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ASSESSMENT OF ECOTOURISM POTENTIAL AND SPATIAL ZONING OF SAMARKAND REGION USING GIS AND MULTI-CRITERIA ANALYSIS (AHP)

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Abstract. Ecotourism is increasingly regarded as a tool for combining nature conservation with local socio-economic development, yet in Uzbekistan the sector remains concentrated around a few cultural-heritage destinations. This study evaluates the ecotourism potential of Samarkand region and divides its territory into zones of different suitability by integrating Geographic Information Systems (GIS), remote sensing and the Analytic Hierarchy Process (AHP). Seven criteria were selected: land cover/vegetation (NDVI), slope, elevation, distance to water bodies, proximity to protected and scenic areas, distance to roads, and proximity to cultural-historical sites. Criterion weights were derived from a pairwise comparison matrix (consistency ratio CR = 0.022 < 0.10), and thematic layers were standardised and combined by weighted linear combination in a GIS environment. The resulting Ecotourism Potential Index was classified into five categories (very low to very high) and aggregated by administrative district. The proposed workflow provides a transparent, repeatable basis for tourism planning, infrastructure prioritisation and the sustainable use of the mountain and foothill landscapes of the Zarafshan basin.

Keywords: ecotourism; Samarkand region; GIS; Analytic Hierarchy Process (AHP); multi-criteria decision analysis; remote sensing; spatial zoning; sustainable tourism.

Introduction

Tourism is one of the priority sectors of Uzbekistan’s economy, and Samarkand is its best-known destination. The historic city, inscribed on the UNESCO World Heritage List in 2001 as *Samarkand – Crossroad of Cultures*, attracts the majority of visitors to

the region. By contrast, the natural assets of the surrounding territory, including the western spurs of the Turkestan and Zarafshan ranges, the Hisar foothills, river valleys and mountain villages, remain much less developed as tourism products. Diversifying the offer toward nature-based and rural tourism could reduce pressure on the historic centre, extend the length of stay and generate income in rural districts.

Ecotourism is commonly defined as responsible travel to natural areas that conserves the environment, sustains the well-being of local people and involves interpretation and education (TIES, 1990; Honey, 2008; Fennell, 2015). Because it depends on the spatial characteristics of a landscape, the identification of suitable areas is a typical geospatial problem. Decisions involve several, often conflicting, factors, such as scenic value, terrain, access and distance from sensitive habitats, so single-factor mapping is insufficient.

GIS-based multi-criteria decision analysis (GIS-MCDA) offers a systematic way to combine such factors (Malczewski, 1999, 2006). Among MCDA techniques, the Analytic Hierarchy Process developed by Saaty (1977, 1980) is widely used because it converts expert judgement into numerical weights and provides a consistency check. GIS-AHP approaches have been applied to ecotourism and nature-based tourism site selection in Thailand (Bunruamkaew and Murayama, 2012), Iran (Ghorbanzadeh et al., 2019) and many other regions. For Central Asia, and for Samarkand region in particular, integrated and reproducible assessments of this kind are still scarce.

The aim of this study is to assess the ecotourism potential of Samarkand region and to produce a spatial zoning map using GIS and AHP. The objectives are: (1) to select and justify evaluation criteria; (2) to prepare and standardise thematic layers from satellite and ancillary data; (3) to derive criterion weights with AHP and test their consistency; (4) to compute and classify an Ecotourism Potential Index (EPI); and (5) to summarise the results by district and formulate planning recommendations.

2. Study Area, Data and Methods

2.1. Study area

Samarkand region lies in the central-eastern part of Uzbekistan, in the middle course of the Zarafshan River, at approximately 39–40° N and 66–68° E, and covers about 16.8 thousand km². Its relief changes from the Zarafshan valley and the Nurata–Mirzachul plains in the west and north to the Zarafshan and Hisar mountain ranges in the east and south, with elevations from roughly 300 m to more than 3,000 m above sea level. The climate is continental and dry, with hot summers and cool winters, and a vertical zonation of vegetation from steppe and irrigated agricultural land to juniper, nut and shrub communities in the mountains. Administratively the region is divided into districts including Urgut, Pastdargom, Nurobod, Oqdaryo, Ishtixon, Kattaqo‘rgon, Narpay, Payariq, Bulungur, Jomboy, Toyloq, Qo‘shrabot and Samarkand district, together with the cities of Samarkand and Kattaqo‘rgon.

