Pro. A supervised classification based on the Maximum Likelihood algorithm was applied. Classification accuracy was assessed using a confusion matrix generated in ArcGIS Pro, based on more than 500 validation points. Overall Accuracy (OA) and the Kappa coefficient (K) were used to evaluate classification performance [12]. The Kappa coefficient was calculated as:

$$K = (Po - Pe) / (1 - Pe)$$

where:
K = Kappa coefficient,
Po = observed agreement,
Pe = expected agreement by chance.
The classification achieved an overall accuracy of 92% and a Kappa coefficient of 0.89, indicating strong agreement between classified and reference data. The final LULC layer was assigned a weight of 16 for the weighted overlay analysis.

Protected Areas are critical for biodiversity conservation and nature-based tourism. Spatial data were obtained from the IUCN database. Euclidean distance analysis was applied and classified into 0–1 km, 1–10 km, 10–20 km, 20–30 km, and >30 km. A weight of 10 was assigned.

Table 2. Protected areas of the Naryn region.

№	Name of Protected area	Area (ha)	IUCN (category)	year established
1	Naryn Protected area	108,023.5	I	1983
2	Karatal-Zhapyryk Protected area	21,016	I	1994
3	Salkyn-Tor National park	10,448	II	2001

Human settlements provide essential infrastructure and services supporting tourism development. The Naryn Region is characterized by a very low level of urbanization and contains only one city, Naryn, while the majority of the population resides in rural settlements (villages). The settlement system is therefore predominantly rural and spatially dispersed.

Settlement data were obtained from administrative sources and OpenStreetMap. Euclidean distance analysis was applied and classified into 0–5 km, 5–15 km, 15–30 km, 30–50 km, and >50 km. A weight of 10 was assigned.

Table 3. Administrative and demographic characteristics of the Naryn Region.

№	Regions	Area (km²)	Number of settlements	Population(thousands)
1	Ak-Talaa	7,266	19	35.1
2	At-Bashy	15,354	18	62.5
3	Kochkor	5,868	35	70.8
4	Jumgal	7,150	30	49.6
5	Naryn	10,502	42	54.2

The road network is a key factor influencing tourism development by improving connectivity and access to destinations. Euclidean distance analysis was used to derive proximity to the road network and classified into 0–1 km, 1–2 km, 2–3 km, 3–4 km, and >4 km. A weight of 11 was assigned.

Cultural heritage sites represent important tourism attractions reflecting historical, archaeological, and cultural values. In this study, heritage sites were identified through field surveys using GPS data and integrated into a GIS environment. Euclidean distance analysis was applied and classified into 0–1 km, 1–10 km, 10–30 km, 30–60 km, and >60 km. A weight of 20 was assigned.

Table 4. Heritage sites of Naryn.

№	Category	Examples	Number of sites	Description
1	Archaeological sites and ancient settlements	Manakeldy, Arpa Valley, Kok-Oy	10	Ancient settlements and archaeological remains
2	Petroglyph complexes	Ak-Tash, Terek-Suu	10	Rock art and prehistoric engravings
3	Fortresses and defensive structures	Koshoy-Korgon, Shyrdakbek, Ak-Muz	6	Medieval military and defensive sites
4	Cultural landscapes and nomadic areas	Song-Kol, Kilemche, Ak-Sai Plateau	8	Pastoral and nomadic land-use areas
5	Caravan routes and Silk Road heritage	Torugart Pass, Kyzart Pass, Moldo-Ashuu	6	Historic trade and transport corridors
6	Museums and religious sites	Naryn Museum, Central Mosque, Kojo-Üngkür	8	Cultural, religious, and heritage institutions

All thematic layers were reclassified into standardized suitability scales using the ArcGIS Pro reclassify tool. This ensured comparability across different spatial variables. The reclassified layers included elevation, water bodies, LULC, human settlements, the road network, protected areas, and cultural heritage sites.

Weighted overlay analysis. The ecotourism suitability map was generated in ArcGIS Pro using the weighted overlay tool within a GIS-based multi-criteria decision analysis framework. Standardized criterion layers were weighted and aggregated to derive the ecotourism suitability map [13].

Spatial suitability mapping. Following the integration of all weighted thematic layers, the final ecotourism suitability map was generated. The resulting output represents a continuous spatial distribution of suitability values across the study area, which was subsequently classified into five categories: very low, low, moderate, high, and very high suitability.

Geospatial data processing and analysis. This study employs a GIS-based multi-criteria approach to assess ecotourism potential in the study area of the Naryn Region. ArcGIS Pro software was used for spatial data processing, analysis, and visualization. The methodology is based on the integration of seven thematic layers representing key environmental and socio-economic factors influencing ecotourism suitability.

The selected criteria include elevation, proximity to water bodies, LULC, human settlements, road accessibility, proximity to protected areas, and cultural heritage sites. These variables were used as input parameters for the spatial analysis, as they significantly affect the distribution and accessibility of potential ecotourism zones.

All spatial datasets were collected, processed, and standardized within ArcGIS Pro. Vector and raster data were converted into comparable formats and reclassified into uniform value scales to ensure compatibility in the analysis. Reclassification was necessary to normalize different data layers and allow for meaningful spatial comparison.

