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## **MULTI-CRITERIA SPATIAL DECISION-MAKING FOR TOURISM RESORT SITE: A CASE STUDY OF KHENCHELA PROVINCE, ALGERIA**

**Abstract:** This study aims to evaluate land suitability for establishing tourist resorts in the Wilaya of Khenchela, a region distinguished by unique natural and historical assets that position it as a prospective tourism destination. The analysis methodology integrates Geographic Information Systems (GIS) with the Analytic Hierarchy Process (AHP) to identify the most suitable sites for tourism investment. The study classified the criteria into major categories: tourism criteria (proximity to tourist resources), economic criteria (proximity to roads and population centers), and environmental and topographic criteria (slope, elevation, terrain aspect, vegetation cover NDVI, fire risk, and air purity AOD). Relative weights were assigned to these criteria based on expert opinions, then spatially processed using GIS tools to generate a tourism suitability map. Results show that the most suitable areas concentrate near tourist resources and main roads, enhancing investment feasibility in these locations. The integration of environmental and topographic factors helps ensure sustainability and mitigate risks associated with tourism projects. The findings emphasize the importance of adopting quantitative and transparent analytical tools in tourism investment planning, supporting sustainable local development, and strengthening Khenchela's position as a national and regional tourism destination.

**Keywords:** tourism resort site, analytic hierarchy process, GIS- Factors, Khenchela Province

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## Introduction

Tourism has experienced a significant resurgence in recent years, largely due to its pivotal role in cultural and social exchange, job creation, and economic circulation. In 2023, international tourist arrivals reached approximately 1.3 billion, generating over 1.5 \$ trillion in revenue (UN Tourism, 2024). Within this dynamic landscape, ecotourism has emerged as one of the fastest-growing and most sustainable tourism models. The global ecotourism market was valued at approximately 232\$ billion in 2023 and is projected to reach 823 \$ billion by 2033 (T Pangarkar, 2024). This growth is attributed to increased tourist awareness and concerted efforts by planners to develop suitable infrastructure that meets the diverse needs of visitors.

In this context, tourist resorts hold a central position, offering an integrated suite of services that encompass accommodation, entertainment, healthcare, cultural activities, and educational programs. These resorts serve as effective tools for activating various tourism resources, often strategically located near specific attractions such as mountains, beaches, therapeutic springs, or archeological sites to enhance their appeal (Shaghaghpour & Larijani, 2017). For instance, a resort typically integrates residential and recreational facilities, allowing visitors to enjoy and benefit from a single natural or heritage environment, thereby increasing the added value of the region.

However, selecting the optimal location for establishing such resorts presents a significant challenge, as it necessitates careful consideration of a multitude of environmental, economic, and social criteria. Environmentally, factors such as terrain morphology, soil type, water availability, and biodiversity protection must be diversified. From a human and architectural perspective, proximity to roads, infrastructure, and local tourism demand are crucial considerations (Huong, Quang, An Thinh, & Luc, 2018). This intricate interplay of criteria makes it difficult, if not impossible, to reconcile them using traditional planning methods.

This is where Geographic Information Systems (GIS), supported by multi-criteria analysis methods such as the Analytical Hierarchy Process (AHP), play a crucial role. They provide an integrated and effective framework for decision-making in selecting tourism sites. These methodologies enable the creation and analysis of multi-layered spatial maps to evaluate each criterion based on its importance and to determine its relative weights, ultimately producing suitability maps that classify areas according to their appropriateness for the project establishment (Harishnaika, Arpitha, Ahmed, & Ashwini, 2023). This methodology has proven effective in applied studies worldwide; for example, multi-criteria analysis has been used in Turkey to identify the most suitable areas for ecotourism development and in India for planning ecotourism sites within a specific geographical region (Aşlıoğlu, 2021). This study aims to apply these advanced methodologies to the selection of suitable locations for a tourist resort project in Khenchela Province, Algeria, utilizing the AHP+GIS approach.

## Literature Review

In recent decades, there has been a marked increase in the use of Geographic Information Systems (GIS) integrated with Multi-Criteria Decision Analysis (MCDA) to develop precise scientific methodologies for assessing tourism site suitability. This integration has proven effective in addressing the complex nature of decision-making processes in environmental

tourism planning by incorporating a range of natural, social, and economic factors into a unified model that enables their spatial analysis in a quantitative and systematic manner. The importance of this approach stems from its ability to provide scientific support to decision-makers in identifying the best sites for tourism investment and advancing sustainable tourism development.

Many recent studies have relied on integrating Geographic Information Systems (GIS) with multicriteria decision analysis (MCDA) techniques to systematically and effectively evaluate the suitability of tourism and environmental sites. For instance, in a study by Khwanruthai and Yuji (2011) on Surat Thani Province in Thailand, they identified nine criteria (including landscape, biodiversity, terrain, proximity to cultural sites, and distances to roads and settlements), based on expert opinions. They employed the Analytical Hierarchy Process (AHP) to determine the weights of these criteria and link them to actual resources within the province. Although this methodology facilitated the identification of highly suitable areas for ecotourism, it relied solely on secondary data and expert judgments without conducting external validation or incorporating field-based data (Khwanruthai & Yuji, 2011).

Geremew and Yohannes (2015) applied Geographic Information Systems (GIS) and the Analytical Hierarchy Process (AHP) to the Bench Maji region in Ethiopia, classifying the areas into four categories: high, moderate, marginal, and unsuitable. Their results showed that only 14.3% of the area was highly suitable, 45.7% moderately suitable, 18.2% marginally suitable, and 21.8% unsuitable. This study relied on five main environmental criteria (vegetation density, land use, elevation, slope, and road networks) but acknowledged the exclusion of other important factors such as ecological sensitivity due to data limitations. Moreover, it was confined to an environmental perspective without integrating social or economic data (Geremew & Yohannes, 2015).

