

Evaluating ecotourism potential in arid oasis landscapes using GIS, AHP, and PROMETHEE: The Saoura Corridor case study

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ABSTRACT

Sustainable spatial planning in hyper-arid and oasis environments requires rigorous, transparent, and reproducible decision-making frameworks to balance ecotourism development with fragile ecosystem conservation. This study introduces an integrated geospatial multi-criteria decision analysis (MCDA) framework combining Google Earth Engine (GEE), geographic information systems (GIS), the analytic hierarchy process (AHP), and the PROMETHEE method to evaluate and prioritize ecotourism suitability across the Saoura corridor (Béchar, Taghit, and Kenadsa) in southwestern Algeria. While focused empirically on this corridor, the framework is designed to be transferable to comparable drylands globally, including the Middle East, Central Asia, and sub-Saharan Africa. Utilizing a 2025 Landsat 8 OLI/TIRS median composite classified with a Random Forest algorithm and ALOS PALSAR DEM data, eight biophysiological, morphometric, and logistic criteria were modeled. The AHP pairwise comparison matrix yielded a high-reliability consistency ratio (CR = 8.5%), identifying land-use/land-cover (LULC) as the most influential criterion (30.7%). The Random Forest classification reached an overall accuracy of 97.5% ($\kappa = 0.97$) on an independent validation subset ($n = 80$), and PROMETHEE II was used to rank 134 spatial alternatives. The results designate Kenadsa, Béchar, and Taghit as priority development poles, providing a robust spatial tool to guide post-petroleum regional tourism planning while safeguarding vulnerable environments in support of SDGs 8, 11, 13, and 15.

Keywords: Google Earth Engine; analytic hierarchy process; PROMETHEE; ecotourism suitability; arid and oasis ecosystems; Saoura corridor; Algeria.

INTRODUCTION

Increasingly recognized as a model of sustainable tourism, ecotourism is distinguished by its dual contribution: promoting ecosystem conservation while stimulating the local economic fabric. It aligns fully with global development priorities, notably the United Nations Sustainable Development Goals (SDGs) (Kiper, 2013; Rasoolimanesh et al., 2023). In this context, ecotourism supports SDG 8 (Decent Work and Economic Growth) through the creation of green jobs, SDG

11 (Sustainable Cities and Communities) through balanced tourism development, SDG 13 (Climate Action) through low-carbon travel, and SDG 15 (Life on Land) through the promotion of terrestrial ecosystem conservation. Arid and dryland environments cover approximately 41% of the Earth's land surface and are home to over two billion people (Reynolds et al., 2007). Despite their ecological and cultural richness, these territories remain among the least studied in the ecotourism literature, particularly with regard to spatial planning methodologies (Abuzaid et al., 2021). This

gap is especially pronounced in North Africa and the Middle East, where post-petroleum economic transitions are generating growing pressure to develop alternative, sustainable economic activities (Aissani et al., 2025). The Saoura corridor of southwestern Algeria represents a paradigmatic case of this global challenge: a territory that simultaneously concentrates exceptional natural heritage (Grand Erg Occidental dunes, oasis palm groves, fossil water systems) and significant socio-economic vulnerabilities linked to the decline of extractive industries.

Critically, the challenges faced in the Saoura corridor are not unique to Algeria. Comparable planning dilemmas balancing ecotourism development with the conservation of fragile dryland ecosystems and intangible cultural heritage have been documented in other drylands, for example in Oman's wadis (Al-Hatrushi et al., 2020) and in hyper-arid desert oases (Abuzaid et al., 2021), while GIS-based multi-criteria approaches to tourism site selection have been applied in contexts as diverse as north-eastern Morocco (Mohamed & Smail, 2025), north-western Iran (Ghorbanzadeh et al., 2019) and the Indian Himalaya (Chaudhary et al., 2022). The methodological framework developed in this study integrating GIS, GEE, AHP, and PROMETHEE is therefore intended to be transferable, after local recalibration, to comparable arid contexts. The influence of local culture on ecotourism outcomes is a dimension that deserves explicit attention. In the Saoura corridor, the Ksuri architectural tradition, Sufi spiritual heritage centered on Kenadsa, and the deeply rooted oasis agricultural practices of palm grove communities constitute cultural filters that profoundly shape visitor expectations, community participation, and heritage interpretation (Brahimi, 2024; Merabet, 2021). This cultural embeddedness distinguishes the Saoura context from purely landscape-driven ecotourism destinations and has direct methodological implications: the inclusion of proximity to ksour as a weighted criterion in the AHP model explicitly captures the role of tangible cultural heritage in determining ecotourism suitability. Future research should extend this approach to incorporate intangible cultural heritage indices and community cultural readiness assessments, building on theoretical frameworks proposed by Rasoolimanesh et al. (2023) and Fettih and Deriche (2025) in the sustainable tourism literature.

The Saoura corridor was selected as the study area for several converging reasons. First, it

constitutes the primary ecotourism development axis identified by Algeria's Tourism Development Master Plan (SDAT 2030), making it a policy-relevant and institutionally supported research context (Zermane et al., 2021). Second, the corridor encompasses three complementary territorial poles: an urban logistical hub (Bechar), a dune and oasis landscape system of global aesthetic and ecological significance (Taghit and the Grand Erg Occidental), and a site of outstanding architectural and spiritual heritage (Kenadsa), offering a rich and representative multi-scalar laboratory for testing the GIS-MCDA approach. Third, the spatial planning challenges focused on this territory constitute an important practical planning need. Fourth, the availability of high-resolution satellite data through GEE and the ALOS PALSAR DEM made it possible to conduct rigorous multi-criteria spatial modeling without the data limitations that typically constrain research in remote arid regions.

Although the integration of GIS, GEE, Random Forest classification, AHP, and PROMETHEE is not methodologically novel in itself, its application to the Béchar-Taghit-Kenadsa corridor provides a geographically specific contribution to the literature on ecotourism planning in arid oasis environments. The contribution of this study lies in adapting and integrating established geospatial and multi-criteria techniques to the particular ecological, cultural, and accessibility conditions of the Saoura region. In particular, the explicit inclusion of proximity to ksour as a separate criterion operationalizes the role of tangible cultural heritage in spatial ecotourism suitability assessment. To the best of our knowledge, few studies have combined these dimensions in a high-resolution suitability assessment of this specific corridor; therefore, the study should be understood as a context-specific empirical and applied contribution rather than as the introduction of a fundamentally new methodology. This positioning is consistent with Flyvbjerg's (2006) argument that the intensive study of a paradigmatic or extreme case can generate theoretical insights that transcend the specific context, provided the analytical framework is sufficiently explicit and reproducible. The study seeks to meet that condition by documenting each step of the GIS-AHP-PROMETHEE workflow and by depositing the input data, intermediate calculations and source code in a public Zenodo record (see Data Availability Statement), so that each step can be independently

inspected and re-run, and the approach adapted, with local calibration of criteria weights, to other arid or semi-arid contexts.

The academic literature on ecotourism has expanded considerably over the past decade, increasingly engaging with questions of spatial equity, community participation, and the political economy of conservation (Rasoolimanesh et al., 2023). Recent contributions have highlighted the need to move beyond purely biophysical suitability assessments toward more integrated frameworks that incorporate cultural, governance, and demand-side variables (Fettih & Derdiche, 2025). This study responds directly to that call by embedding cultural heritage proximity specifically, distance to ksour as an explicit spatial criterion in the AHP model. The intersection of ecotourism and arid environments has received growing attention in recent years, driven by the recognition that drylands harbor exceptional biodiversity, unique geomorphological landscapes, and deeply embedded cultural heritage that constitute genuine comparative advantages for nature-based tourism development (Neffah & Bahoussi, 2019; Rabehi et al., 2023). However, the spatial planning literature specific to arid ecotourism remains limited, with most GIS-MCDA studies focused on humid tropical or temperate mountain environments (Ghorbanzadeh et al., 2019; Chaudhary et al., 2022). This study addresses that balance by producing a high-resolution GIS-AHP-PROMETHEE suitability assessment for an arid oasis corridor in North Africa.

The integration of geographic information systems with multi-criteria decision analysis (GIS-MCDA) has become a cornerstone methodology in ecotourism suitability research (Ghorbanzadeh et al., 2019; Bagheri & Mohamadi, 2025). The analytic hierarchy process (AHP), developed by Saaty (1980) and extended by Saaty and Vargas (2006), remains a widely applied MCDA method in this domain due to its mathematical tractability, transparency, and capacity to handle both quantitative and qualitative criteria. Recent studies have further enriched this methodological tradition by coupling AHP with complementary outranking methods such as PROMETHEE (Preference Ranking Organization METHod for Enrichment Evaluations) (Bakshi et al., 2025; Taherdoost & Madanchian, 2023), TOPSIS (Guechi et al., 2023), and machine-learning classification algorithms applied through Google Earth Engine (Benoumeldjadj et al., 2025). A key theoretical debate in the GIS-MCDA literature concerns the

subjectivity inherent in AHP weight assignment and the extent to which expert-derived weights reflect community values and local ecological knowledge (Tang et al., 2025). This study acknowledges this limitation explicitly and proposes stakeholder-participatory AHP as a priority direction for future research, consistent with the community-centered ecotourism governance frameworks advocated in the sustainable tourism literature by Rasoolimanesh et al. (2023) and Fettih and Derdiche (2025).