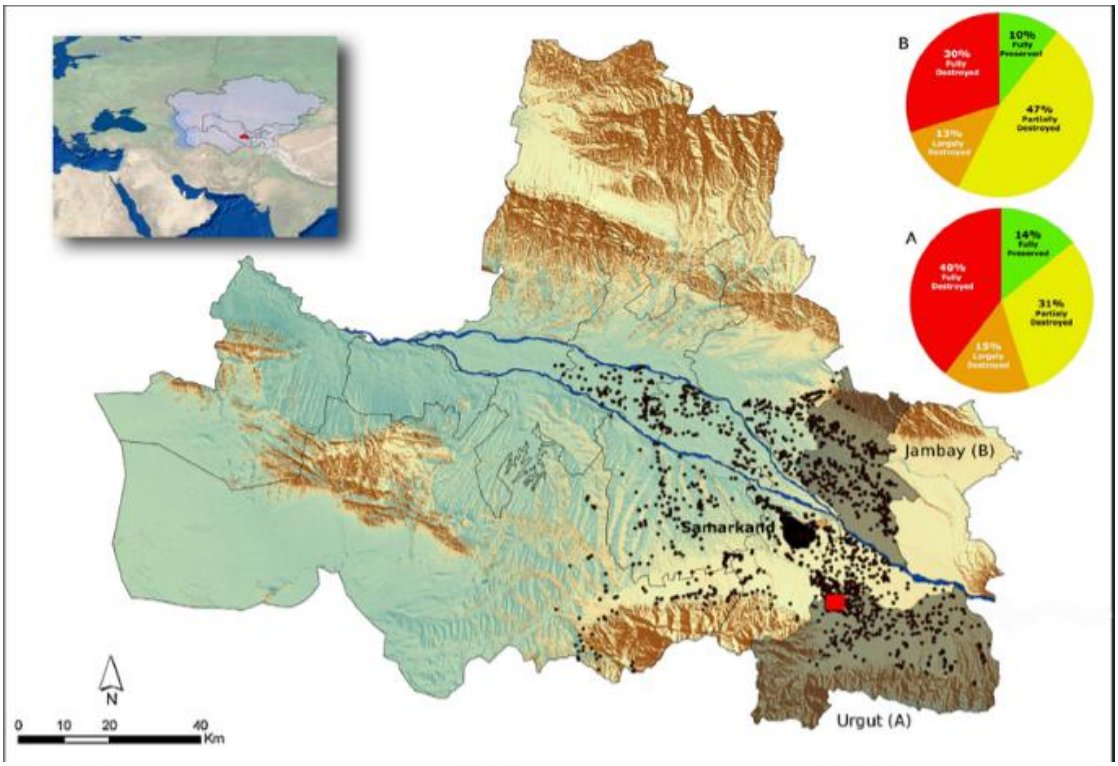

Figure 1. Satellite image of Samarkand region with district boundaries (Sentinel-2 true-colour mosaic, 10 m resolution).

2.2. Data sources. The analysis uses freely available datasets (Table 1). All layers

should be reprojected to a common coordinate system (WGS 84 / UTM zone 42N or 43N, depending on the extent used) and resampled to a uniform 30 m grid.

Table 1. *Input data and derived products.*

Layer	Source	Derived product
Multispectral imagery	Sentinel-2 MSI (Drusch et al., 2012)	NDVI and land cover classes
Digital elevation model	SRTM 1 arc-second (Farr et al., 2007)	Elevation, slope
Hydrography	OpenStreetMap / HydroSHEDS	Distance to rivers, canals, reservoirs
Road network	OpenStreetMap	Distance to roads
Protected areas	Committee for Ecology and Environmental Protection; WDPA	Distance to protected and scenic areas
Cultural-historical sites	Heritage registers; OpenStreetMap	Distance to heritage sites
Administrative boundaries	National cadastral data / GADM	District boundaries

2.3. Evaluation criteria

Seven criteria grouped into three themes were selected on the basis of the literature and the regional context:

– **Natural attractiveness:** land cover and vegetation condition (C1, NDVI), proximity to protected and scenic areas (C5), and distance to water bodies (C4).

– **Physical suitability:** slope (C2) and elevation (C3).