Similarly, Zerghi, Alireza, and Sayed (2019) conducted a study in the Bazingan Lake basin in Iran using GIS and Multi-Criteria Decision Making (MCDM) techniques. They extracted eight main criteria and 44 sub-criteria covering physical factors (topography, climate, soil), biological, social, and economic aspects. The resulting suitability map indicated that approximately 59% of the basin area was highly suitable for tourism, 20% moderately suitable, and 21% poorly suitable. However, the researchers noted that these findings were specific to local conditions and had not undergone independent evaluation (Zerghi, Alireza, & Sayed, 2019).

Conversely, N. Chaminda Withanage et al. (2024) developed an environmental tourism suitability index for a World Heritage city using 20 criteria distributed across six main categories, including topography, vegetation cover, accessibility, and negative factors. The results indicated that 45.4% of the area was classified as highly suitable or suitable for environmental tourism, with significant influence from forest cover and accessibility variables (Withanage et al., 2024).

In the same context, Çetinkaya and colleagues (2018) proposed a four-stage framework integrating GIS, AHP, and PROMETHEE methods to identify optimal sites for environmental tourism in the Black Sea region of Turkey, emphasizing the importance of stakeholder engagement in determining criterion weights to achieve more realistic and appropriate outcomes (Çetinkaya, Kabak, & Özceylan, 2018). Additionally, research demon-

strated that multi-criteria decision analysis provides more accurate and straightforward results compared to conventional methods, without requiring complex criterion weighting procedures (Jokar, Massoudi, & Karimi, 2021)

These studies support the significance of integrating spatial analysis with expert inputs and multiple criteria, providing a powerful tool for decision-makers in sustainable tourism planning and identifying priority areas for environmental tourism development.

Overall, literature review reveals that previous models offered valuable initial insights for identifying suitable tourism sites using Geographic Information Systems and multi-criteria analysis techniques (GIS and AHP). However, they share several methodological limitations that restrict their comprehensiveness and practical accuracy. Most focused exclusively on the natural dimension while overlooking social and economic aspects, and relied on inputs from a limited number of experts without conducting field verification against actual data. Furthermore, these studies did not address the prevention and hazard mitigation dimension that may affect tourism sustainability, such as risks from steep slopes, flooding, or wildfires, despite their importance for safe and sustainable tourism planning.

In this context, the present study seeks to address these gaps by adopting a more integrated methodology that combines environmental, social, and economic criteria simultaneously, while incorporating environmental protection and natural hazard mitigation as components of tourism suitability assessment. This approach is grounded in more comprehensive expert opinions and field survey findings, utilizing field data and actual indicators to validate results, while enhancing spatial analysis through higher spatial resolution. Thus, the study contributes to developing a more realistic and comprehensive model for assessing tourism suitability that transcends conventional previous models and reinforces principles of sustainability and hazard prevention in tourism planning.

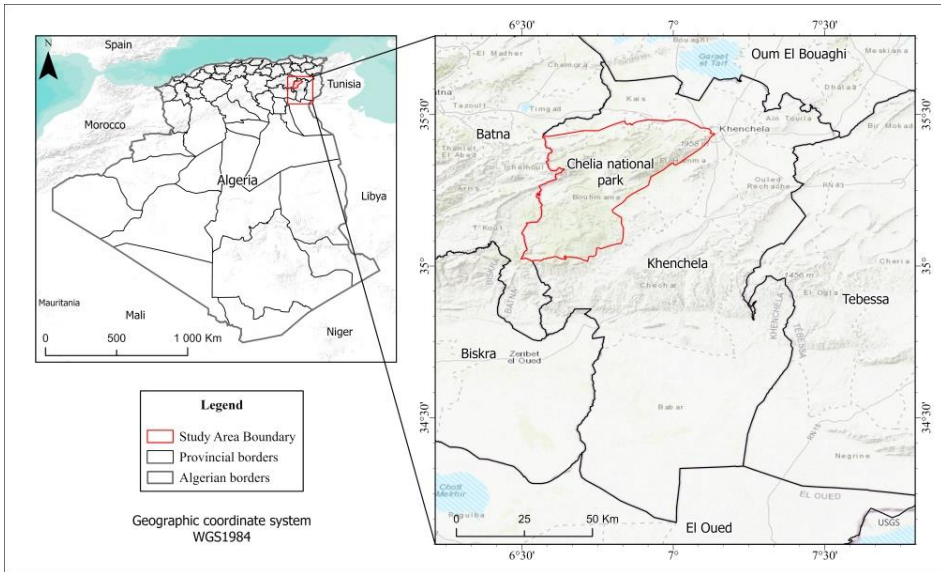
## **Materials and Methods**

### ***Study Area***

The study area is located in the Wilaya of Khenchela in eastern Algeria, within geographic coordinates ranging between latitudes 35.15° and 35.483° North and longitudes 6.497° and 7.137° East, covering a total area of approximately 1,574.8 km<sup>2</sup>. The region is predominantly characterized by rugged mountainous terrain as it forms part of the Aures mountain range, which includes the highest peak in eastern Algeria, Mount Chelia, with an elevation of approximately 2,328 meters. Additionally, the Nemamcha plateaus, which represent an extension of the Saharan Atlas, rise to a maximum elevation of about 1,712 meters. The area is marked by deep valleys and steep slopes, resulting from its diverse topographic structure. The climate is Mediterranean mountainous with a local continental influence, characterized by hot, dry summers with temperatures exceeding 30°C, and cold, wet winters during which temperatures sometimes drop below freezing, accompanied (Khenchela Directorate of Tourism and Handicrafts, 2024).

