UDC: 332.3:630*6:528.8:004.9(575.1)

IMPROVING THE USE OF FOREST FUND LANDS IN BOSTANLIQ DISTRICT THROUGH MULTI-CRITERIA GEOSPATIAL ANALYSIS (GIS–MCDA) AND FUNCTIONAL ZONING

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https://doi.org/10.5281/zenodo.23244681

Abstract: Visitor numbers in Bostanliq district (Tashkent region) rose from 850 thousand in 2019 to more than 12 million in January–November 2024, while in 2023–2025 forest fund lands lost 1,335 ha and industrial, transport and other lands grew by 25.7%. A GIS–MCDA framework is proposed that assesses recreational potential, anthropogenic pressure and ecological sensitivity as independent blocks, weights criteria by the Analytic Hierarchy Process (CR < 0.10), applies a protection mask and converts three-axis discordance into four functional zones. Sentinel-2 L2A analysis (2017–2025; NDVI, NDRE, SAVI) shows the dense-forest share falling from 18.1% to 13.5% and the non-forested share rising from 13.1% to 33.2%, mainly near settlements and roads.

Keywords: forest fund lands; GIS–MCDA; AHP; Sentinel-2; NDVI; recreational pressure; functional zoning; land cadastre.

Annotatsiya: Bo‘stonliq tumani o‘rmon fondi yerlaridan foydalanishni ko‘p mezonli geofazoviy tahlil (GIS–MCDA) va zonalash asosida takomillashtirish. Toshkent viloyati Bo‘stonliq tumaniga tashriflar soni 2019-yildagi 850 mingdan 2024-yilning yanvar–noyabr oylarida 12 milliondan oshdi; 2023–2025-yillarda o‘rmon fondi yerlari 1335 ga ga kamaygan, sanoat, transport va boshqa maqsadlardagi yerlar esa 25,7% ga oshgan. Rekreatsion salohiyat, antropogen bosim va ekologik sezgirlikni mustaqil bloklar sifatida baholaydigan, mezonlarni AHP usulida (CR < 0,10) vaznlaydigan, muhofaza maskasini qo‘llaydigan va uch o‘qli nomuvofiqlikni to‘rtta funksional zonaga aylantiradigan GIS–MCDA modeli taklif etildi. Sentinel-2 L2A tahlili (2017–2025; NDVI, NDRE, SAVI) zich o‘rmonlar ulushi 18,1% dan 13,5% gacha kamayganini, o‘rmonsiz yerlar ulushi esa 13,1% dan 33,2% gacha oshganini ko‘rsatdi; o‘zgarishlar asosan aholi punktlari va yo‘llar yaqinida kuzatildi.

Kalit so‘zlar: o‘rmon fondi yerlari; GIS–MCDA; AHP; Sentinel-2; NDVI; rekreatsion bosim; funksional zonalash; yer kadastri.

INTRODUCTION

Bostanliq district, the headwater area of the Chirchik basin, holds 377,832 ha of forest fund lands (76.6% of its territory), of which only 22,425 ha is covered by forest stands (1

January 2025); the rest are open slopes, grasslands and shrublands highly susceptible to trampling, grazing and erosion.

Recreational demand on these lands has grown roughly fourteen-fold, from about 850 thousand visitors in 2019 to more than 12 million in January–November 2024 ("Dunyo" News Agency, 2024). The growth is policy-driven: Decree PF-6053 (27.08.2020) set a special management regime for tourism in the district, Resolution PQ-21 (12.01.2024) promotes ecological tourism, and Decree PF-87 (15.05.2025, Annex 5) provides for new cable-car lines. The Law "On Forests" (ZRU-475, 16.04.2018) requires protective forest functions to be preserved. Between 2023 and 2025, forest fund lands decreased from 379,167 to 377,832 ha (−1,335 ha), while lands of industry, transport and other purposes grew from 6,634 to 8,336 ha (+25.7%) (Tashkent Regional Cadastre Department & Bostanliq State Forestry Enterprise, 2025). These figures show that conversion occurs, but not where, nor whether the remaining lands can sustain the load.

