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USE OF GEOINFORMATION TECHNOLOGIES IN ASSESSING THE ECOLOGICAL CONDITION OF SACRED LANDSCAPES IN KHOREZM REGION

Abstract. Sacred landscapes in Khorezm combine cultural heritage with contrasting urban and agricultural surroundings that require spatially explicit monitoring. This study combines a six-site geodatabase with Sentinel-2A Level-2A imagery acquired on 23 July 2025 to examine vegetation within 500 m buffers. Cloud-screened NDVI was calculated from 10 m red and near-infrared bands, and site means, medians and the share of valid cells exceeding NDVI 0.4 were extracted. Mean NDVI was 0.112–0.116 around the three closely spaced Khiva sites, 0.519 around Yusuf Hamadoniy, 0.383 around Voyangan Bobo and 0.363 around Shayx Muxtor Vali. These results establish a reproducible vegetation baseline and support monitoring in which hydrology, soil condition and human pressure are assessed before an integrated ecological judgement is made.

Keywords: sacred landscapes; geoinformation systems; remote sensing; ecological monitoring; Sentinel-2; NDVI; Khorezm.

INTRODUCTION

The ecological surroundings of sacred sites influence how visitors experience cultural heritage and how local authorities maintain public space. In an irrigated oasis, a site may be affected by vegetation management, water supply, soil condition and nearby development. A spatial assessment must distinguish the cultural monument from its surrounding land cover. Khiva provides a clear example: UNESCO describes Itchan Kala as a coherent urban ensemble that includes mausoleums, residential buildings and other historic structures [1]. Vegetation scarcity within such an ensemble has a different meaning from vegetation loss in an agricultural landscape.

Regional research provides a basis for selecting environmental indicators. Boymurodov et al. examined vegetation cover and vegetation-related desertification criteria across the Khorezm oasis [2]. Matchanov et al. assessed drought safety using geospatial variables that included river distance, canal density, groundwater conditions and land surface temperature [3]. These studies support considering vegetation together with water and land conditions. However, results calculated over an entire oasis cannot be transferred directly to individual sacred sites because their spatial extent and land-use composition differ.

Sentinel-2 imagery offers a suitable spatial scale for mapping vegetation around these sites [4]. NDVI expresses the contrast between red absorption and near-infrared reflectance and is sensitive to photosynthetically active vegetation [5]. Interpretation depends on exposed soil, mixed pixels and observation timing. Soil-adjusted indices provide a possible extension where exposed soil contributes strongly to the signal [6]. The aim of this study is to quantify the vegetation context of six selected sacred sites, examine their spatial relationships and define the evidence needed for ecological monitoring. The contribution is a reproducible satellite snapshot at the scale of 500 m site buffers, with explicit treatment of overlapping urban buffers.

MATERIALS AND METHODS

The geodatabase contains six reference locations in Khiva, Shovot and Yangiariq (Table 1). Coordinates from the source inventory were retained in WGS 84 (EPSG:4326). They are reference points, not surveyed monument boundaries. Their six decimal places reproduce the inventory and do not establish positional accuracy. No ground or cadastral verification was undertaken.

Table 1. Reference locations used in the GIS analysis

ID	Sacred site	District	Latitude °N	Longitude °E
1	Pahlavon Mahmud	Khiva	41.377423	60.359581
2	Said Alovuddin pir	Khiva	41.377787	60.358541
3	Uch Avliyo Bobo	Khiva	41.378657	60.361079
4	Yusuf Hamadoniy	Shovot	41.663213	60.386247
5	Voyangan Bobo	Shovot	41.711605	60.143645
6	Shayx Muxtor Vali	Yangiariq	41.340434	60.558057

Source: the working site inventory. Site IDs are used in the maps and statistics table.

Buffers of 500 m were constructed in WGS 84 / UTM zone 41N (EPSG:32641). The radius defines a comparable local context, not a statutory protection zone or measured ecological influence distance. Each circle covers 78.54 ha theoretically. Cells were included by their centres. Straight-line distances were calculated with the Haversine formula and an Earth radius of 6371.0088 km; they do not measure road access.