– **Accessibility and cultural context:** distance to roads (C6) and proximity to cultural-historical sites (C7).

NDVI is calculated as (NIR − Red)/(NIR + Red) (Tucker, 1979), using Sentinel-2 bands B8 and B4 from a cloud-free composite for the peak vegetation season. Slope is derived from the DEM using the standard neighbourhood method. Distance layers are produced with the Euclidean distance tool.

2.4. Standardisation

Each layer was reclassified into a common 1–5 suitability scale (1 = unsuitable, 5 = highly suitable), as shown in Table 2. Thresholds are expert-based and should be adjusted to the final data and local consultation.

Table 2. *Reclassification scheme (illustrative thresholds).*

Criterion	5 (very high)	4	3	2	1 (very low)
C1 NDVI	> 0.6	0.4–0.6	0.3–0.4	0.2–0.3	< 0.2
C2 Slope (°)	5–15	15–25	0–5	25–35	> 35
C3 Elevation (m)	1,000–2,000	600–1,000	2,000–2,600	400–600	< 400 or > 2,600
C4 Distance to water (m)	< 500	500–1,000	1,000–2,000	2,000–4,000	> 4,000
C5 Distance to protected/scenic areas (km)	< 2	2–5	5–10	10–20	> 20
C6 Distance to roads (m)	< 500	500–1,500	1,500–3,000	3,000–6,000	> 6,000
C7 Distance to heritage sites (km)	< 5	5–10	10–20	20–40	> 40

2.5. Analytic Hierarchy Process

The relative importance of the criteria was determined by pairwise comparison on Saaty's 1–9 scale (Saaty, 1980, 2008). The matrix $\mathbf{A} = [a_{ij}]$ is reciprocal ($a_{ji} = 1/a_{ij}$). Weights are the normalised principal eigenvector, and consistency is checked with:

$$CI = (\lambda_{max} - n)/(n - 1), \quad CR = CI/RI,$$

where n is the number of criteria and RI is the random index (RI = 1.32 for n = 7). A matrix is accepted if CR < 0.10. In a full study, the judgements should be collected from a panel of experts (for example, ecologists, geographers, tourism planners and local administrators), and individual matrices combined by the geometric mean.

The pairwise comparison matrix used in this draft is given in Table 3.

Table 3. *Pairwise comparison matrix.*

	C1	C2	C3	C4	C5	C6	C7
C1 NDVI	1	3	3	2	1/2	4	3
C2 Slope	1/3	1	2	1/2	1/3	2	1
C3 Elevation	1/3	1/2	1	1/2	1/4	2	1/2
C4 Water	1/2	2	2	1	1/2	3	2
C5 Protected/scenic	2	3	4	2	1	5	2
C6 Roads	1/4	1/2	1/2	1/3	1/5	1	1/3
C7 Heritage	1/3	1	2	1/2	1/2	3	1

2.6. Weighted overlay and zoning

The Ecotourism Potential Index for each cell was computed as a weighted linear

combination:

$$EPI = \Sigma (w_i \times x_i),\ i = 1 \ldots 7,$$

where w_i is the AHP weight and x_i the standardised score of criterion i. Exclusion (constraint) layers, such as strictly protected core zones, military areas, built-up urban land and intensively irrigated cropland, were masked out. The EPI was classified into five classes by equal intervals or natural breaks (Jenks), and zonal statistics were calculated for each district. Processing was carried out in QGIS or ArcGIS Pro.

3. Results and Discussion

3.1. Criterion weights

The AHP procedure gave the weights in Table 4. The principal eigenvalue was $\lambda_{max} = 7.175$, giving CI = 0.029 and CR = 0.022, well below the 0.10 threshold, so the judgements are considered consistent.

Table 4. *AHP criterion weights.*

Criterion	Weight	Rank
C5 Proximity to protected/scenic areas	0.290	1
C1 Land cover / NDVI	0.236	2
C4 Distance to water	0.154	3
C7 Proximity to cultural-historical sites	0.109	4
C2 Slope	0.096	5
C3 Elevation	0.069	6
C6 Distance to roads	0.046	7
Total	1.000	

The natural-attractiveness criteria together account for about 68% of the total weight, reflecting the principle that ecotourism is primarily driven by the quality of the natural environment. Accessibility received the lowest weight because roads already reach most of the settled parts of the region and because remoteness is itself part of the ecotourism experience; at the same time, accessibility is a practical constraint, which is why the sensitivity analysis below is important.