GIS-based multi-criteria decision analysis (MCDA) with the Analytic Hierarchy Process (AHP) (Saaty, 1980; Malczewski, 2006) has been used to map forest health (Dutta et al., 2021), plan national park management (Lakicevic & Srdjevic, 2022) and zone protected areas (Geneletti & van Duren, 2008); pressure has been mapped by human-footprint indices (Sanderson et al., 2002) and tolerable load by carrying capacity (Cifuentes, 1992). National studies have assessed infrastructure factors of forest fund lands (Karomatov & Raximov, 2023), the efficiency of their use (Babajanov et al., 2026) and GIS-based monitoring (Nazarova & Boboqulov, 2025; Primova, 2026). These studies treat suitability, pressure and capacity separately, and to our knowledge none links their spatial discordance to functional zoning of mountain forest fund lands in Central Asia. The aim of this study is to propose such a GIS–MCDA and zoning method for Bostanliq district and to present preliminary remote-sensing evidence.

MATERIALS AND METHODS

Study area and data. The district lies in the Western Tien Shan (Ugam, Pskem and Chatkal ranges). Lands for environmental, health and recreational purposes (25,026 ha) and reserve lands enter the model as a constraint mask. Sentinel-2 Level-2A scenes (Drusch et al., 2012) of 30 August 2017, 2021 and 2025 (0% cloud) were obtained from the Copernicus Data Space Ecosystem, using bands B4, B5 (resampled to 10 m) and B8. Slope and aspect are derived from a 30 m Copernicus DEM. Ancillary layers (cadastral accounts for 2023–2025, forest fund boundaries, OpenStreetMap roads and water, recreational facilities) are set to a 10 m grid (WGS 84 / UTM 42N) in ArcGIS and QGIS.

Vegetation indices and classification. Three indices were computed:

$$\mathrm{NDVI} = \frac{\mathrm{B8} - \mathrm{B4}}{\mathrm{B8} + \mathrm{B4}}, \quad \mathrm{NDRE} = \frac{\mathrm{B8} - \mathrm{B5}}{\mathrm{B8} + \mathrm{B5}}, \quad \mathrm{SAVI} = \frac{(1 + \mathrm{L})(\mathrm{B8} - \mathrm{B4})}{\mathrm{B8} + \mathrm{B4} + \mathrm{L}}, \ \mathrm{L} = 0.5 \qquad (1\text{–}3)$$

NDVI (Rouse et al., 1974) saturates over closed canopies, NDRE (Gitelson & Merzlyak, 1994) retains sensitivity to chlorophyll in dense stands, and SAVI (Huete, 1988) suppresses the soil background on sparse slopes. The stacked indices were partitioned by the ISO Cluster (unsupervised) algorithm into clusters that were labelled by the author, using the index ranges

and visual interpretation, as dense forest, sparse forest and shrubland, grassland, and non-forested land.

Criteria system and AHP weighting. Each factor enters only one block, so that potential and pressure are never derived from the same variable (Table 1).

Table 1.

Criteria system of the GIS–MCDA model

Block	Criteria	Role
Recreational potential (R)	Proximity to water; viewshed; landscape diversity; access to roads and facilities	Weighted: attractiveness
Anthropogenic pressure (A)	Negative NDVI trend 2017–2025; trail density; buffers of facilities and settlements	Weighted: actual impact
Ecological sensitivity (E)	Slope; aspect; erosion risk; soil and vegetation type	Weighted: tolerance to load
Constraint mask (M)	Protective forests; protected areas; water protection zones	Not weighted: use excluded

Criteria are min–max standardised to 0–1 (inversely for cost criteria); within each block, 10–15 experts in forestry, cadastre and GIS complete Saaty's 1–9 pairwise matrices, aggregated by the geometric mean; the weights are the normalised principal eigenvector, accepted when

$$\mathbf{Aw} = \lambda_{max}\mathbf{w}, \qquad CI = \frac{\lambda_{max} - n}{n - 1}, \qquad CR = \frac{CI}{RI} < 0.10 \qquad (4)$$

Block scores (R, A, E) are weighted linear combinations of the standardised criteria, with weights summing to 1 in each block. Carrying capacity (Cifuentes, 1992) is estimated per plot to set visitor limits.