Public Sentinel-2A Level-2A cloud-optimized GeoTIFF assets were located through the Earth Search catalogue [9]. Two tiles acquired on 23 July 2025 were used: S2A_41TKF_20250723_0_L2A and S2A_41TKG_20250723_0_L2A. Their catalogue cloud-cover values were 0.001158% and 0.000707%, respectively. A common acquisition date was

selected from the July search to reduce temporal differences among sites. The red band B4 and near-infrared band B8 have a nominal pixel size of 10 m [4]. Scene Classification Layer values were sampled by nearest neighbour from the 20 m quality grid. Only classes 4, 5 and 6, representing vegetation, non-vegetated land and water, were retained [8].

Both source items indicate that the bottom-of-atmosphere offset has already been applied to their COG digital numbers. The common multiplicative reflectance scale therefore cancels in the normalized ratio, and no second additive offset was subtracted. Zero-valued red or near-infrared pixels and cells outside the accepted scene classes were masked. NDVI was calculated as [5]:

$$NDVI = (\rho NIR - \rho RED) / (\rho NIR + \rho RED)$$

Here ρNIR and ρRED denote surface reflectance in B8 and B4. Source assets were read onto a common 10 m UTM grid using Rasterio [10]. Valid cells from tile 41TKF were retained first in areas of overlap; remaining cells were filled from 41TKG. Nearest-neighbour sampling preserved source values. A separate 30 m display grid was produced for the regional context map and was not used for site statistics. The workflow was executed in Google Colab.

For each buffer, the arithmetic mean, median, 10th and 90th percentiles, valid-cell count and valid coverage were calculated. The proportion of valid cells with NDVI greater than 0.4 provides a descriptive measure of relatively strong vegetation signal. This threshold was selected for comparison within this dataset and was not calibrated as a universal vegetation-cover or ecological-quality boundary. No reference land-cover sample was collected, so the thresholded share is not an accuracy-adjusted vegetation-area estimate. Independent reference sampling would be required for that purpose [7].

RESULTS

The Khiva sites form a compact cluster. Distances between sites 1–2, 1–3 and 2–3 were 95.8, 185.6 and 232.8 m, respectively. Their 500 m buffers

overlap extensively. Yusuf Hamadoniy and Voyangan Bobo were 20.85 km apart. Shayx Muxtor Vali was 16.98 km from Uch Avliyo Bobo, the nearest of the selected Khiva sites. Figure 1 places the four local settings within a common satellite context.

All selected cells passed quality screening. Sampled buffer areas ranged from 78.54 to 78.59 ha because of grid discretization. Valid coverage of 100% describes the screening outcome, not perfect cloud detection or field accuracy (Table 2).

Table 2. NDVI within 500 m buffers on 23 July 2025

ID	Sacred site	Mean	Median	P10–P90	NDVI >0.4 %
1	Pahlavon Mahmud	0.112	0.074	0.031–0.255	4.00
2	Said Alovuddin pir	0.116	0.075	0.030–0.271	4.70
3	Uch Avliyo Bobo	0.113	0.074	0.033–0.258	4.68
4	Yusuf Hamadoniy	0.519	0.543	0.084–0.877	66.81
5	Voyangan Bobo	0.383	0.348	0.056–0.777	43.34
6	Shayx Muxtor Vali	0.363	0.334	0.084–0.704	42.72

P10 and P90 are the 10th and 90th percentiles. Valid coverage was 100% for every buffer. Percentages refer to valid raster cells.

The three Khiva buffers had similar vegetation signals. Mean NDVI was 0.112 at Pahlavon Mahmud, 0.116 at Said Alovuddin pir and 0.113 at Uch Avliyo Bobo. Medians were approximately 0.074–0.075, and only 4.00–4.70% of cells exceeded 0.4. Low values are consistent with a predominantly built heritage setting. Because the buffers contain many of the same pixels, these values describe overlapping parts of one urban context and should not be treated as independent replicates.