3.2. Spatial pattern of ecotourism potential

The EPI map (Figure 2) is classified into five zones: very low, low, moderate, high and very high potential. Based on the landscape structure and the weighting scheme, the

highest values are expected in the mountain and foothill belt of the Zarafshan and Hisar ranges (notably Urgut, Pastdargom, Nurobod and Oqdaryo districts), where vegetation cover, rivers and scenic landscapes coincide with moderate slopes and reasonable road access. Moderate values are expected in the foothill zone where irrigated landscapes and cultural sites are combined. The lowest values are expected in the intensively farmed lowland plains and the arid steppe, where natural attractiveness is low and land is under agricultural use.

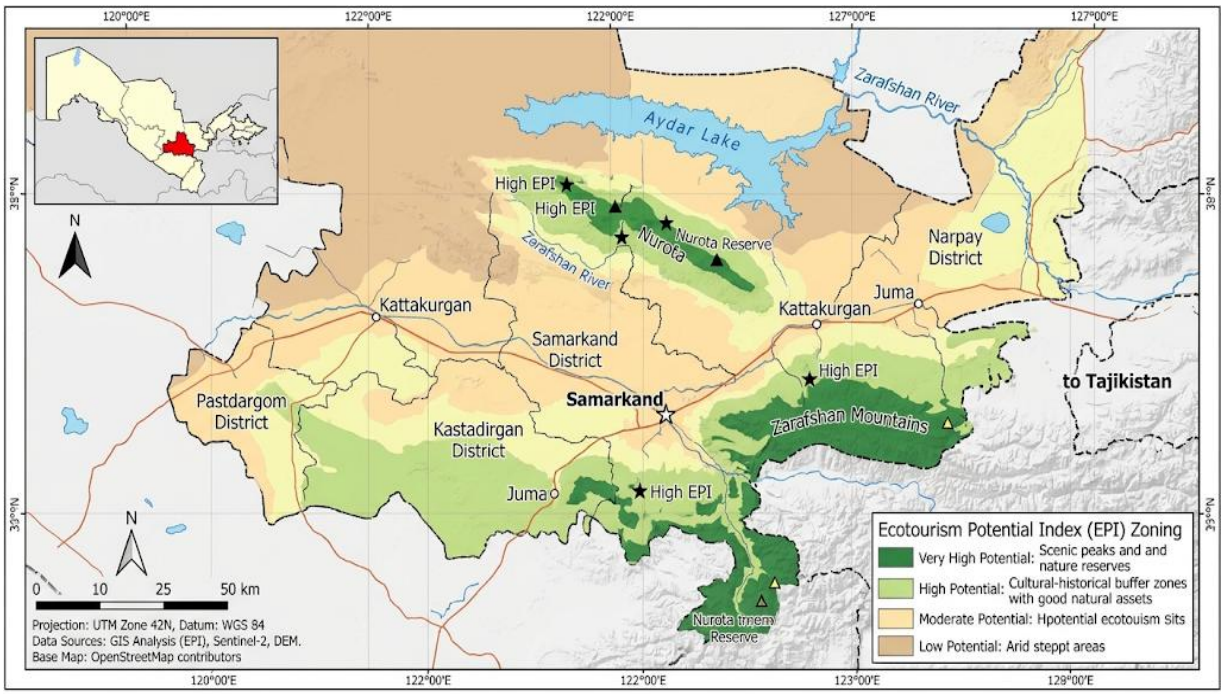

Figure 2. Ecotourism Potential Index (EPI) and zoning of Samarkand region, generated through GIS analysis.

3.3. District-level zoning

Zonal statistics (mean EPI and share of high and very high classes) should be reported for each district and used to group districts into three planning types: (a) priority districts for ecotourism development, (b) districts suitable for complementary rural and agro-tourism, and (c) districts where tourism should be limited to cultural routes. This district-level view links the raster output to administrative decision-making.

3.4. Sensitivity and validation

The stability of the result should be tested by changing each weight by ±10–20% and recalculating the EPI (one-at-a-time sensitivity analysis), and by comparing the high-

potential zones with existing tourist sites, trails and visitor numbers. Field verification of selected points and, where possible, ROC/AUC evaluation against known sites would strengthen the validity of the model.