After reclassification, each thematic layer was transformed into a standardized suitability index map. A weighted overlay approach was then applied, in which relative weights were assigned to each criterion according to its importance for ecotourism suitability, based on expert judgment and a literature review. The weights were normalized to sum to 100%, and the weighted layers were integrated to generate a final ecotourism suitability map identifying areas with varying levels of potential for tourism development within the study region.

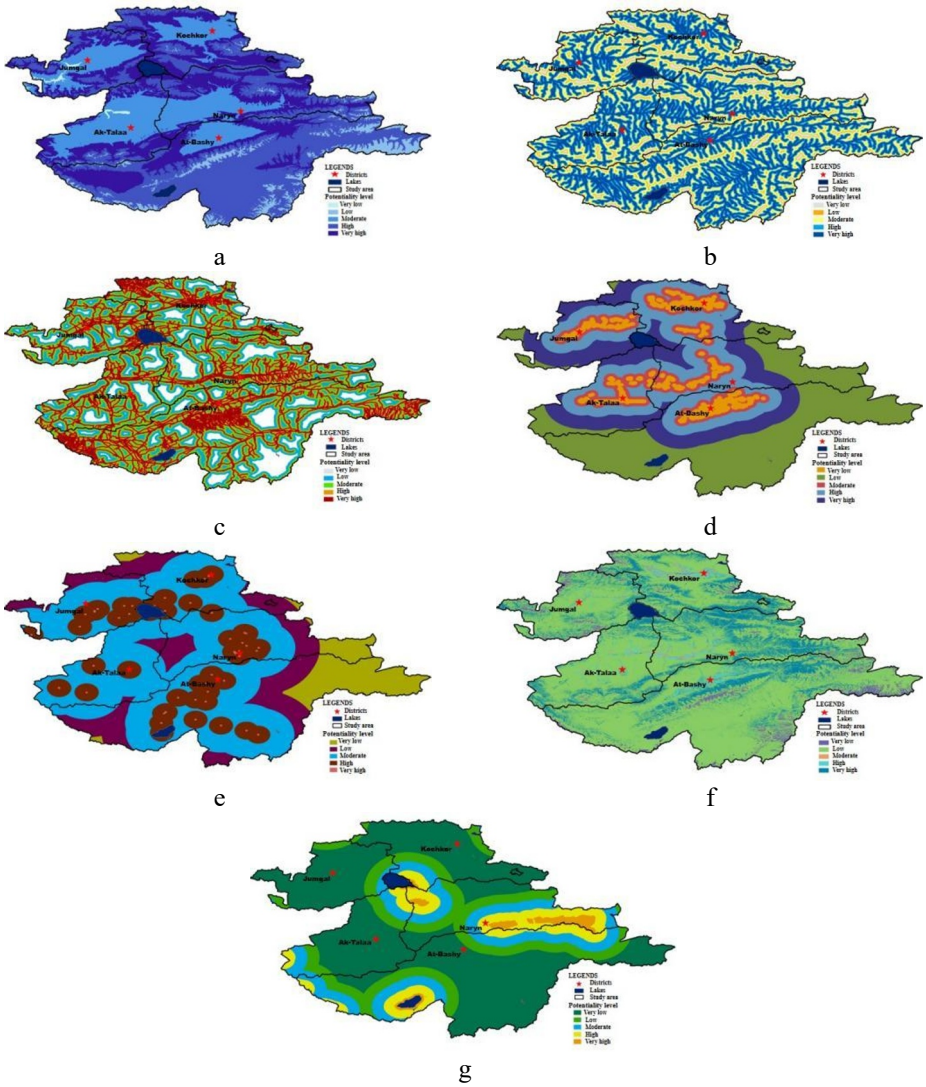

Fig. 3. Thematic maps (Index maps for finding potential ecotourism): a. Elevation, b. Water bodies, c. The road network, d. Human settlements, e. Cultural heritage sites, f. Land use land cover (LULC), g. Protected Areas

3 Results and decision

The spatial analysis of ecotourism suitability in the Naryn Region reveals strong spatial heterogeneity driven by topography, accessibility, and proximity to environmental and cultural resources. The final suitability map classifies the study area into five categories: very high, high, moderate, low, and very low suitability.

The quantitative distribution of suitability classes shows that moderately suitable areas dominate the study region, covering approximately 51.49% of the total area, followed by highly suitable zones (43.50%), while low-suitability areas account for 3.48%. Very low suitability zones represent less than 0.01%, whereas very highly suitable areas occupy the smallest proportion, at approximately 1.52%. This spatial pattern reflects the dominance of

transitional mountainous landscapes characterized by strong altitudinal gradients and rapid changes in environmental conditions over short distances.

Spatially, high and very high suitability zones are concentrated in areas with favorable environmental conditions, particularly near water bodies, protected areas, and cultural heritage sites. These zones collectively represent approximately 45.02% of the region. Similar spatial patterns have been observed in other mountain ecotourism studies, where ecological richness and accessibility strongly influence tourism potential [2]. In contrast, low and very low suitability areas, together covering approximately 3.48%, are mainly associated with steep terrain, high elevation, and limited accessibility. These results are consistent with previous studies highlighting topographic constraints as a major limiting factor for mountain tourism development [14].