The use of satellite remote sensing for land cover mapping in arid environments has advanced substantially with the democratization of cloud-computing platforms such as Google Earth Engine (Gorelick et al., 2017). The Random Forest algorithm, applied in this study for supervised LULC classification, has demonstrated superior performance in heterogeneous dryland landscapes compared to traditional maximum likelihood classifiers, particularly in distinguishing spectrally similar land cover types such as sparse vegetation, bare rock, and degraded palm groves (Belgiu & Drăguț, 2016; Benoumeldjadj et al., 2025). The integration of ALOS PALSAR DEM data with optical Landsat and Sentinel-2 imagery further enhances the spatial accuracy of morphometric criteria (elevation, slope, aspect) that are critical determinants of ecotourism suitability in mountainous and dissected desert terrain (Rane et al., 2024; Shiferaw, 2021).

The academic literature increasingly recognizes that the success of ecotourism initiatives in culturally rich environments depends not only on biophysical suitability but on the social and institutional capacity of host communities to participate in, benefit from, and govern tourism development (Woyesa & Kumar, 2021; Fong et al., 2017). In the specific context of Saharan Algeria, the ksour fortified earthen architecture villages that have served as centers of trans-Saharan trade, Islamic scholarship, and oasis governance for centuries constitute heritage assets of outstanding universal value that have been systematically underexploited in tourism strategies (Brahimi, 2024; Merabet, 2021). Kenadsa, in particular, is home to the Ziyaniyya Sufi lodge (zawiya), a living spiritual center that attracts pilgrims from across North and West Africa and represents a form of religious and intangible heritage tourism with significant development potential.

The primary aim of study is to develop and apply a transparent, documented, and spatially

explicit decision-support framework for ecotourism suitability assessment in arid oasis environments, using the Béchar-Taghit-Kenadsa corridor as a representative empirical case. The secondary aim is to apply this framework to produce a high-resolution suitability map that identifies and ranks spatial units according to their ecotourism potential, distinguishing between areas suited to immediate development, transitional zones requiring preparatory investment, and ecological sanctuaries requiring strict conservation management. The tertiary aim is to extract from this empirical application a set of methodological lessons and theoretical propositions that extend the existing GIS-MCDA ecotourism literature and inform planning practice in comparable dryland contexts globally.

MATERIALS AND METHODS

Study area

Located in southwestern Algeria, Béchar lies approximately 950 km from the capital, Algiers, to which it is connected by the RN 6 road (via Aïn Sefra) and by an air network whose main infrastructure, Boudghene Ben Ali Lotfi Airport, is located 6 km from the city. Administratively, the city has been the capital of the eponymous wilaya since the 1974 territorial reorganization, establishing itself as the main urban, logistical, and decision-making hub of the Saoura region. To conduct high-resolution spatial modeling and avoid scale biases related to the vast Saharan expanses, this study focuses on the Béchar-Taghit-Kenadsa territorial transect. This perimeter is defined by the geographic coordinates approximately between 30°43' and 32°00' north latitude and 0°55' and 3°05' west longitude (Fig. 1).

The study area covers 16,123 km² (1,612,341 ha). This value is the sum of the areas of the 30 m pixels of the classified study-area raster in Google Earth Engine and is used as the single reference area for all calculations, tables and figures of this study (land-cover statistics in Table 2, suitability mapping and PROMETHEE analysis). It encompasses the major biophysical, cultural, and functional entities of the Saoura Valley. It corresponds to the territory of three complementary communes (Fig. 1): Béchar, an urban centre and accessibility node; Taghit, an oasis and dune system emblematic of Saharan biodiversity and the

Grand Erg Occidental; and Kenadsa, a historical and heritage centre renowned for its Ksuri and spiritual architecture. The geodesic area of the vector boundary polygon of the three communes, computed in Google Earth Engine, is slightly larger (16,145 km²; 1,614,524 ha). The difference of 22 km² (2183 ha, i.e. 0.14%) is not a data error: it results from the rasterization of the boundary at 30 m resolution, because the stepped outline of the raster does not coincide exactly with the continuous outline of the polygon. Since every quantitative result of the analysis is derived from the raster, the raster-based value (16,123 km²; 1,612,341 ha) is retained consistently throughout the manuscript, tables, figures and supplementary materials, and the polygon value is reported here only to explain the difference.

Data acquisition and preprocessing

The Google Earth Engine (GEE) cloud-computing platform was used to acquire and process Landsat 8 OLI/TIRS Collection 2 Tier 1 top-of-atmosphere (TOA) reflectance imagery (LANDSAT/LC08/C02/T1_TOA) acquired between 1 January and 31 December 2025 over the Béchar-Taghit-Kenadsa territorial transect. Only scenes with a cloud cover below 1 % were retained, and a per-pixel median composite was computed and clipped to the study area. Thematic land-use/land-cover (LULC) mapping was performed by supervised classification directly within GEE using the Random Forest machine-learning algorithm. The multi-criteria spatial analysis, involving variable reclassification and weighted-overlay modeling according to the AHP weights, was carried out in ArcGIS Pro using the open-source ALOS PALSAR Digital Terrain Model (DTM 12.5 m resolution), topographic maps, and high-resolution orthophotos. Secondary data and heritage inventories of the ksour were provided by the Directorate of Tourism and Handicrafts of the wilaya of Béchar, the Directorate of Culture and Arts, and the National Agency for Territorial Planning (ANAT).

Sampling procedure and validation

Land cover was classified with the Random Forest algorithm implemented in GEE (ee.Classifier.smileRandomForest, 50 trees, other hyper-parameters at default values), using as predictors the Landsat 8 bands B1–B5 and B7–B11

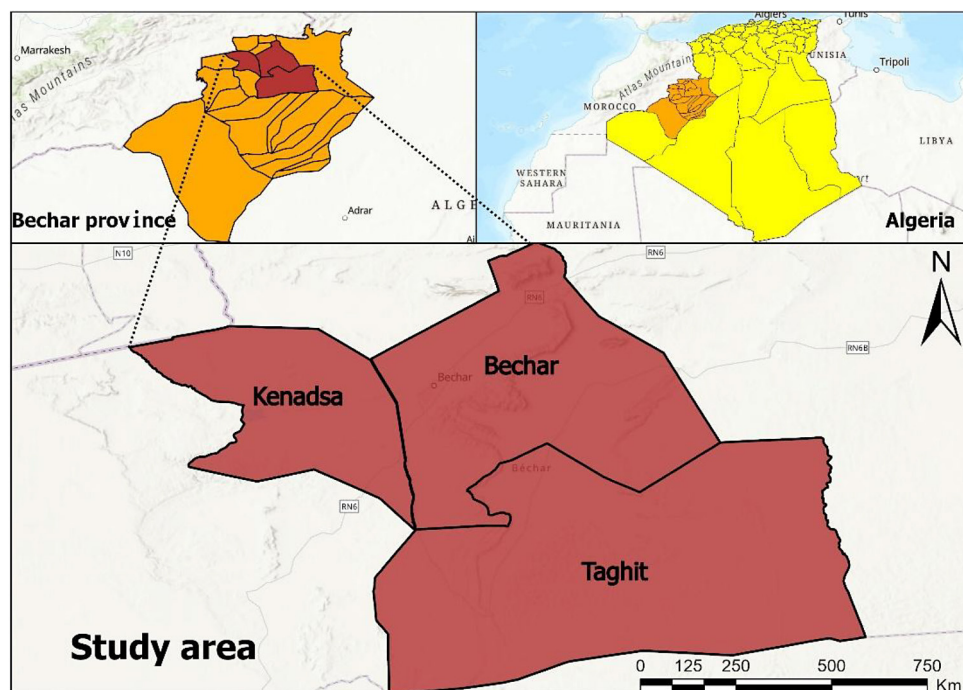


Figure 1. Study area map

of the 2025 median composite, all sampled at 30 m. A total of 168 reference points were digitized in GEE by visual interpretation of the 2025 composite and high-resolution Google Earth imagery, supported by field knowledge from the Directorate of Tourism and Handicrafts of Béchar. A class-stratified design was used, with points digitized separately for each class: built-up area ($n = 40$), palm groves ($n = 35$), sparse vegetation ($n = 18$), sand dunes ($n = 16$), rocky areas and bare soil ($n = 41$) and water bodies ($n = 18$). Each point was assigned a uniform random number (GEE randomColumn, seed = 0); points with a value below 0.6 were used for training and the remaining points were held out for validation, which yielded 88 training points and 80 independent validation points that were never used during training (per-class counts in Table 1 and Supplementary File S3). Accuracy was assessed from the confusion matrix of the validation subset (Table 1; Supplementary File S4), using overall accuracy, producer's and user's accuracies, and the Kappa coefficient, following established good-practice recommendations (Congalton, 1991; Olofsson et al., 2014). The classifier achieved an overall accuracy of 97.5% (78 of 80 validation points correctly classified; 95 % Wilson confidence interval: 91.3–99.3%) and a Kappa coefficient of 0.969, indicating almost perfect agreement (Landis & Koch, 1977).