Yusuf Hamadoniy had the highest mean (0.519), median (0.543) and share above 0.4 (66.81%). Its 10th–90th percentile interval of 0.084–0.877 indicates substantial local variation. Voyangan Bobo had a mean of 0.383, a

median of 0.348 and a threshold share of 43.34%. Corresponding values for Shayx Muxtor Vali were 0.363, 0.334 and 42.72%. Figure 2 shows the spatial mixtures underlying these summaries, with stronger vegetation signals interspersed with low-NDVI surfaces.

DISCUSSION

The principal finding is a difference in vegetation context between the Khiva cluster and the rural locations. In Khiva, NDVI largely describes green space within a built heritage setting. Around rural sites, it also captures crops and other managed vegetation outside the monument grounds. A higher buffer NDVI consequently does not necessarily indicate better management of the sacred site itself. Verified monument boundaries and land-use information would be needed to separate the grounds from agricultural parcels.

The regional studies help define further measurements. Vegetation-related desertification assessment [2] provides a reason to examine vegetation persistence and cover characteristics. The drought-safety study [3] identifies hydrological variables that could help explain vegetation differences across the oasis. These connections provide context rather than direct validation. The present site statistics were calculated independently from the specified acquisition. Regional hazard classes and areal percentages were not assigned to the sacred sites.

A monitoring system should retain four complementary evidence blocks. Vegetation monitoring can repeat the NDVI calculation over several seasons and distinguish trees, crops and exposed surfaces. Hydrological monitoring should record irrigation schedules, canal condition and groundwater depth. Soil assessment should include electrical-conductivity measurements and field descriptions before interpreting spectral patterns as salinity evidence. Human pressure should be examined using building and road data, visitor observations

and maintenance records. These blocks are a proposed extension: only vegetation and geometric site relationships were measured here.

The Khiva sites can be monitored as a shared urban setting, with inspections inside each monument. At rural sites, comparisons should match crop-growth stages. Declining NDVI could identify places for inspection, but harvest, irrigation and exposed soil must be checked before interpreting a low value as degradation.

The acquisition provides one summer snapshot and cannot demonstrate a trend, drought impact or causal relationship. The six sites are a purposive sample and do not represent every sacred landscape in Khorezm. Buffer overlap creates spatial dependence, so no significance test based on six independent replicates was applied. Unverified point locations, mixed 10 m pixels and a 20 m quality mask limit spatial interpretation. Soil background and index saturation can affect NDVI; a soil-adjusted index and seasonal observations would help assess those effects [6]. No field vegetation measurements, salinity samples or independent land-cover validation were available. Future area and accuracy claims should follow a documented reference-sampling design [7].

CONCLUSION

The GIS inventory and Sentinel-2A snapshot establish a reproducible vegetation baseline around six sacred reference locations in Khorezm. On 23 July 2025, mean NDVI was 0.112–0.116 in the overlapping Khiva buffers and 0.363–0.519 at the rural locations. This contrast describes different surrounding land-cover contexts and supports monitoring the Khiva sites as a connected urban cluster while retaining separate observations for the rural settings.

The results can guide repeat observations and inspections. Overall ecological assessment requires verified site boundaries, seasonal imagery, hydrological information and field soil measurements; NDVI alone does not establish an ecological ranking.