Accessibility plays a critical role in spatial suitability distribution. Areas closer to transportation networks and settlements show significantly higher suitability values, confirming that infrastructure availability is a key driver of ecotourism development. Similar findings have been reported in GIS-based tourism suitability studies, where accessibility consistently emerges as one of the most influential variables [9].

From a planning perspective, the dominance of moderate suitability areas (51.49%) indicates that the Naryn Region has substantial but spatially selective ecotourism potential. While high-value zones exist, they are fragmented and require targeted development strategies. This aligns with sustainable tourism principles emphasizing spatial planning and environmental sensitivity in fragile mountain ecosystems [7, 15].

Overall, the results confirm that GIS-based multi-criteria decision analysis provides a robust framework for ecotourism suitability assessment in mountainous environments [9, 15].

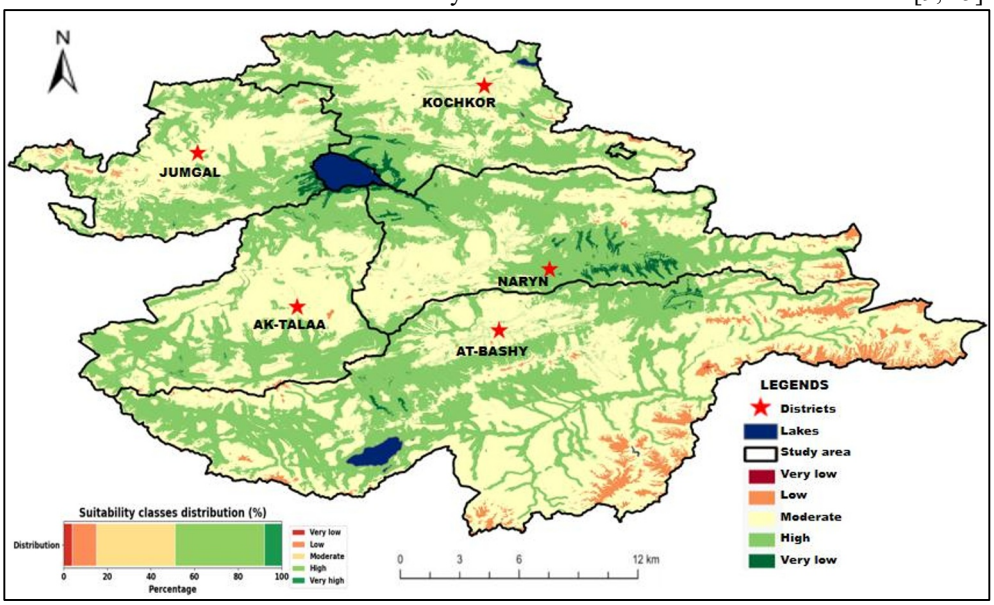

Fig. 4. The suitability map for ecotourism in the Naryn Region, Kyrgyz Republic.

4 Conclusion

This study demonstrated the applicability of integrating Geographic Information Systems (GIS), remote sensing data, and multi-criteria decision analysis to assess ecotourism suitability in the Naryn Region of the Kyrgyz Republic. By incorporating environmental, topographic, accessibility, and cultural heritage variables within a GIS-based weighted

overlay framework, a spatially explicit ecotourism suitability map was successfully developed to identify areas with varying levels of tourism potential. The findings reveal substantial spatial heterogeneity in ecotourism suitability across the study area, reflecting the influence of terrain characteristics, proximity to water resources, human settlements, transportation accessibility, protected areas, and cultural heritage sites. Areas classified as high and very high suitability are predominantly concentrated in environmentally attractive and relatively accessible locations, whereas low suitability zones are mainly associated with mountainous terrain, high elevations, and infrastructural constraints. The predominance of moderate suitability areas further suggests that the region possesses considerable ecotourism potential, although tourism opportunities remain spatially selective and environmentally sensitive.

The study confirms that GIS-based multi-criteria spatial analysis provides a robust and reproducible framework for identifying suitable ecotourism development zones in complex mountain environments. The integration of multiple environmental and socio-economic criteria within a spatial decision-support system contributes to evidence-based tourism planning and supports sustainable land-use management in ecologically fragile regions. From a practical perspective, the generated suitability map may serve as a valuable decision-support tool for policymakers, regional authorities, tourism planners, and environmental managers in prioritizing sustainable tourism investments, ecotourism zoning, and conservation-oriented development strategies. The results may further contribute to balancing tourism development with biodiversity conservation and landscape protection in the Naryn Region.

Despite the strengths of the proposed approach, several limitations should be acknowledged. The study primarily relies on selected environmental and accessibility indicators and does not explicitly incorporate additional terrain parameters such as slope and aspect, tourism demand, socio-economic variables, or community perceptions. Future research should integrate these factors together with field-based validation and stakeholder participation to further improve the robustness, reliability, and practical applicability of ecotourism suitability modelling in mountainous regions.

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