The only two errors were one palm-grove point classified as built-up area and one water-body point classified as rocky area and bare soil.

Criteria selection and justification

The suitability criteria were rigorously selected to meet the central objective of the study identifying priority areas for sustainable ecotourism development within the Béchar-Taghit-Kenadsa territorial transect using variables that reflect, on the one hand, the fundamental biophysical conditions determining the landscape attractiveness and environmental sensitivity of Saharan and oasis ecosystems, and on the other hand, the logistical feasibility of travel and accessibility to service infrastructure and heritage sites (Ghorbanzadeh et al., 2019; Chaudhary et al., 2022). The final set of criteria was determined according to a three-fold requirement: alignment with the reference variables commonly used in GIS-MCDA-based ecotourism suitability modeling (Bagheri & Mohamadi, 2025); direct relevance to the territorial realities of the Béchar-Taghit-Kenadsa transect (sensitive oasis ecosystems, contrasting dune and rocky relief, urban expansion, and the fragility of the arid environment) (Benmihoub et al., 2024); and the availability of

Table 1. Confusion matrix of the Random Forest classification computed on the independent validation subset (n = 80); rows = classified classes, columns = reference classes

Classified reference	Built-up	Palm groves	Sparse Veg.	Sand dunes	Rocky bare	Water	Total	User's acc (%)
Built-up area	16	1	0	0	0	0	17	94.1
Palm groves	0	16	0	0	0	0	16	100
Sparse vegetation	0	0	7	0	0	0	7	100
Sand dunes	0	0	0	8	0	0	8	100
Rocky areas and bare soil	0	0	0	0	21	1	22	95.5
Water bodies	0	0	0	0	0	10	10	100
Total (reference)	16	17	7	8	21	11	80	
Producer's acc. (%)	100	94.1	100	100	100	90.9		

Note: Overall accuracy = 97.5% (78/80; 95% Wilson CI: 91.3–99.3%); Kappa = 0.969. Training subset: 88 points (built-up 24, palm groves 18, sparse vegetation 11, sand dunes 8, rocky areas and bare soil 20, water bodies 7).

homogeneous, high-resolution geospatial data coverage across the entire study area (Gorelick et al., 2017). Accordingly, this study integrates a comprehensive set of eight criteria: Four biophysical and morphometric criteria land use/land cover (LULC), elevation (DEM), slope, and aspect, were combined with four accessibility, hydrological and heritage criteria: distance to roads, distance to watercourses, distance to water points, and distance to ksour (fortified heritage settlements). The final AHP model therefore integrates eight criteria in total. The selection of each parameter is justified by its direct and decisive influence either on the ecological suitability and landscape value conducive to nature-based activities, or on the logistical feasibility of accessing and operating sites without inducing excessive or degrading infrastructure expansion.

Land use is a key spatial descriptor for assessing the degree of landscape naturalness, aesthetic quality, and intrinsic ecological vulnerability. Vegetated formations and open natural areas show optimal compatibility with low-impact ecotourism development. In contrast, urban expansion and intensive agricultural areas generate strong competition for land use, significantly reducing the suitability and ecotourism vocation of the territories concerned (Rafique et al., 2024). In this study, land cover was derived from the 2025 GEE image composite through supervised Random Forest classification, ensuring comprehensive coverage and consistent spatial representation. Water resources, represented by the distance to watercourses and proximity to water points play a vital ecological and recreational role in

hyper-arid Saharan and oasis landscapes, structuring both wildlife habitats and tourist attraction nodes. Elevation plays a decisive role in microclimate, landscape appeal, and visitor comfort, and can also indirectly constrain the technical feasibility of infrastructure (Chaudhary et al., 2022); elevation was extracted from the DEM used in this study to provide a continuous surface for reclassification. Slope was calculated from the same DEM to ensure internal consistency with the elevation layer and aspect (Shiferaw, 2021). Aspect influences sunlight exposure, vegetation, and temperature, which directly affects visitor comfort. It was therefore calculated from the DEM and classified by direction to accurately capture terrain microclimates (Rane et al., 2024); aspect was calculated from the DEM and categorized to represent directional differences relevant to local terrain and microclimatic variability. Proximity to existing tourist sites and historical monuments specifically the traditional ksour is a key asset for ecotourism, as it facilitates cultural heritage interpretation, management, promotion, and the creation of grouped itineraries. Developing these neighboring areas requires less new infrastructure while strengthening synergies among sites (Cardinali et al., 2024).

Tourist destinations and ksour inventories were established using maps and local sources mentioned in the Data section. Since road access is essential for safety, cost, and logistics, ecotourism must strike a balance between accessibility and preservation; this is why proximity to existing roads was favored, allowing access to sites without constructing new heavy infrastructure (Xu et al., 2025).

Analytical framework and mathematical formulations

The flowchart (Fig. 2) summarizes the methodological framework adopted to assess the ecotourism potential of the Béchar-Taghit-Kenadsa transect by coupling GIS, AHP and PROMETHEE. The analytical sequence begins with the pre-processing of satellite imagery in Google Earth Engine and the extraction of the eight criterion layers: land use/land cover, elevation, slope, aspect, distance to roads, distance to watercourses, distance to water points, and distance to ksour. Compiled and standardized within a geodatabase, these layers are reclassified and combined by weighted overlay using AHP weights validated by the consistency ratio. In parallel, the reclassified scores of the eight criteria are extracted at 134 candidate sites, which are ranked with PROMETHEE II using the same AHP weights to identify priority ecotourism sites.

AHP simplifies multi-criteria decision-making by organizing analysis parameters within a clear hierarchical structure (Saaty & Vargas, 2006). It determines the relative weight of individual characteristics using pairwise comparison matrices, relying on a continuous numerical scale from 1 to 9 to express the intensity of preference judgments. The final weights assigned to the different criteria layers are then extracted and validated using the principal right-eigenvector method (Benoumeldjadj et al., 2025).

$$a_{ij} = 1 / a_{ji} \quad (1)$$

In the case of the reciprocal matrix, a_{ij} follows the equality $a_{ij} = p_i / p_j$, where p_i represents the preference of alternative i , as shown below (Eq. 2).

$$A = [P_i / P_j] \text{ for } i, j = 1 \dots n \quad (2)$$

($n \times n$ reciprocal matrix)

Summing all components of column j in matrix A gives Eq. (3):

$$\frac{P_1}{P_j} + \frac{P_2}{P_j} + \dots + \frac{P_n}{P_j} = \sum (P_i / P_j), i = 1 \dots n \quad (3)$$

The priority vector $w = (w_1, \dots, w_n)$ is obtained as the normalized principal right eigenvector of the pairwise comparison matrix A (Saaty, 1980), using Eq. (4):

$$A \cdot w = \lambda_{\max} \cdot w, \text{ with } \sum w_i = 1 \quad (4)$$

The consistency ratio (CR) evaluates the reliability of the pairwise comparisons among

parameters and their subcategories, as formulated in Eq. (5):

$$CR = CI / RCI \quad (5)$$

where: CR is the consistency ratio, CI is the consistency index, and RCI is the random consistency index. CI was calculated using Eq. (6):

$$CI = (\lambda_{\max} - n) / (n - 1) \quad (6)$$

where: CI is the consistency index and $\lambda_{\max}$ represents the principal (largest) eigenvalue of the pairwise comparison matrix. $\lambda_{\max}$ is calculated using Eq. (7):

$$\lambda_{\max} = (1/n) \cdot \sum [(A \cdot w)_i / w_i], i = 1 \dots n \quad (7)$$

where: $(A \cdot w)_i$ is the i -th element of the product of matrix A and the weight vector w , and w_i is the weight of criterion i .

The random consistency index RCI equals 1.41 for $n = 8$ (Saaty, 1980). A CR value ≤ 0.1 indicates an acceptable AHP result; if $CR > 0.1$, the result is inconsistent and the pairwise comparisons must be revised.

Weighted overlay analysis

To generate the final tourism-suitability map, the weighted-overlay method (Eq. 8) was applied to combine all factors using quantitative measures. Assessing a site requires assigning a specific weight to each thematic layer in proportion to its impact on the vulnerability of the study area; this spatial overlay made it possible to precisely identify the most sensitive sectors.

$$\sum (W_i \times S_i), i = 1 \dots n \quad (8)$$

where: W_i is the weight of the selected parameters and S_i is the weight of the sub-parameters.