The study area is distinguished by a unique natural, historical, and tourism assets that make it highly suitable for developing investment projects in the tourism sector. The region encompasses prominent natural resources such as Mount Chelia, dense forest cover, and mineral springs such as Hammam Essalihine, in addition to Roman archeological sites and religious landmarks that reflect the area's cultural and historical heritage. Its geographical

location at the intersection of the Aures Mountains and the Nemamcha plateaus establishes a natural linkage between northern and southern Algeria, granting it strategic value in connecting mountain tourism with Saharan tourism.



*Fig. 1. Study area location*

Moreover, the importance of this study lies in the fact that the area remains underexploited in terms of tourism relative to its potential. This creates opportunities for tourism investment as an effective tool to achieve sustainable local development by generating employment, improving infrastructure, and strengthening the province's position as a tourism destination at both the national and international levels.

## **Materials**

### ***Sources and Types of Data***

This study employed diverse spatial data (Table 01) to support tourism planning using Geographic Information Systems (GIS) and the Analytic Hierarchy Process (AHP). All spatial analyses and map processing were conducted using ArcGIS Pro 3.2.0. Tourism feature data were obtained from the local tourism directorate (points of interest such as historical and natural sites) through field surveys and contemporary tourism maps, with the objective of determining the spatial distribution of resources and tourism-attractive areas. In this context, recent studies demonstrate that GIS is utilized to integrate multiple layers (topography, vegetation cover, infrastructure) to identify sites characterized by unique properties that attract tourists. Additionally, road maps and residential area data derived from the Open Street Map platform were employed to assess accessibility to tourism sites (proximity to highways, streets, and neighborhoods), a critical factor in supporting decision-making regarding site selection and distribution patterns.

The datasets and spatial layers used in this study were derived from multiple sources with varying spatial resolutions, as detailed in Table 01. To ensure analytical consistency, spatial resolution standardization and calibration procedures were implemented, bringing all layers to the same spatial resolution prior to conducting the multi-criteria analysis.

Regarding natural features and topographic phenomena, the study relied on global digital elevation models. The ALOS World 3D (AW3D30) global model provided elevation data at 30-meter spatial resolution, enabling the extraction of elevation and slope maps for studying the region's terrain. Vegetation cover data extracted from Sentinel-2 satellite imagery (10-meter resolution), part of the European Copernicus Mission, were utilized to calculate the Normalized Difference Vegetation Index (NDVI) to identify green areas with environmental appeal, particularly those suitable for environmental tourism and sites with high natural quality.

Environmental factors also included air quality indicators and fire hazard assessment. Aerosol Optical Depth (AOD) index data were obtained from MODIS sensors aboard the Aqua satellite via the Google Earth Engine platform to support the exclusion of environmentally polluted areas from tourism planning.

Furthermore, a forest fire susceptibility map prepared using GIS techniques and hierarchically classified according to the AHP method was incorporated, categorizing lands according to natural fire hazard levels. This map contributes to identifying the safest areas for tourism while avoiding areas with high fire susceptibility.

*Table 1. List of data source*

Criterion	Data type	Source	Collection method	Resolution/ temporal coverage
Tourism assets	Raster	Directorate of Tourism and Traditional Crafts	Field survey and tourist maps	Updated 2024
Proximity to roads	Vector (polyline)	<a href="https://www.openstreetmap.org/">https://www.openstreetmap.org/</a>	Open Street Map + GIS processing	2025
Proximity to residential area	Vector (point)	<a href="https://www.openstreetmap.org/">https://www.openstreetmap.org/</a>	Open Street Map + GIS processing	2025
Slope	Raster	<a href="https://opentopography.org/">https://opentopography.org/</a>	Shuttle Radar Topography Mission (SRTM)	30 m
Elevation	Raster	<a href="https://opentopography.org/">https://opentopography.org/</a>	SRTM	30 m
Aspect	Raster	<a href="https://opentopography.org/">https://opentopography.org/</a>	SRTM	30 m
NDVI	Raster	<a href="https://browser.dataspace.copernicus.eu/">https://browser.dataspace.copernicus.eu/</a>	Sentinel-2 satellite	10 m (july,2025)
AOD (Aerosol Optical Depth)	Raster	<a href="https://earthengine.google.com/">https://earthengine.google.com/</a>	MODIS (Aqua satellite)	2025
Forest fire vulnerability	Raster	<a href="https://doi.org/10.15291/geoadria.4218">https://doi.org/10.15291/geoadria.4218</a>	Forest fire vulnerability map + GIS-Based Processing	2023/12/28

### Identifying factors and gathering data

The existence of various criteria for selecting suitable locations necessitates the use of multi-criteria decision analysis methods, with the Analytic Hierarchy Process (AHP) being the most common. To identify appropriate sites for establishing tourist resorts, several criteria have been adopted, as depicted in Figure N°2, such as proximity to tourist resources and residential areas, accessibility, topographical factors (slopes, elevations, terrain aspect), and environmental factors (Normalized Difference Vegetation Index (NDVI), forest fire vulnerability, and Air Pollution Indicator (AOD)). Each of these criteria is assigned weights according to the AHP model and then integrated into Geographic Information Systems (ArcGIS Pro 3.2.0) to determine suitable locations and classify them according to their degree of suitability. The integration of GIS and AHP fully leverages the advantages of GIS in high speed, efficiency, and spatial data overlay, and the advantages of AHP in quantitative and multi-criteria analysis (Yanlong & Li, 2020).