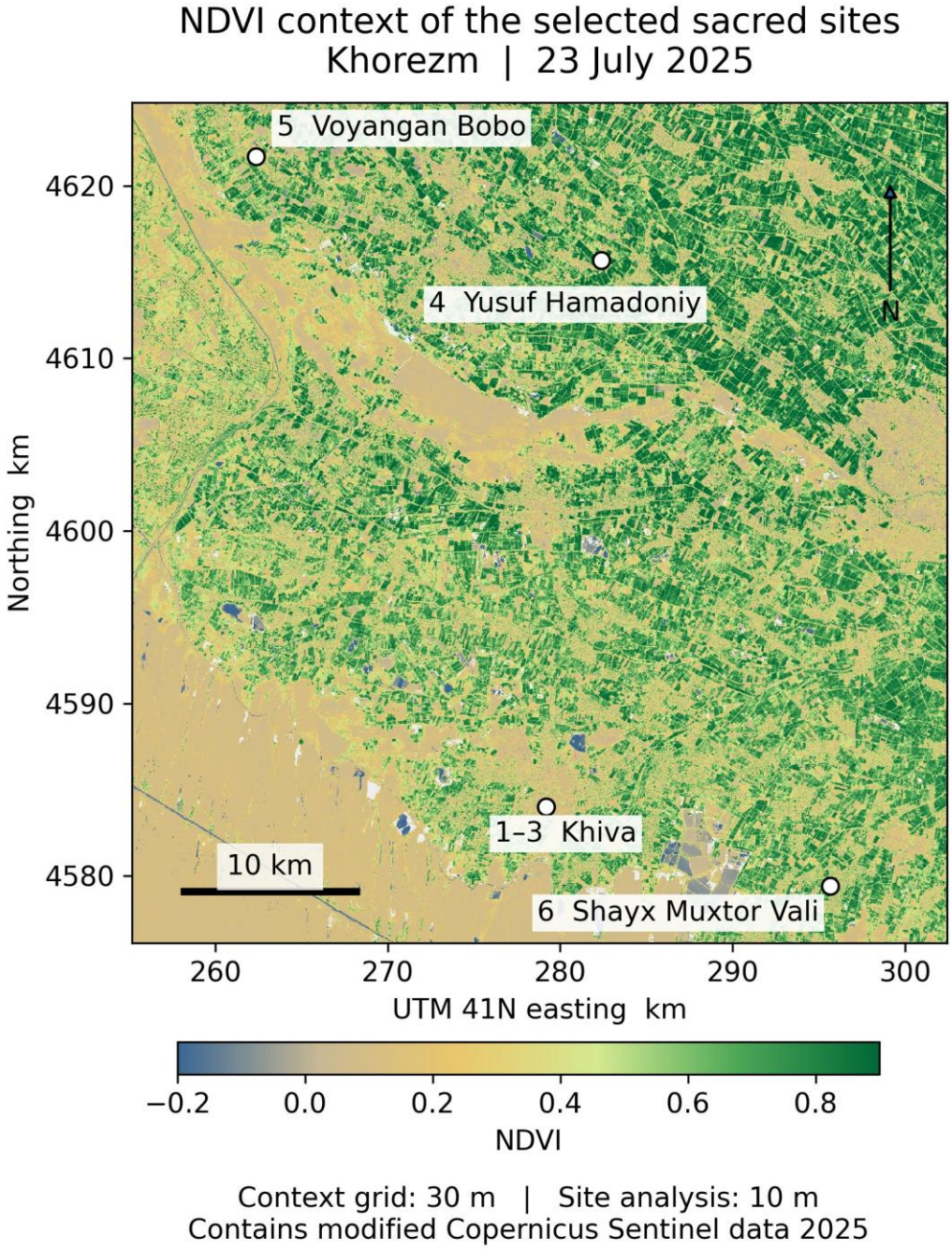


Figure 1. NDVI context of the selected sacred sites on 23 July 2025. The rectangular extent is a local study window, not the administrative boundary of Khorezm. The display grid is 30 m; buffer statistics use 10 m cells. Grey cells are masked. End colours include values outside the displayed interval −0.2 to 0.9. Source: modified Copernicus Sentinel data 2025, processed by the authors.