PROMETHEE method

Implementation of the method relies on evaluating a preference function $P_j(a, b)$ for each criterion j , representing the preference of alternative a over alternative b based on the difference in their performance:

$$P_j(a, b) = F_j(d(a, b)) \quad (9)$$

where: $d(a, b) = g_j(a) - g_j(b)$ expresses the performance difference between two alternatives a and b for criterion j .

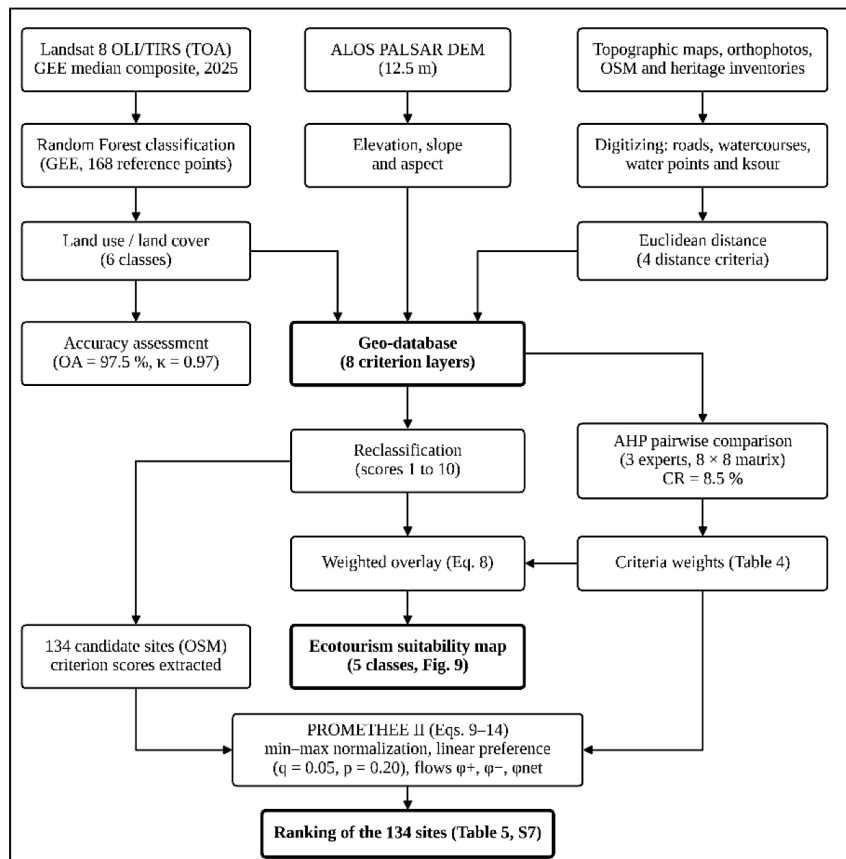


Figure 2. Methodological flowchart of the GIS-MCDA framework for ecotourism suitability mapping. The workflow illustrates the integration of remote sensing data (Google Earth Engine), spatial database creation, reclassification, AHP pairwise comparison (Eqs. 1–7), weighted overlay analysis (Eq. 8), and PROMETHEE II ranking of the candidate sites (Eqs. 9–14).

An overall preference index $\pi(a, b)$ is then calculated by aggregating the weighted preferences across all n criteria:

$$\pi(a, b) = \sum W_j \cdot P_j(a, b) \quad (10)$$

where: W_j is the weight assigned to criterion j (derived from the AHP method). Finally, for each alternative, the method computes two preference flows outgoing and incoming.

The outgoing preference flow $\phi^+(a)$ measures the dominance of alternative a over all others:

$$\phi^+(a) = [1/(m-1)] \cdot \sum \pi(a, x), x \in A, x \neq a \quad (11)$$

The incoming preference flow $\phi^-(a)$ measures the extent to which alternative a is dominated by the other alternatives:

$$\phi^-(a) = [1/(m-1)] \cdot \sum \pi(x, a), x \in A, x \neq a \quad (12)$$

where: m is the number of alternatives ($m = 134$), so that ϕ^+ and ϕ^- range from 0 to 1 and ϕ_{net} from -1 to 1 .

The net preference balance, $\phi_{net} = \phi^+(a) - \phi^-(a)$, obtained from the difference between the outgoing and incoming flows, makes it possible to establish the final ranking and precisely discriminate the most efficient and robust ecotourism sites within the Saoura transect.

For each criterion j , a linear preference function with an indifference threshold (q_j) and a preference threshold (p_j) was adopted, appropriate for continuous spatial variables (Brans & Vincke, 1985), as expressed in Eq. (13):

$$P_j(d) = 0 \text{ if } d \leq q_j; P_j(d) = (d - q_j)/(p_j - q_j) \text{ if } q_j < d \leq p_j; P_j(d) = 1 \text{ if } d > p_j \quad (13)$$

Before the pairwise comparisons, the value of each criterion j for each alternative a was normalized with the min–max method, $g_j(a) = [g_j(a) - \min_j] / [\max_j - \min_j]$ (Eq. 14), where $\min_j$ and $\max_j$ are the minimum and maximum values of criterion j over the 134 alternatives, so that all criteria vary between 0 and 1 and heterogeneous units

become comparable. The criterion values entered in PROMETHEE are the reclassified suitability scores of the eight criteria (1 = very low to 10 = excellent; Supplementary File S6), in which the direction of preference of the raw variables (for example, a shorter distance to roads corresponds to a higher score) is already encoded; all eight criteria were therefore treated as criteria to be maximized. The same linear preference function (Eq. 13) was applied to all criteria, with an indifference threshold $q_j = 0.05$ (5% of the normalized criterion range) and a preference threshold $p_j = 0.20$ (20% of the range), following Taherdoost & Madanchian (2023); the weight, direction, preference function and thresholds of each criterion are summarized in Table 6. The alternatives consisted of 134 candidate sites extracted from OpenStreet-Map (OSM) within the study area, comprising features of heritage, tourist and service interest (mainly ruins and ksour, together with heritage districts, a rock-art archaeological site, a café, a recreation ground, transport stops and road segments); linear and polygonal features were represented by their centre points, at which the values of the eight reclassified criterion layers were extracted. For each ordered pair of alternatives ($134 \times 133 = 17,822$ pairs), the unicriterion preferences $P_j(a, b)$ (Eqs. 9 and 13) and the aggregated preference index $\pi(a, b)$, weighted by the AHP weights (Eq. 10; Table 4), were computed, followed by the positive, negative and net flows (Eqs. 11–12) and the complete PROMETHEE II ranking, alternatives with identical net flows receiving the same rank. Of the 135 features initially retrieved from OSM, one (way/737904037) had no geometry in the final candidate-site layer and could not be assigned criterion values; the analysis was therefore carried out on the remaining 134 sites, so that the input data, calculations and results reported here all refer to the same set of alternatives. Because all 134 sites lie within the highest suitability class (score 10) for distance to roads and distance to ksour, these two criteria do not discriminate among the alternatives (their unicriterion preferences are zero for every pair), and the ranking is driven by the six remaining criteria. All PROMETHEE II calculations were performed with an open-source Python script (Supplementary File S8), which regenerates every step from the input matrix. The complete input dataset (OSM identifiers, feature types, names, coordinates and the eight criterion values of the 134 alternatives), the normalized values, the preference parameters, the

unicriterion and aggregated pairwise preferences, the positive, negative and net flows and the final ranks are provided in Supplementary File S7.

RESULTS AND DISCUSSION

Land use and land cover

The land-use/land-cover (LULC) classification of the Saoura Valley includes built-up areas, palm groves, sparse vegetation, sand dunes, rocky areas and bare soil, and water bodies. Algeria's Saharan ecosystems and natural oases, particularly the emblematic dunes and historic ksour of the Béchar-Kenadsa-Taghit axis offer exceptional potential for the development of ecotourism and cultural tourism. Nevertheless, this sector remains at an early stage of development. This study indicates that socio-economic and biophysical characteristics are the main drivers of land-use change. Conversion factors fall into two categories: direct (proximate) causes and underlying causes. Direct causes are actions that immediately modify the environment, such as urban expansion, sand encroachment, or agricultural development in oasis areas. Moreover, research on land use in drylands has focused mainly on desertification dynamics and land-cover change, paying little attention to the impacts of these changes on oasis ecosystem services. Table 2 shows that the study area covers a total surface of 16,123 km² (1,612,341 ha), comprising 52.6% rocky areas and bare soil, 22.1% sand dunes, 11.5% sparse vegetation, 7.1% palm groves, 6.6% built-up areas, and 0.2% water bodies. This Saharan region is dominated by rocky terrain and bare soil (52.6%), while sand dunes and sparse vegetation account for 22.1% and 11.5%, respectively. The predominance of rocky surfaces and dunes (together nearly 75% of the territory) can be explained by the hyper-arid climate and Saharan topography of the region. From an ecotourism perspective, although the overall landscape of the Saoura Valley is characterized by a severe arid environment, the presence of dense palm groves (7.1%), contrasting with monumental sand dunes, creates unique oasis landscapes highly conducive to tourist attractiveness.