3.5. Planning implications

The zoning supports several practical measures: development of marked trails and eco-lodges in the highest-potential zones; integration of nature routes with the cultural programme of Samarkand to create combined itineraries; capacity limits and monitoring in ecologically sensitive areas; and community-based tourism that keeps income within local villages. Infrastructure investment can be prioritised in zones that have high potential but low accessibility.

3.6. Limitations

The approach has several limitations. AHP weights depend on subjective expert judgement, and the thresholds in Table 2 are simplified. Climatic factors, seasonality, biodiversity data, safety and the existing tourist infrastructure (accommodation, services) were not included because of data availability. The 30 m resolution may not capture small-scale features. Future work could add these variables and compare AHP with other methods such as fuzzy AHP, TOPSIS or machine-learning models.

4. Conclusion

This study presented a GIS- and AHP-based framework for assessing ecotourism potential and spatial zoning in Samarkand region. By combining satellite-derived vegetation and terrain information with hydrographic, protected-area, road and heritage data, and weighting them through a consistent pairwise comparison (CR = 0.022), the method produces a transparent Ecotourism Potential Index that can be classified into planning zones and summarised by district. The results highlight the mountain and foothill belt as the main area for nature-based tourism and show how it can complement the cultural-heritage tourism of Samarkand city. The workflow relies on open data and can be repeated, updated and transferred to other regions of Uzbekistan. We recommend that the weights be validated with a broader expert panel, that sensitivity and field verification be carried out, and that the results be used by regional authorities in tourism

master planning and protected-area management.

References

1. Boers, B., & Cottrell, S. (2007). Sustainable tourism infrastructure planning: A GIS-supported approach. *Tourism Geographies, 9*(1), 1–21.

2. Bunruamkaew, K., & Murayama, Y. (2012). Site suitability evaluation for ecotourism using GIS & AHP: A case study of Surat Thani Province, Thailand. *Procedia – Social and Behavioral Sciences, 50*, 269–278.

3. Ceballos-Lascuráin, H. (1996). *Tourism, Ecotourism, and Protected Areas: The State of Nature-Based Tourism around the World and Guidelines for Its Development.* IUCN, Gland.

4. Drusch, M., Del Bello, U., Carlier, S., et al. (2012). Sentinel-2: ESA's optical high-resolution mission for GMES operational services. *Remote Sensing of Environment, 120*, 25–36.

5. Farr, T. G., Rosen, P. A., Caro, E., et al. (2007). The Shuttle Radar Topography Mission. *Reviews of Geophysics, 45*(2), RG2004.

6. Fennell, D. A. (2015). *Ecotourism* (4th ed.). Routledge, London.

7. Ghorbanzadeh, O., Pourmoradian, S., Blaschke, T., & Feizizadeh, B. (2019). Mapping potential nature-based tourism areas by applying GIS-decision making systems in East Azerbaijan Province, Iran. *Journal of Ecotourism, 18*(3), 261–283.

8. Honey, M. (2008). *Ecotourism and Sustainable Development: Who Owns Paradise?* (2nd ed.). Island Press, Washington, DC.

9. Malczewski, J. (1999). *GIS and Multicriteria Decision Analysis.* John Wiley & Sons, New York.

10. Malczewski, J. (2006). GIS-based multicriteria decision analysis: A survey of the literature. *International Journal of Geographical Information Science, 20*(7),

703–726.

11. Saaty, T. L. (1977). A scaling method for priorities in hierarchical structures. *Journal of Mathematical Psychology*, *15*(3), 234–281.

12. Saaty, T. L. (1980). *The Analytic Hierarchy Process.* McGraw-Hill, New York.

13. Saaty, T. L. (2008). Decision making with the analytic hierarchy process. *International Journal of Services Sciences*, *1*(1), 83–98.

14. The International Ecotourism Society (TIES). (1990). *What is ecotourism?* Washington, DC.

15. Tucker, C. J. (1979). Red and photographic infrared linear combinations for monitoring vegetation. *Remote Sensing of Environment*, *8*(2), 127–150.

16. UNESCO World Heritage Centre. (2001). *Samarkand – Crossroad of Cultures.* https://whc.unesco.org/en/list/603