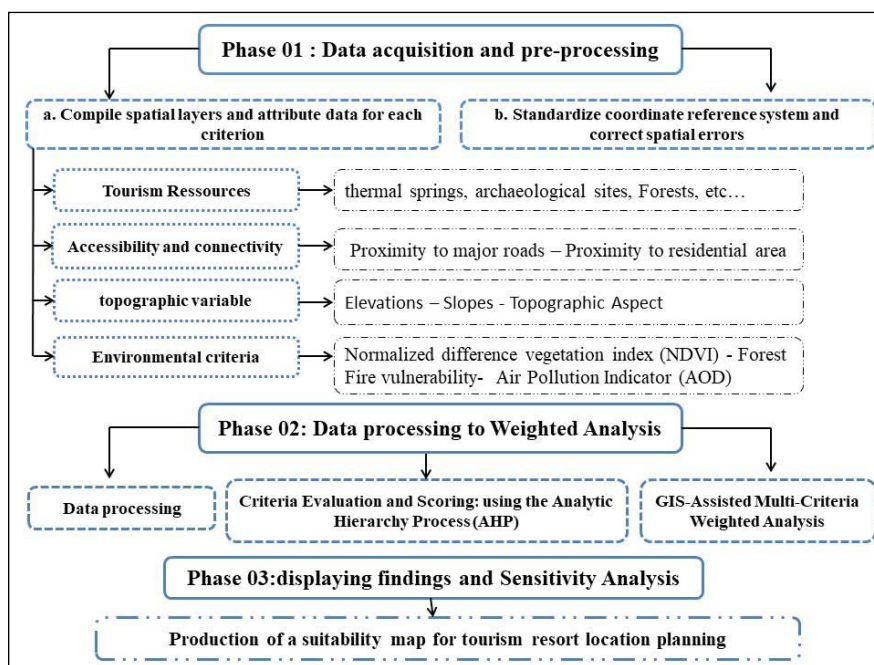


Fig. 2. Structure of the Research

The process of identifying factors for land suitability assessment relied on a combination of spatial, environmental, and socio-economic parameters tailored to the specific characteristics of Khenchela Province. Each factor was selected based on its direct or indirect influence on the feasibility, accessibility, and sustainability of tourism resort development:

- Proximity to tourism resources: Chosen because sites located near natural, historical, or cultural attractions (e.g., thermal baths, Roman ruins, mountain landscapes) are more attractive to visitors, enhancing the resort’s competitiveness and reducing travel time for tourists.
- Proximity to major roads: Road accessibility was considered essential given the absence of an airport in the province. Sites closer to national and local road networks

ensure easier access for tourists, reduce transport costs, and facilitate logistical operations.

- Proximity to residential areas: This factor ensures availability of local labor, infrastructure (such as water and electricity), and creates a nearby consumer market, which is vital for both service provision and domestic tourism demand.
- Slope: Selected due to its impact on construction feasibility and safety. Gentle to moderate slopes are more suitable for development, while steep slopes increase construction costs and hazards such as landslides.
- Elevation: Incorporated because altitude affects climate, accessibility, and scenic quality. Moderate elevations balance panoramic views with ease of access, while extreme elevations may pose climatic challenges.
- Terrain aspect: Orientation of slopes influences solar exposure, temperature, and microclimate. Southern slopes may provide warmer conditions, whereas northern slopes help maintain cooler climates, both of which can affect resort design and energy efficiency.
- Normalized Difference Vegetation Index (NDVI): Used as a proxy for vegetation cover, indicating ecological value and aesthetic appeal. Dense vegetation enhances the attractiveness of resorts and contributes to microclimate regulation.
- Forest fire vulnerability: Integrated to account for environmental risk management. Given the history of large-scale wildfires in the region, this factor helps avoid high-risk zones and supports sustainable site planning.
- Air Pollution Indicator (AOD): Aerosol Optical Depth data was employed to reflect atmospheric clarity. Areas with lower AOD values indicate cleaner air, which is an important consideration for tourist comfort and environmental sustainability.

Each of these criteria was subsequently standardized, weighted through the Analytical Hierarchy Process (AHP), and integrated into a Geographic Information System (GIS) environment to generate a comprehensive suitability map for tourist resort development.

## **Methods**

### *The Analytic Hierarchy Process (AHP) framework*

The Analytic Hierarchy Process (AHP) is a multi-criteria decision-making (MCDM) method that provides a systematic framework for constructing indicators and managing decisions by building a hierarchical structure composed of the main goal, a set of criteria, and alternatives. It relies on the opinions of experts, specialists, and decision-makers, who perform pairwise comparisons between criteria using a defined numerical importance scale (1, 3, 5, 7, 9). Criterion weights are then derived using Saaty's traditional methods, such as the eigenvector method or equivalent computational techniques, and normalized so their sum equals one. To verify the consistency of expert judgments, the maximum eigenvalue ( $\lambda_{\max}$ ) is calculated, and consistency indices are extracted through formulas:

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

Where (n) is the number of criteria and RI is the Random Index from a reference table. Consistency is generally acceptable if  $CR < 0.1$ . AHP facilitates selecting the most suitable option based on multiple weighted criteria after ranking the alternatives according to their relative importance (Banai-Kashani, 1989; Al-Akahli & Aldahmashi, 2024; Malinić et al., 2025).