Distance to road

Ecotourism and independent travel are genuine drivers of the economy of rural and oasis

territories. In areas such as the Saoura corridor (linking Béchar, Kenadsa, and Taghit), landscape enhancement and the development of transport infrastructure play a decisive role in the region's attractiveness (Qin et al., 2023; Fong et al., 2017).

The interactions between the road network and tourism activity are close and multidimensional. On one hand, the tourism boom stimulates the development and modernization of communication routes as well as the diversification of traffic flows. On the other hand, improved road connections facilitate long-distance travel and shorten travel times to remarkable sites. Finally, the establishment of reception facilities and associated services in this region rests mainly on three fundamental pillars: accessibility, territorial attractiveness, and quality of development (Toufik et al., 2022).

The maximum distance to the road network reaches 37.2 km, while the minimum distance occurs in the immediate vicinity of the main axes (Fig. 3); the road network of the urban center of Béchar is denser and more developed than that of the oasis and peripheral areas due to its central role. Regarding ecotourism, transport infrastructure is essential while ensuring that the Saharan ecosystem is not disturbed and that the oasis and Ksuri heritage is not weakened, with walking and hiking favored where direct road access is absent. Accessibility is thus structured around an immediate proximity zone of 0–2.5 km allowing quick access, an intermediate zone of 2.5–6 km for short excursions, transition zones of 6–20 km requiring all-terrain vehicles or a supervised hike, and finally the deep

Saharan expanses beyond 20 km, which are markedly more isolated. Despite the constraints of the arid environment, road service along the Béchar-Kenadsa-Taghit corridor facilitates travel to the main points of interest and boosts the local economy.

However, road infrastructure does not necessarily guarantee sufficient access to tourist attractions, as this depends on efficient organization of access and transport. Investment in tourism infrastructure is often assessed in terms of its potential to drive tourism growth, increase tourism spending, and affect economic development. Accordingly, the Saoura study area has a sufficient main road network to ensure overall accessibility, although the development of suitable tracks remains necessary to connect certain isolated sites without compromising the environment (RN 6). The configuration of the network and its accessibility make it easier for visitors to engage with the local population and discover the scenic and geographic beauty of Béchar, Kenadsa, Taghit, and their surroundings.

Topography

Topography describes the relief of the Earth's surface through elevation and slope, both determining factors for scenic beauty and tourist appeal. In the Saoura region (Béchar, Kenadsa, Taghit), elevation ranges from 511 to 1,954 m, illustrating the contrasts between oasis valleys, regs, and the surrounding relief conducive to exploration (Figure 4).

Figure 5 shows that in the eastern part of the Saoura Valley, slope displays substantial variation, with angles ranging from 13.85° to 65.44°. This area also lies at higher elevation. Variations in elevation and slope increase the frequency of slope changes. In the context of ecotourism, higher elevations and steeper slopes offer exceptional panoramic views of the surrounding landscape (Chaudhary et al., 2022). The oasis landscape and picturesque ksour of the Béchar, Taghit, and Kenadsa region will undoubtedly captivate visitors. These areas are more frequented by hikers than developed zones. The most uniform terrain in the region (slope angles of 0°–2.31°) corresponds to regs and extension zones, and the vast desert plateau with its steep escarpments constitutes an ideal study site.

Analysis of slope orientation (aspect), a determining parameter in GIS-AHP modeling for

Table 2 . Extent of the LULC classes (areas computed from the 30 m classified raster; reference study area = 16,123 km², i.e. 1,612,341 ha)

Class	Area (ha)	%
Built-up area	107,138	6.6%
Palm groves	114,252	7.1%
Sparse vegetation	184,898	11.5%
Sand dunes	356,201	22.1%
Rocky areas and bare soil	847,394	52.6%
Water bodies	2,457	0.2%
Total	1,612,341	100%

Note: Class areas are rounded to the nearest hectare; their sum (1,612,340 ha) differs from the total (1,612,341 ha) by 1 ha because of rounding, 1 km² = 100 ha.

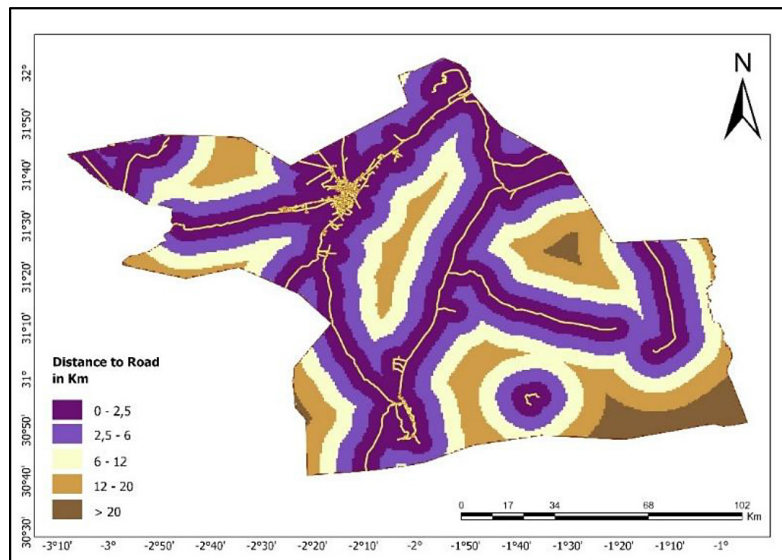


Figure 3. Distance to road

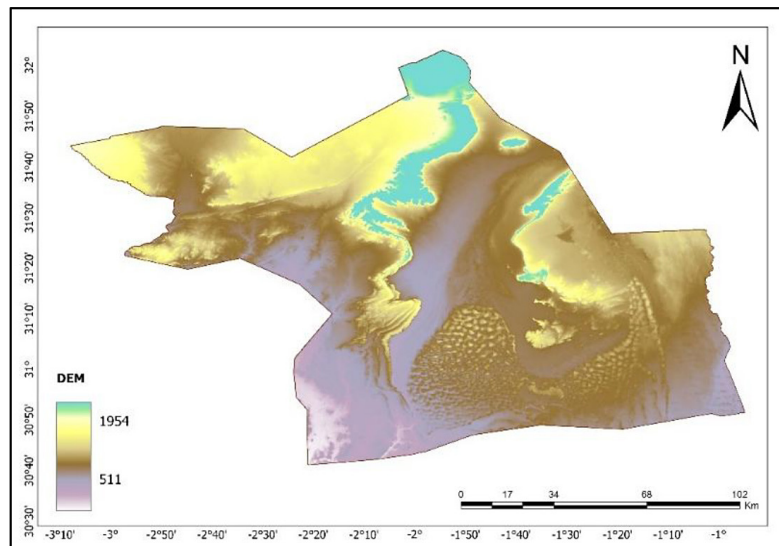


Figure 4. DEM map

ecotourism in Saharan environments, reveals strong morphological heterogeneity along the Béchar-Kenadsa-Taghit transect. Expressed in cardinal exposures, this variable directly affects microclimate, visitor thermal comfort, and the distribution of oasis vegetation. North- and northwest-facing slopes, as well as flat areas, offer shading and thermal-stress mitigation conditions that are particularly favorable for the enhancement of hiking trails and Ksuri heritage. Conversely, south- and southeast-facing slopes, characterized by maximum solar exposure, are subject to intense heat stress, requiring rigorous planning of ecotourism routes and reception infrastructure (Fig. 6).

Reclassification

To perform the weighted-overlay analysis along the Béchar-Kenadsa-Taghit transect, all eight input layers, including aspect, were reclassified into ten standardized suitability ranging from 1 (very low) to 10 (excellent); the reclassification rules for each criterion are provided in Supplementary File S6. Reclassification is a crucial step that standardizes diverse spatial datasets, allowing their integration into a single suitability model for Saharan ecotourism planning. The land-cover layer (LULC), derived from the 2025 Random Forest classification performed in GEE, was classified into six landscape entities characteristic of