Step-by-step model logic. (1) Harmonise layers on the 10 m grid within forest fund boundaries; (2) derive and standardise criteria; (3) weight them by AHP (CR < 0.10); (4) aggregate them into R, A and E surfaces (0–1); (5) classify each surface into low, medium and high (natural breaks), giving 27 combinations; (6) compute the discordance index, where 1 − E expresses ecological tolerance and D > 0 marks overload:

$$D = A - (1 - E) = A + E - 1, \qquad D \in [-1,1] \qquad (5)$$

(7) assign Zone 4 where M = 1 and apply the rules of Table 3 elsewhere; (8) validate by varying weights by ±20%, comparing zones with at least 50 field points per class, and assessing accuracy with an error matrix and kappa (Olofsson et al., 2014).

RESULTS

Vegetation and land-cover dynamics. All indices declined in 2021 and partly recovered in 2025 (Fig. 1). In 2017, NDVI of 0.39–1.0 dominated the north-eastern and central uplands and 0.07–0.20 the southern and lower slopes. In 2021, NDRE values of 0.04–0.20 expanded and the SAVI maximum fell from 1.49 to about 1.0; by 2025, NDVI ≥ 0.5 again concentrated in dense woodlands and SAVI reached 1.5. NDRE stayed at 0.5–0.7 in the northern high-altitude massifs (stable cores), whereas NDVI and SAVI fell to 0.10–0.25 in the lower and middle belts near settlements, roads and recreation sites (degradation hotspots).

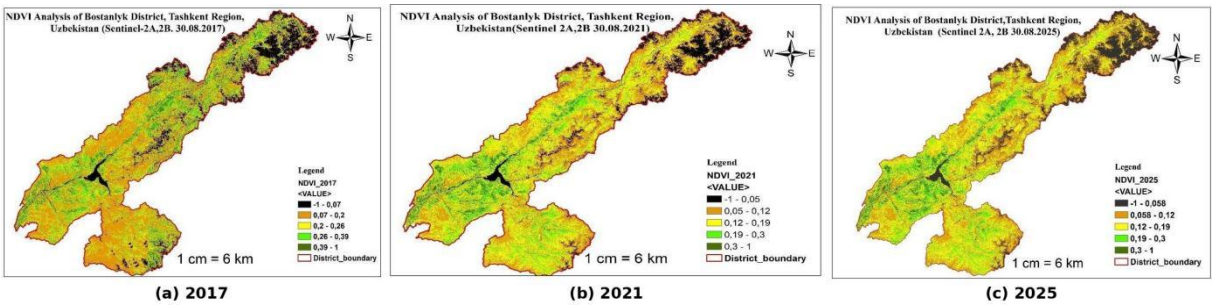

Figure 1. NDVI from Sentinel-2 L2A, 30 August: (a) 2017, (b) 2021, (c) 2025 (Primova, 2026).

Because the classified extent differed between dates (454.6 vs 406.6 thousand ha) owing to snow, shadow and water masking, change is assessed by shares (Table 2, Fig. 2).

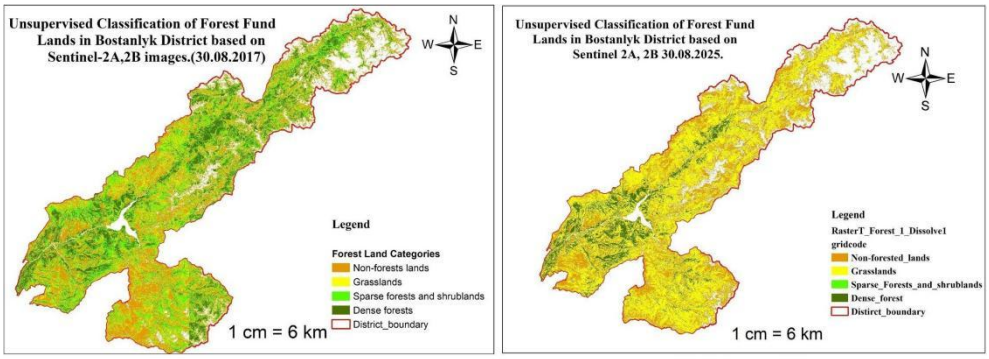

Figure 2. ISO Cluster classification, 30 August: (a) 2017, (b) 2025 (Primova, 2026).

Table 2.