The overarching methodology of this study follows sequential stages beginning with the identification of critical factors influencing site suitability, followed by comprehensive data collection. Subsequently, the gathered information undergoes rigorous processing and analysis, culminating in the generation of a suitability map for optimal tourist resort development. This process is widely applied in geographic information systems (GIS) contexts to ensure reliable weighting of criteria in spatial decision model.

### ***Developing Criteria and Factors***

#### *Sub-rating of the criteria*

This step is one of the most crucial stages in geographic data processing, as it involves classifying the criteria using a coding scale ranging from 1 to 5. The number 1 indicates complete unsuitability for tourism resort development, while the number 5 signifies a very high level of suitability, as shown in Table 2.

*Table 2. Reclassification of suitability criteria*

Criteria	Level of suitability				
	Very high (5)	High (4)	Moderate (3)	Low (2)	Very Low (1)
Tourism Resources	0 – 1000 m	1000–3000m	3000-7000m	7000-1200m	< 1200 m
Proximity to major roads	0 – 800 m	800– 1600m	1600-2400m	2400-3200m	>3200 m
Proximity to residential area	0 – 200 m	200 – 400 m	400 – 600 m	600 – 800 m	>800 m
Elevations	1300-1600m	1600-1900m	1000-1300m	1900-2328m	630-1000m
Slope	0 – 8 %	8 – 15 %	15 – 25 %	25 – 35 %	>35 %
Topographic Aspect	East and Northeast	North and West	Southwest and Northwest	Southeast	South
Normalized difference vegetation index (NDVI)	0.45 – 0.839	0.31 – 0.45	0.19 – 0.31	0.1 - 0.19	-0.448 – 0.1
Forest Fire vulnerability	Low	Moderate	Hight	Very high	Water body/ Urban area
Air Pollution Indicator (AOD)	0.078-0.095	0.095-0.11	0.11-0.125	0.125-0.140	0.140-0.159

Following the assignment of values to each criterion according to the predetermined scale of 1 to 5, this classification procedure was systematically applied to all criteria considered in the study. To achieve this, the Reclassify tool embedded within the GIS software was employed. This tool enables the spatial data values to be redefined into designated classes. Specifically, each geographic information layer underwent reclassification whereby every pixel or spatial unit was allocated a new value between 1 and 5, based on the established criteria. This standardization process ensures uniformity across all spatial datasets and thereby facilitates the subsequent integration and aggregation of multiple layers during the multi-criteria analysis phase (Gelan, 2021).

#### *Calculation of criteria weights Weighting Criteria*

The Analytic Hierarchy Process (AHP), developed by Thomas Saaty in 1980, relies on pairwise comparisons to determine criteria weights, utilizing Saaty's scale (1–9) (Table 3) to estimate the importance of one criterion relative to another. These comparisons are conducted within a hierarchical structure that includes the overall goal at the top, criteria and sub-criteria in the middle, and alternatives at the bottom (Edvan et al., 2025).

A pairwise comparison matrix is constructed and then normalized to extract relative weights using the principal eigenvector method, adopting an absolute scale that minimizes the impact of preference fluctuations. After integrating the weights of criteria and alternatives, the optimal option is selected, and a sensitivity analysis is performed to test the robustness of the decision (Bahurmoz, 2004).

Table 3. Saaty's Pairwise Comparison Scale: A Structured Framework for Importance Assessment

Intensity of Importance	Definition	Explanation
1	Equal importance	Both elements contribute equally.
3	Moderate importance	Experience and opinion favor one element over the other.
5	Strong importance	One element is strongly favored.
7	Very strong importance	One element is very strongly favored over the other.
9	Extreme importance	One element is overwhelmingly more important.
2,4,6,8	Intermediate values	Used when a compromise between two judgments is needed.

Edvan et al., 2025

### Normalization Procedure

The normalization of the pairwise comparison matrix is a fundamental step in the Analytic Hierarchy Process (AHP) to ensure the comparability and accurate extraction of weights. This process begins by summing up the values of each column in the pairwise comparison matrix. Subsequently, each entry in the matrix is divided by the sum of its respective column, resulting in a normalized matrix where all values are on the same scale and thus comparable (Mu & Pereyra-Rojas, 2017). In the final step, the total weights for each criterion are calculated by averaging the values of each row in the normalized matrix (Esen, 2023). This method ensures that the extracted weights are consistent and objective, reflecting the relative importance of each criterion in the decision-making process.

$$w_i = \frac{1}{n} \sum_{j=1}^n \bar{a}_{ij} \quad (2)$$

Where:  $w_i$  = the value of the relative weight for the row parameter

$\frac{1}{n} \sum_{j=1}^n \bar{a}_{ij}$  = the sum of the normalized values corresponding to a specific criterion, divided by the number of criteria.

$n$  = the total number of criteria included in the analysis.