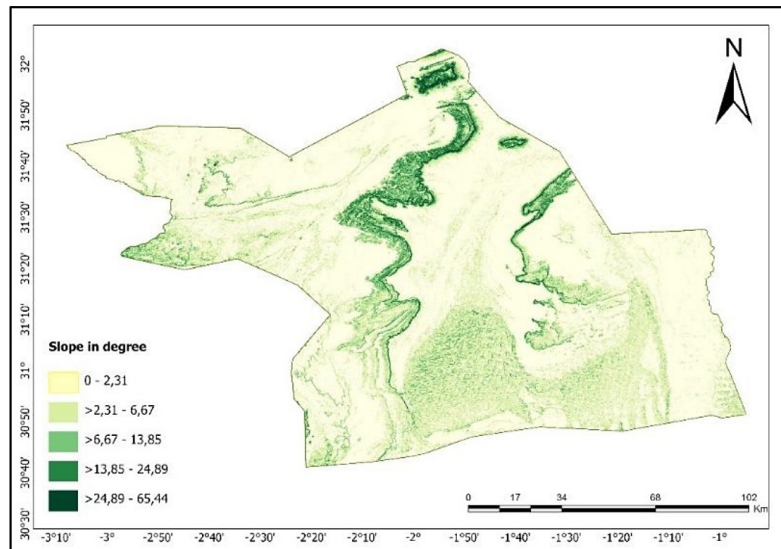


Figure 5. Slope map

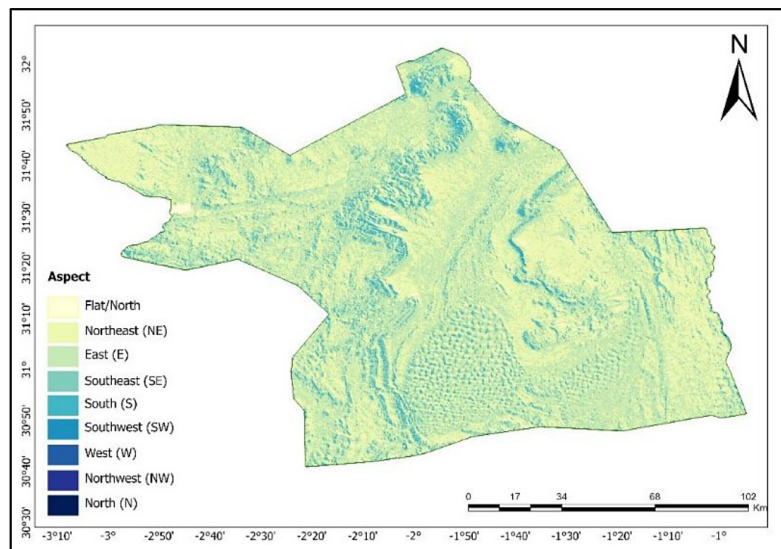


Figure 6. Aspect map

the oasis and Saharan environment: built-up area, palm groves, sparse vegetation, sand dunes, rocky areas and bare soil, and water bodies.

The results of the spatial modeling show that all evaluated criteria, including the classified land cover (LULC), topography (DEM and slope), slope aspect, and proximity to road infrastructure, ksour, water courses, and water points were reclassified on a standardized scale from 1 to 10 (from very low to excellent). This spatialization highlights the strong heterogeneity of the oasis and Saharan environment, where contact zones between palm groves, dune ridges, and communication routes achieve the highest potential for the planning and development of

sustainable ecotourism along the Béchar-Kenadsa-Taghit corridor.

Analytic hierarchy process and weight derivation

To determine the relative weight and significance of each parameter in the Béchar-Kenadsa-Taghit ecotourism model, a pairwise comparison matrix was established using the analytic hierarchy process (AHP). This approach relied on a standard numerical scale to assess the relative importance of landscape dynamics, topographic contrasts, slope orientation, and the different communication networks, heritage proximities,

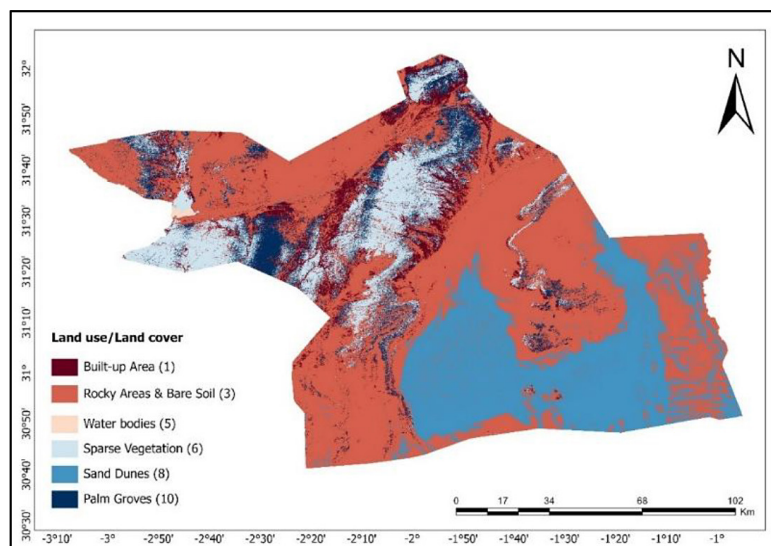


Figure 7. LULC map reclassified

and water and oasis resources. The eigenvalues of each factor were then normalized to generate a priority vector summing to 1.

The pairwise comparison matrix was constructed through a structured expert elicitation process. Three experts with documented expertise in Saharan geography, oasis ecology, and tourism planning were consulted independently: (i) a senior planner from the Directorate of Tourism and Handicrafts of Béchar wilaya, (ii) a geographer specializing in Saharan oasis systems, and (iii) a remote sensing specialist. Each expert completed the 8×8 pairwise comparison using Saaty's 1-9 scale. Individual matrices were aggregated using the geometric mean method (Saaty & Vargas, 2006), which preserves the reciprocal property of the matrix. The aggregated matrix yielded $\lambda_{\max} = 8.840$, $CI = 0.120$, and $CR = 8.5\%$, below the 10% acceptability threshold (Table 3). Individual expert matrices and the aggregation steps are provided in Supplementary File S5.

These weights reflect the biophysical, morphological, and landscape specificities of the study area as well as insights from the scientific literature dedicated to ecotourism planning in the Sahara. The pairwise comparison matrix for the eight criteria of the ecotourism model was used to determine the relative weight of each parameter. The results show that land use (LULC) ranks first with the highest weight (30.7%), followed by distance to watercourses (To_waterway, 14.2%) and proximity to water points (To_waterpoint, 12.8%). These are followed by distance to roads (To_road, 12.0%), proximity to ksour

(To_ksour, 11.1%), elevation (DEM, 8.7%), slope (7.4%), and finally aspect, which carries the lowest weight (3.1%). The consistency of the pairwise comparisons was validated with a consistency ratio (CR) of 8.5% (below the critical threshold of 10%), based on 28 comparisons and an eigenvector solution that converged in 6 iterations (principal eigenvalue of 8.840), confirming the reliability of the weights assigned for mapping the region's ecotourism potential.

The final suitability map (Fig. 9), derived from the weighted overlay in ArcGIS Pro using the validated AHP coefficients, highlights a contrasting spatial distribution of ecotourism potential across the Béchar-Kenadsa-Taghit transect. The spatial modeling results classify the territory into five distinct suitability classes, ranging from very low to very high. Areas of very low and low suitability are located mainly on extensive rocky plateaus and regs devoid of vegetation or subject to major topographic and accessibility constraints, requiring strict precautionary measures or substantial logistical investment before any tourism development can be considered. Areas of moderate suitability represent a significant share of the study area and act as transition/buffer zones around communication routes and major landscape structures. Finally, areas of high and very high suitability are concentrated along the oasis corridor, in the immediate vicinity of water networks, traditional palm groves, and heritage/architectural sites (ksour) a strong suitability explained by the optimal convergence of the landscape appeal of ergs and oases, the availability of microclimatic