Land-cover classes of the analysed area, 2017 and 2025

Class	2017, ha	2017, %	2025, ha	2025, %	Change, p.p.
Dense forest	82,304.8	18.1	54,758.8	13.5	−4.6
Sparse forest and shrubland	144,605.5	31.8	2,633.8	0.6	−31.2
Grassland	168,197.4	37.0	214,104.8	52.7	+15.7
Non-forested land	59,457.7	13.1	135,104.2	33.2	+20.1
Total classified	454,565.4	100.0	406,601.6	100.0	—

Dense forest lost 4.6 percentage points and non-forested land gained 20.1. The collapse of the sparse forest class reflects re-assignment of open woody cover to grassland by unsupervised clustering, not an actual loss of 142 thousand ha (the two classes combined fell from 68.8% to 53.3%).

Block indicators, discordance and functional zones. The 2017–2025 index decline populates the disturbance indicator of block A, with hotspots in settlement, road and facility buffers; block E is least tolerant on steep south-facing slopes under sparse xerophytic cover; block R is shaped by the Charvak reservoir, river valleys and roads. AHP weights will be finalised after the expert survey, while the zoning rules (Table 3) were fixed in advance so that zoning cannot be tuned to the outcome.

Table 3.

Decision rules and regimes of the functional zones

Zone	Rule	Management regime
1. Recreational use	R high; A low; E low; M = 0	Trails, viewpoints and light infrastructure within carrying capacity
2. Regulated use	Other pixels with M = 0 and D ≤ 0	Visitor quotas, designated trails, seasonal closures, rotational grazing
3. Protection and restoration	M = 0 and D > 0	Closure to recreation and grazing; anti-erosion afforestation
4. Strict protection	M = 1, whatever R, A, E	No new construction; monitoring and research only

Zone 3 candidates lie in the degradation hotspots of the lower and middle belts; Zone 4 covers protective forests, protected areas and water protection strips; Zone 1 is expected on gentle, accessible, low-sensitivity slopes outside forest stands, and Zone 2 on most open slopes and grasslands.

DISCUSSION

Degradation along access gradients agrees with the human-footprint concept (Sanderson et al., 2002). Unlike the single forest-health index of Dutta et al. (2021), pressure and sensitivity remain separate axes, so a fragile but green slope is not masked by good condition; unlike park-level ranking (Lakicevic & Srdjevic, 2022) and multiobjective zoning (Geneletti & van Duren, 2008), regimes are allocated plot by plot by pre-set, traceable rules. The model also adds ecological state and recreational load to national studies (Karomatov & Raximov, 2023; Babajanov et al., 2026). Spectrally dense vegetation (54.8 thousand ha in 2025) exceeds registered forest-covered land (22.4 thousand ha) more than twice, calling for a harmonised cadastre–remote sensing nomenclature.

Limitations define the next stage: single-date scenes are sensitive to precipitation; class thresholds (dense forest at NDVI ≥ 0.39 in 2017, ≥ 0.30 later) and extents differ by year; accuracy is not yet assessed (Random Forest with an error matrix and area-adjusted estimates is planned; Olofsson et al., 2014); and pressure relies on proxies in the absence of plot-level visitor counts.

CONCLUSIONS

1. In 2023–2025 forest fund lands lost 1,335 ha and industrial, transport and other lands grew by 25.7%, against a roughly fourteen-fold rise in visitors since 2019; categorical accounting cannot locate these shifts, so plot-level spatial assessment is required.

2. A four-block GIS–MCDA framework is proposed, with block-separated criteria, AHP weights (CR < 0.10) and the discordance index D = A + E − 1, which converts assessment into four functional zones by transparent, reproducible rules.

3. Preliminary Sentinel-2 indices indicate that low values (0.10–0.25) concentrate in the lower and middle belts near settlements and roads, while northern high-altitude massifs remain stable (NDRE 0.5–0.7); these findings are indicative until the classification is validated and its accuracy assessed.

4. Recommendations (after validation of the model): the Bostanliq State Forestry Enterprise could use the zoning as a precondition for allocating plots to tourism and prioritise

anti-erosion afforestation in Zone 3; the Tashkent Regional Cadastre Department could add a functional-zone attribute and an annual Sentinel-2 change layer to the forest fund cadastre; the district khokimiyat could screen projects under PF-6053 and PF-87 for zoning compliance.

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