Table 4. Pairwise comparison matrix and Criteria weights (CW)

Criteria	a	b	c	d	e	f	g	h	i	CW
a	1	3.00	4.00	2.00	6.00	8.00	5.00	7.00	9.00	0.309
b	0.33	1	2.00	0.50	4.00	6.00	3.00	6.00	7.00	0.157
c	0.25	0.50	1	0.33	3.00	5.00	2.00	5.00	6.00	0.110
d	0.50	2.00	3.00	1	5.00	7.00	4.00	6.00	8.00	0.221
e	0.17	0.25	0.33	0.22	1	3.00	0.50	2.00	4.00	0.051
f	0.12	0.17	0.20	0.14	0.33	1	0.25	3.00	2.00	0.032
g	0.20	0.33	0.50	0.25	2.00	4.00	1	3.00	5.00	0.074
h	0.14	0.17	0.20	0.17	0.50	0.33	0.33	1	3.00	0.029
i	0.11	0.14	0.17	0.12	0.25	0.50	0.20	0.33	1	0.018

Note: (a) Proximity to Tourism Resources (b) Proximity to major roads (c) Proximity to residential area (d) Slopes (e) Elevation (f) Topographic Aspect (g) Normalized difference vegetation index (NDVI) (h) Forest Fire vulnerability (i) Air Pollution Indicator (AOD)

### Calculating the Consistency Ratio (CR)

The consistency ratio (CR) serves as a consistency index for the pairwise comparison matrices used in both the Analytic Hierarchy Process (AHP) and the Analytic Network Process (ANP)(Omid, Samerah, Thomas, & Bakhtiar, 2019; Zabihi et al., 2015). The principle of transitivity in Multi-Criteria Decision Analysis (MCDA) methods is formulated as follows: for any three distinct evaluation factors a, b, and c, if a is preferred over b and b is preferred over c, then a should be preferred over c. This transitivity principle underpins the pairwise comparison technique within MCDA. Accordingly, the consistency ratio (CR) can be defined as follows:

$$CR = \frac{\lambda_{\max} - n}{RI(n-1)} \quad (3)$$

Where  $\lambda_{\max}$  represents the maximum eigenvalue of the pairwise comparison matrix, and RI (as shown in Table N°4) denotes the random index corresponding to the number of criteria is the order of the matrix A subjected to pairwise comparison. In cases where decision makers detect inconsistency within their pairwise comparison matrix, they must reevaluate and adjust their judgment values accordingly (Malczewski & Rinner, 2015).

Table 5. The average random index

n	1	2	3	4	5	6	7	8	9
RI	0	0	0.52	0.89	1.11	1.25	1.35	1.4	1.45

Samerah, et al., 2019

The consistency of the judgment matrix is considered acceptable when the  $CR < 0.10$ . Otherwise, the judgment matrix must be revised appropriately. If  $CR > 0.10$ , the data will not produce reliable or meaningful results unless it undergoes thorough re-evaluation.(Kader et al., 2024)

In our study, the value of RI was 1.45 according to the average random index. Accordingly, the consistency ratio (CR) for the pairwise comparison matrix was calculated to be 0.049, which is generally considered an acceptable value.

## Results

### Suitability values of each factor

This study presents the results of applying the Analytic Hierarchy Process (AHP) integrated with Geographic Information Systems (GIS). It focuses on developing an integrated approach for the sustainable development of tourist areas by identifying suitable locations for establishing tourism resorts. This is achieved through the selection of a set of criteria based on the characteristics of the region, its available resources, and the surrounding environmental features. Accordingly, nine criteria were incorporated, each assigned a relative weight reflecting its importance in the decision-making process. These weights were derived from spatial data analysis and comparative evaluation supported by previous studies. Variations in the significance and impact among the criteria were observed and can be summarized as follows:

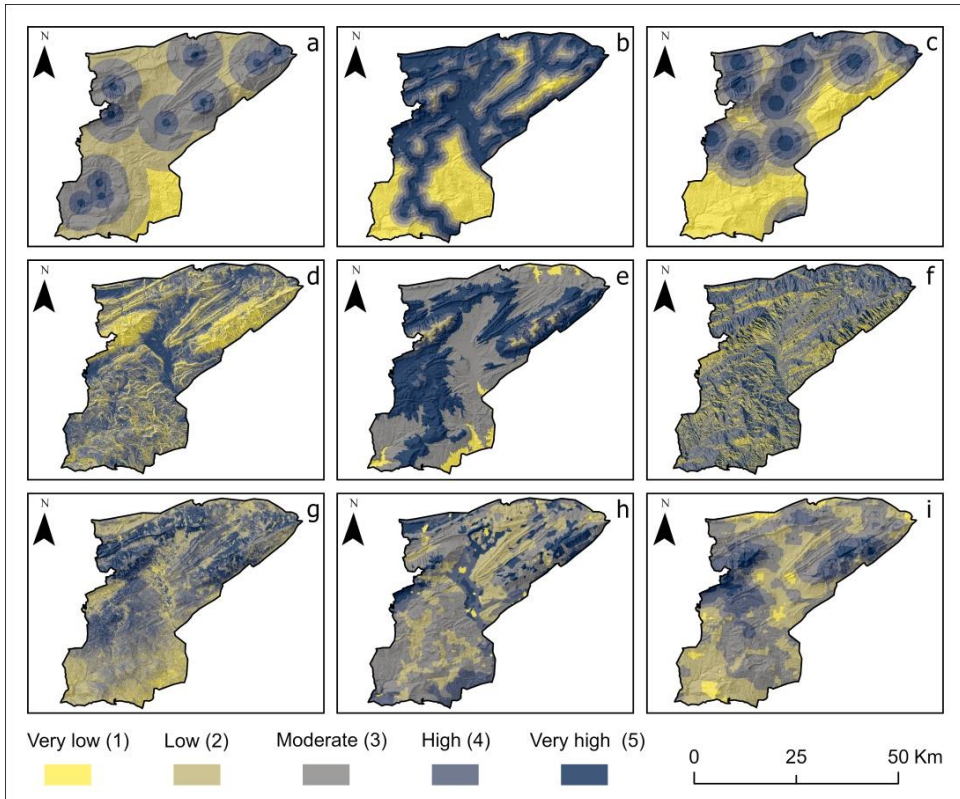


Fig. 3. Maps of criteria

Note: (a) Proximity to Tourism Resources (b) Proximity to major roads (c) Proximity to residential area (d) Slopes (e) Elevation (f) Topographic Aspect (g) Normalized difference vegetation index (NDVI) (h) Forest Fire vulnerability (i) Air Pollution Indicator (AOD)