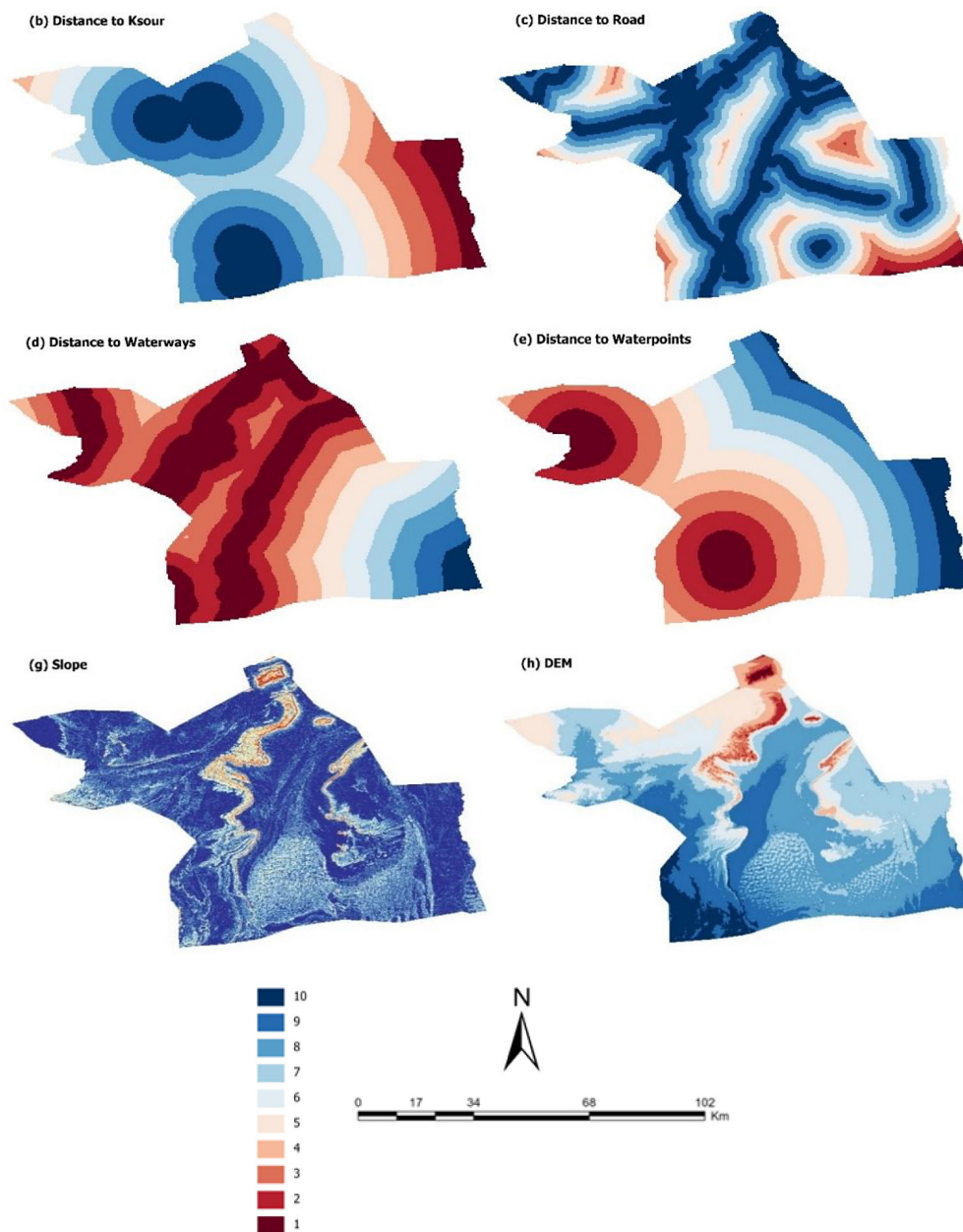


Figure 8. Reclassified criteria maps (suitability scores from 1 = very low to 10 = excellent): (b) distance to ksour; (c) distance to roads; (d) distance to watercourses; (e) distance to water points; (g) slope; (h) elevation (DEM). The reclassified LULC layer (a) is shown in Fig. 7; the reclassification rules of all criteria, including aspect, are given in Supplementary File S6

Table 3. Pairwise comparison matrix for ecotourism suitability

Criteria	LULC	Water_way	Water_point	To_Roads	To_Ksour	DEM	Slope	Aspect
LULC	1.00	4.00	3.00	4.00	2.00	4.00	3.00	6.00
Water_way	0.25	1.00	2.00	1.00	3.00	1.00	2.00	3.00
Water_point	0.33	0.50	1.00	2.00	2.00	2.00	1.00	4.00
To_Roads	0.25	1.00	0.50	1.00	3.00	1.00	2.00	3.00
To_Ksour	0.50	0.33	0.50	0.33	1.00	3.00	2.00	5.00
DEM	0.25	1.00	0.50	1.00	0.33	1.00	2.00	3.00
Slope	0.33	0.50	1.00	0.50	0.50	0.50	1.00	4.00
Aspect	0.17	0.33	0.25	0.33	0.20	0.33	0.25	1.00

Table 4. Criteria weight

Rank	Criterion	Weight
1	LULC	30.7%
2	Distance to water_way	14.2%
3	Distance to water_point	12.8%
4	Distance to roads	12.0%
5	Distance to ksour	11.1%
6	DEM (elevation)	8.7%
7	Slope	7.4%
8	Aspect	3.1%

shade favorable to visitor thermal comfort, and logistical accessibility structured by National Road No. 6 (RN 6). This spatialization thus provides territorial managers and planners with an essential decision-support tool for directing ecotourism investment as a priority toward high-potential areas while ensuring the preservation of vulnerable oasis and cultural environments.

Prioritization and multi-criteria selection of ecotourism sites using the PROMETHEE method

To refine the selection of potential sites derived from the weighted-overlay model, the PROMETHEE multi-criteria method was applied to establish a rigorous ranking of territorial alternatives. Using multi-criteria preference flows, synthesized through the net preference balance (ϕ_{net}) and the resulting ranking, makes

it possible to finely discriminate among the most efficient spatial units. The results reveal a clearly separated top tier, led by two alternatives located on the same pixels, the Ksar de Kenadsa and the Café Ksar within it, which share the maximum net flow ($\phi_{net} = 0.417391$) owing to their high scores for land cover, proximity to watercourses and slope. Conversely, the least favorable alternatives rank at the bottom with markedly negative net flows, down to $\phi_{net} = -0.443105$ for the last-ranked site (rank 134; Table 5); these sites are penalized mainly by their land-cover and water-proximity scores, since distance to roads and distance to ksour are identical for all candidate sites. This final prioritization thus offers decision-makers and managers a clear and rigorous operational view for prioritizing development investment and reconciling the tourism enhancement of south-western Algeria with the preservation of vulnerable oasis and cultural environments (Fig. 10).

Analysis of Figure 11 highlights the spatial distribution of preferred ecotourism areas across the Saoura transect. Three major sites emerge: Site 1, located near Kenadsa; Site 2, anchored in the urban and peri-urban pole of Béchar; and Site 3, extending across the oasis and dune system of Taghit. The PROMETHEE ranking (Table 5) refines this picture at the level of individual candidate sites: the three best-ranked alternatives are located in Kenadsa: the Ksar de Kenadsa and the Café Ksar within it (tied at rank 1) and the old ksar district (Cité Vieux Ksar, rank 3). They are followed by ruins located south of Taghit (ranks 4–15), whereas ruins close to Taghit and the Palais

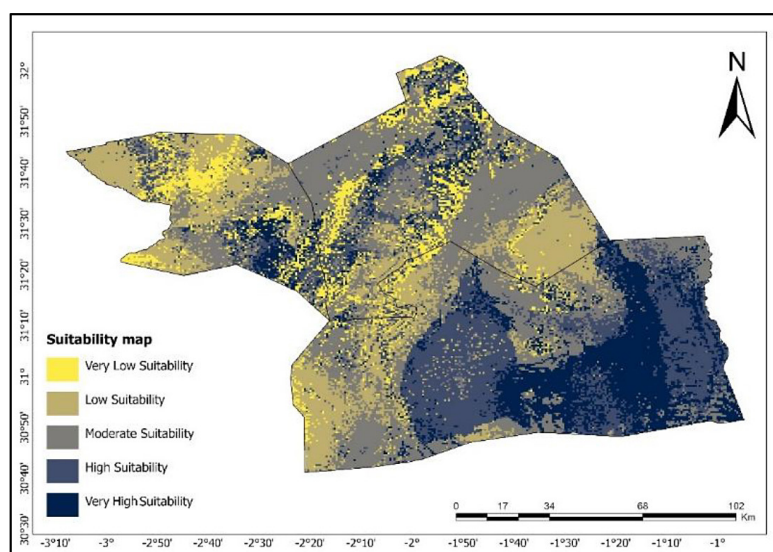
**Figure 9.** Suitability map

Table 5. PROMETHEE II ranking of the highest-ranked (ranks 1–10) and lowest-ranked (ranks 125–134) of the 134 candidate sites; tied alternatives share the same rank (the complete input data, pairwise preferences, flows and ranks of all 134 alternatives are given in Supplementary File S7)

Rank	OSM identifier	OSM feature type	Name	ϕ_{net}
1 (tied)	way/377283893	amenity = cafe	Café Ksar	0.417391
1 (tied)	way/318824596	historic = heritage	Ksar de Kenadsa	0.417391
3	node/4307128138	place = suburb	Cité Vieux Ksar	0.377661
4	node/3969022724	historic = ruins	–	0.313865
5 (5 tied)	node/3969022497; node/3969022473; node/3969022345; node/3968884108; node/3969022528	historic = ruins	–	0.311549
10 (6 tied)	node/3969022279; node/3969022745; node/3969022556; node/3969022677; node/3969022886; node/3969022286	historic = ruins	–	0.278484
...	...	...	...	...
125	node/3969048075	historic = ruins	–	–0.361338
126	node/2675796513	historic = castle	–	–0.385147
127 (7 tied)	node/3968499321; node/3968499527; node/3968499287; node/3968499294; node/3968499539; node/3968499304; node/3968499333	historic = ruins	–	–0.406013
134	node/3967945322	historic = ruins	Palais de Taghit	–0.443105

Note: Tied alternatives share the same rank; ϕ_{net} is dimensionless and ranges from –1 to 1 (Eqs. 11–12, $m = 134$).

de Taghit occupy the lowest ranks (127–134). This contrast shows that the strong landscape potential of the Taghit dune–oasis system is not matched, at site level, by the performance of all of its heritage features on the weighted criteria, which calls for a closer examination of the constraints affecting these sites. Together, these areas combine strong biophysical suitability, proximity to structuring transport routes (such as RN 6), and accessibility to heritage assets, offering a basis for guiding sustainable tourism investment and the enhancement of Saharan heritage.