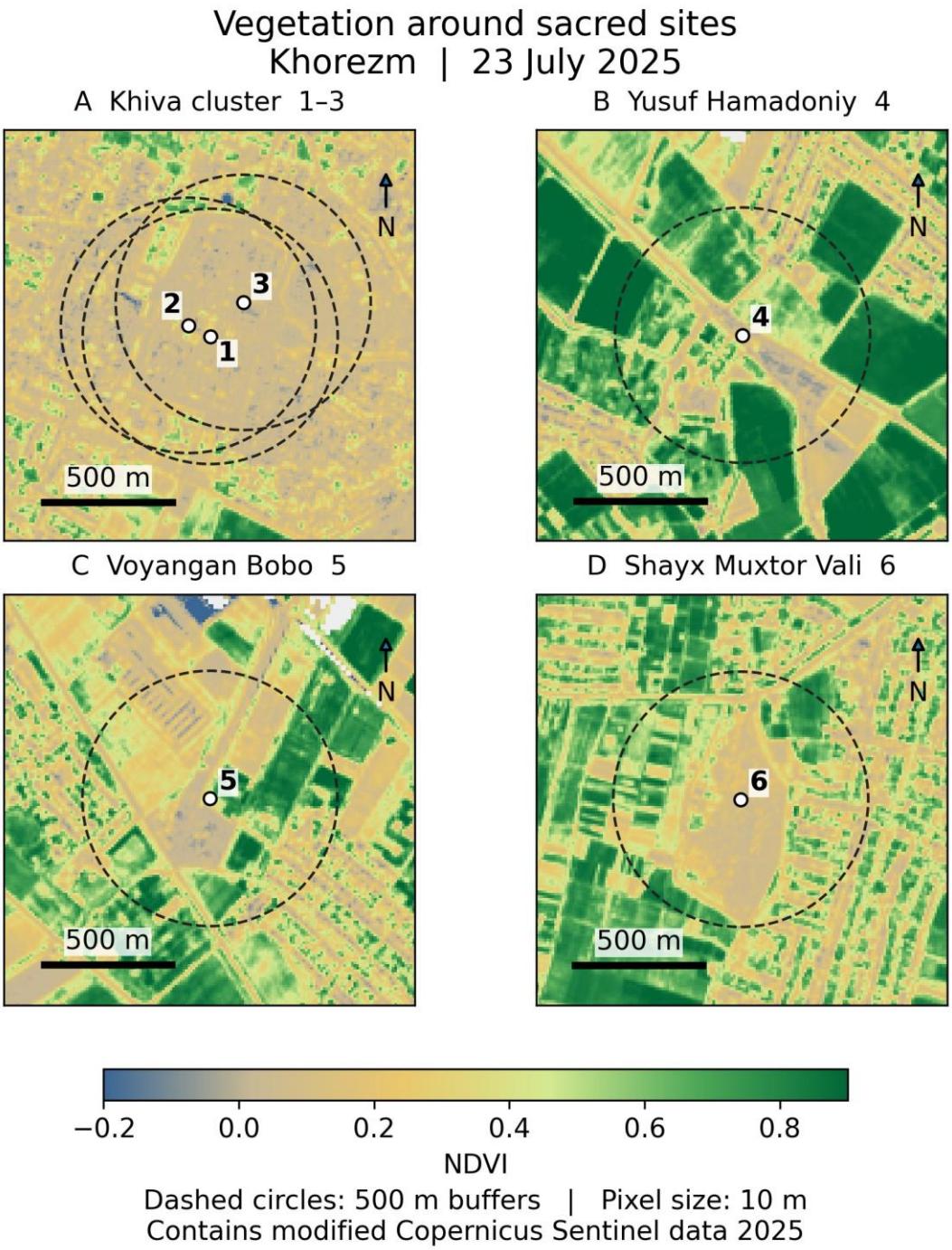


Figure 2. NDVI around the selected sacred sites on 23 July 2025. Panel A shows the three Khiva locations and overlapping buffers; panels B–D show the rural locations. Dashed circles have a radius of 500 m. Site IDs correspond to Tables 1 and 2. Grey cells are masked. End colours include values outside −0.2 to 0.9. Source: modified Copernicus Sentinel data 2025, processed by the authors.

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