#### *Tourism Resources*

The criterion of proximity to tourism resources (Map a) is a pivotal factor in the decision-making process for establishing resorts, as it directly affects the site's attractiveness and the economic and social feasibility of the project. A resort located near natural, historical, or cultural landmarks facilitates visitor access, increases occupancy rates and tourist expenditure, reduces transportation costs, and enhances integration between the resort and its surrounding environment. For example, an AHP analysis of the coastal areas of West Bengal showed that proximity to villages near the beaches accounted for 17.05% of the relative weight in determining suitable sites for eco-tourism (Aditi et al., 2022). Other studies indicate that the spatial clustering of tourist attractions increases a destination's appeal more than isolated locations (Adi, Richard, & Allan, 2009).

Areas with strong potential for ecotourism are typically characterized by natural resources such as forests, lakes, and mountains, alongside supportive infrastructure. Tourism experts can assess these features to estimate their impact on tourist inflows (Omid, Samerah, et al., 2019). This is clearly applicable to the province of Khenchela, which possesses significant natural and historical diversity: proximity to dense forests and biodiversity enhances the attractiveness of eco-resorts; mineral springs such as the Hammam Al-Salihine

serve as draws for therapeutic and recreational tourism; while Roman ruins and historical landmarks (such as the tomb of Sidi Yass and Mount Chelia) contribute to supporting cultural and archeological tourism.

In light of this, the criterion "proximity to natural and cultural tourism resources" holds the highest measured weight ( $CW = 0.309$ ), confirming that proximity to landmarks is a decisive factor in the competitiveness of tourism investment. Therefore, these factors should be carefully considered when selecting and planning resort sites. Locations near integrated resources (natural, historical, and therapeutic) offer greater competitive advantages and increase the likelihood of project sustainability and economic success (Guan & Qiao, 2013).

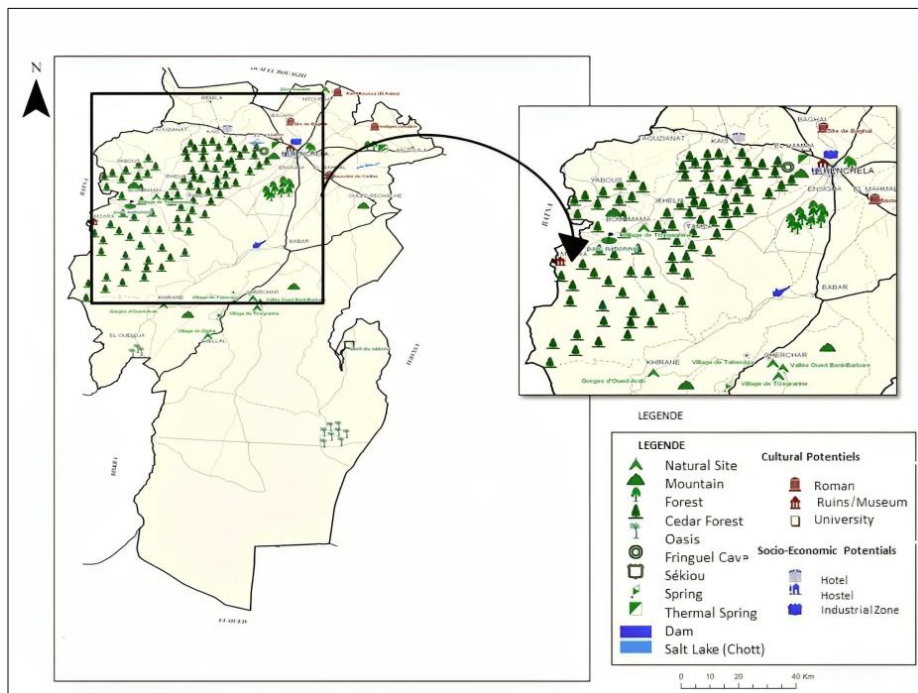


Fig. 4. Tourism resources map (Source: Directorate of Tourism and Traditional Crafts)

#### Accessibility and Connectivity (Economic Criteria)

The criteria of proximity to major road networks (Map b) and population centers (Map c) exert a critical influence on the decision-making process regarding the establishment of tourist resorts, particularly in regions like Khenchela Province. Proximity to a developed road network ensures ease of access for tourists, both domestic and international, reducing travel time and transportation costs while enhancing the resort's appeal and accessibility. Ease of access is also essential to support the resort's logistical operations and to guarantee the timely availability of supplies, which is crucial for operational sustainability and the quality of services provided (Guan & Qiao, 2013).

Proximity to population centers (Map b) provides an important local market for tourists, especially for domestic tourism and short stays. It also enables tourism projects to benefit from the availability of local labor and nearby suppliers, thereby contributing to regional eco-

conomic development (Lin & Juan, 2010). In the context of Khenchela, linking natural and historical resources (such as forests, mineral springs, and Roman ruins) with a well-developed road network and proximity to population centers ensures a steady flow of visitors and strengthens investment viability, with the potential to achieve a balance between environmental conservation and sustainable tourism development (Pin-ju & Shin-Yi, 2013).