The ecotourism-potential assessment conducted along the Béchar-Kenadsa-Taghit territorial transect used GIS, GEE, AHP and PROMETHEE techniques to produce a weighted-overlay map of suitable areas. This map classified the study area into five levels of suitability potential. The spatial distribution results for land cover (LULC), covering the study area of 16,123 km² (1,612,341 ha), reveal that rocky areas and bare soil dominate the territory with 847,394 ha (52.6%), followed by sand dunes with 356,201 ha (22.1%), sparse vegetation with 184,898 ha (11.5%), traditional palm groves with 114,252 ha (7.1%), built-up areas with 107,138 ha (6.6%), and finally water bodies with 2,457 ha (0.2%).

Among the eight AHP evaluation criteria (validated with a consistency ratio of 8.5%),

land cover (LULC) obtained the highest weight (30.7%), underscoring its major influence on the suitability analysis. This is followed by distance to watercourses (14.2%), proximity to water points (12.8%), distance to roads (12.0%), proximity to ksour (11.1%), DEM elevation (8.7%), slope (7.4%), and aspect, with the lowest weight (3.1%). Topographic analysis indicates that elevation ranges from 511 to 1,954 m, while slope shows substantial variation in the east, with angles ranging from 13.85° to 65.44°, contrasting with the flat regs (0°–2.31°).

Three main priority poles and preferred sites were highlighted by the modeling (notably via the PROMETHEE method). Zone 1 (near Kenadsa) stands out for its architectural and spiritual heritage. Zone 2 (Béchar region) offers a peri-urban attraction combining accessibility and logistical dynamism along RN 6. Zone 3 (Taghit dune and oasis system) combines the monumental landscapes of the Grand Erg Occidental with dense palm groves, making it a preferred destination for nature-based ecotourism and hiking.

Despite its strengths, this study has several limitations. The AHP model relies on expert judgment for weight assignment, which introduces a degree of subjectivity and may affect the precision of the final map. It should be noted that the potential map produced in this study primarily

Table 6. PROMETHEE II parameters applied to the eight criteria (criterion values = reclassified suitability scores, normalized by the min–max method, Eq. 14)

Criterion	AHP weight	Direction	Preference function	q	p
LULC	0.307	Maximize	Linear (Eq. 13)	0.05	0.20
Distance to watercourses	0.142	Maximize	Linear (Eq. 13)	0.05	0.20
Distance to water points	0.128	Maximize	Linear (Eq. 13)	0.05	0.20
Distance to roads	0.120	Maximize	Linear (Eq. 13)	0.05	0.20
Distance to ksour	0.111	Maximize	Linear (Eq. 13)	0.05	0.20
Elevation (DEM)	0.087	Maximize	Linear (Eq. 13)	0.05	0.20
Slope	0.074	Maximize	Linear (Eq. 13)	0.05	0.20
Aspect	0.031	Maximize	Linear (Eq. 13)	0.05	0.20

Note: q and p are expressed on the normalized [0, 1] scale, i.e. 5 % and 20 % of the range of each criterion over the 134 alternatives. Direction = maximize for all criteria because the reclassified scores already increase with suitability (Supplementary File S6).

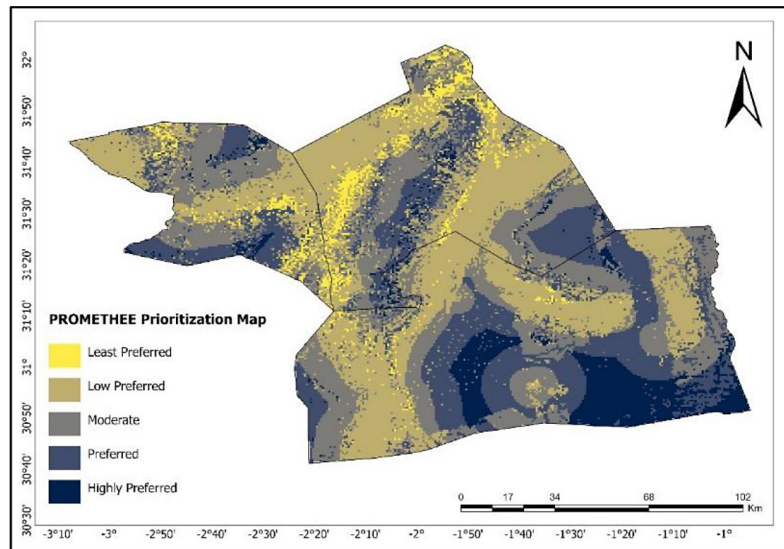


Figure 10. Multi-criteria prioritization map of ecotourism sites using the PROMETHEE method

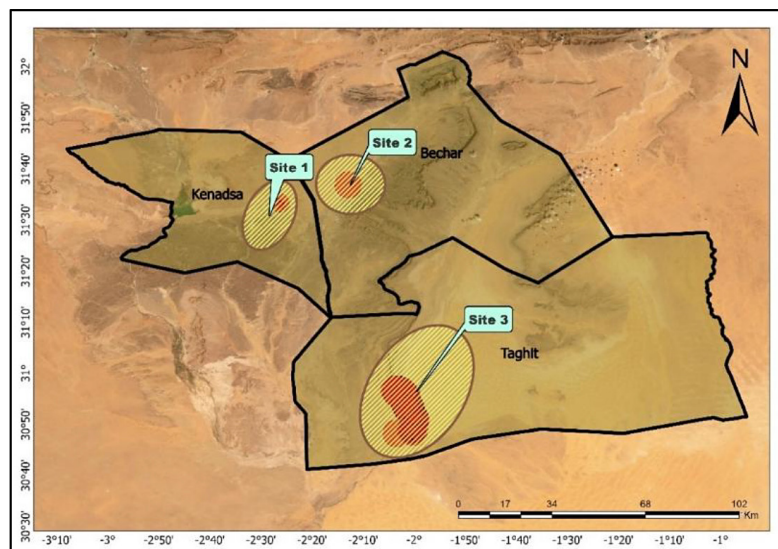


Figure 11. Preferred ecotourism sites

represents physical suitability, based on biophysical and morphological conditions and logistical accessibility along the corridor. Although these factors are necessary to identify areas suited to ecotourism activities in arid environments, they are not sufficient to determine the full tourism potential of a given place. The performance of a destination also depends on factors not fully captured by the current model, such as the uniqueness and interpretive value of Ksurian attractions, the willingness and capacity of the local community to host visitors, governance and safety conditions, service availability, and market demand. In addition, the classification was validated with a relatively small independent sample (80 points, with only 7–11 points for some classes) derived from visual interpretation of imagery rather than from a field survey; the resulting accuracy estimates therefore carry non-negligible uncertainty (95 % confidence interval of overall accuracy: 91.3–99.3%), and a larger, field-based validation campaign would provide a more robust assessment.

CONCLUSIONS

The results show that a significant portion of the study area presents moderate to high suitability for ecotourism development. Land use (LULC) was found to be the most influential factor, followed by distance to watercourses, proximity to water points, distance to roads, proximity to ksour, DEM elevation, slope, and aspect. Three major priority poles (Kenadsa, Béchar, and Taghit) were highlighted for their rich ecological, cultural, and architectural (Ksurian) significance, offering diversified opportunities for nature-based, spiritual, and community ecotourism. Despite these promising results, the study also revealed constraints such as urban expansion, the vulnerability of oasis ecosystems, and uneven accessibility in some arid areas.

These findings contribute significantly to the achievement of global sustainable development targets: SDG 8 (Decent Work and Economic Growth), through the creation of tourism-related income opportunities; SDG 11 (Sustainable Cities and Communities), by promoting decentralized tourism growth between urban and oasis hubs; SDG 13 (Climate Action), through support for low-emission practices such as hiking; and SDG 15 (Life on Land), through the preservation of natural landscapes and palm groves. The study

also provides a documented decision-support framework, whose input data, intermediate calculations and code are deposited in a public repository for independent verification, and a context-specific empirical contribution to reconciling post-oil economic growth with environmental conservation in arid environments.

Data availability statement

All data, code and intermediate results needed to verify the results of this study are deposited in a public, open-access Zenodo record (<https://doi.org/10.5281/zenodo.23022933>) under a CC-BY 4.0 licence; the DOI resolves to the published record and all files can be downloaded without registration or access request. The record contains Supplementary Files S1–S9 listed below, which are also provided as Supplementary Material to this article, together with a README file describing the content and format of each file. This includes the reference points, classification and accuracy-assessment files, AHP matrices, reclassification rules, the complete PROMETHEE II dataset and calculations, the source code and the geospatial layers (previously available only on request). Candidate-site data derived from OpenStreetMap (Supplementary Files S7 and S9) are © OpenStreetMap contributors and are redistributed under the Open Database License (ODbL).

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