In our study, it was found that the criterion of proximity to major roads ( $CW = 0.221$ ) ranks second in importance and highlights the vital role of terrestrial transportation networks in supporting tourism activities. In the case of Khenchela Province, sources indicate that national and local roads serve as the primary connections to major cities and neighboring provinces. The province lacks an airport, which makes reliance almost entirely dependent on the terrestrial road network. Therefore, proximity to these roads is a critical factor for securing tourist and logistical mobility and benefiting from adjacent markets.

Equally significant is the criterion of proximity to population centers ( $CW = 0.157$ ), which represents a moderately high economic factor. Being near population centers ensures a local consumer market and available labor, facilitates the provision of essential services and infrastructure (such as electricity and water), and reduces operating costs related to recruitment and supply (Lin & Juan, 2010). In Khenchela, given its dispersed rural nature and low-density population spread over large areas, determining proximity to towns and villages is particularly important when evaluating the suitability of sites for tourism investment. Balancing sufficient closeness to guarantee a local market while maintaining adequate distance to preserve environmental quality is a practical standard in planning.

#### *Topographic variable and Environmental criteria*

Topographic and environmental variables have a decisive impact on selecting sites for resort development, particularly in mountainous and nature-rich regions such as Khenchela Province. Integrating topographic considerations (elevation, aspect, slope, wind rose) with environmental criteria (vegetation cover measured by NDVI, fire susceptibility, and air quality indicated by AOD) enables the identification of balanced locations that ensure climatic and scenic appeal, constructability and economic feasibility, safety, and environmental sustainability.

- Slope (Map d): it is a critical criterion from both technical and economic perspectives. Gentle slopes are preferred for construction ease, accessibility, and reducing excavation and leveling costs, while steep slopes pose engineering challenges and higher construction expenses, though they may be suitable for activities such as mountain hiking or skiing (Kerebeh, 2020). This criterion carries a moderate and significant weight ( $CW = 0.221$ ). In Khenchela, due to its mountainous nature and elevation variability (Tourism Development Master Plan, 2016), sites with low to moderate slopes are favored to ensure buildability while maintaining scenic views.
- Elevation (Map e) plays a pivotal role in determining the local climate and providing attractive panoramic views, which enhances the appeal of mountain resorts and offers fresh air (Kefa Fey, 2020). However, higher elevations may have colder temperatures, more limited accessibility, and require attention to seasonal needs. In terms of weighted importance, elevation is assigned secondary significance ( $CW = 0.051$ ), reflecting its consideration as a supporting factor when other fundamental requirements are met.

- Aspect (Map f): it determines the amount of solar radiation and temperature levels, impacting building design and the spatial distribution of activities within the resort. South-facing slopes may be preferred in colder regions to maximize sun exposure, whereas northern exposures might be favored for cooler temperatures. This factor is given a relatively low weight ( $CW = 0.032$ ) but remains important for enhancing guest comfort depending on the resort type (Hakimi et al., 2011).

Based on climatic data and wind rose analysis for the study area, prevailing winds generally blow from south to north and are accompanied by warm air currents. Therefore, it is recommended to orient resort sites toward the northeastern or northwestern sectors to avoid direct exposure to hot winds, achieve a more comfortable climate for tourists, and reduce the need for intensive artificial cooling in tourist facilities.

- *Vegetation Cover (NDVI) (CW = 0.074)*: The Normalized Difference Vegetation Index (Map g) measures the density and health of vegetation cover and serves as an indicator of environmental attractiveness for ecotourism areas. High vegetation cover provides scenic landscapes, improved local climate, and opportunities for recreation and leisure activities (Yerik & Danny, 2022). In Khenchela, forests cover a significant portion of the area (forests, green valleys, and coniferous trees). Therefore, proximity to areas with rich vegetation cover enhances site appeal as a supporting factor, following foundational and construction requirements.
- *Forest Fire vulnerability (CW = 0.029)*: it is a critical factor for safety and sustainability (Map h). Studies indicate that the Aures forests in Khenchela suffered substantial damage (in 2021 around 9,837.28 hectares was affected) (Djabri, et al., 2023). Fire occurrences were concentrated on steep south-facing slopes, confirming that forest structure, topography, human activity, and climate play major roles in fire vulnerability. The risk intensifies with increased tourist presence during spring and summer seasons (Djabri et al., 2023; Zeraib et al., 2022). Thus, this criterion requires avoiding high-risk sites or implementing strict preventive measures such as protection rings, escape routes, fuel management, and visitor awareness (Omid et al., 2019). Its relatively low weight reflects its seasonal nature and prevention potential but remains an indispensable criterion.
- *The Aerosol Optical Depth (AO) (CW = 0.018)*: index measures atmospheric particulate levels and visibility quality (Map i); lower values are preferable for tourist health, comfort, and the efficiency of outdoor activities. Conversely, air pollution reduces the attractiveness of tourist destinations (Zhang, Ran, Zhang, & Zhang, 2020). Though assigned a small weight, this criterion is significant, especially for sites targeting ecotourism or therapeutic tourism.

#### *Final suitability analysis for tourism resort location planning*

The results indicate that criteria such as proximity to natural and cultural tourism resources, ease of access, and connectivity to road networks and population centers are paramount in influencing site attractiveness and the sustainability of tourism investment. Additionally, topographic and environmental variables, including elevation, slope, solar exposure, and vegetation density, play supportive and critical roles in ensuring a balance between economic viability and environmental conservation.

This relative weighting distribution reflects the importance of integrating economic aspects (access to tourism resources, roads, and settlements) with natural and environmental factors (topographic characteristics, vegetation density, air quality, and the area's sensitivity to wildfires) in determining the optimal locations. This integration enabled us to produce a final spatial distribution map of areas according to their suitability levels (Figure 5).

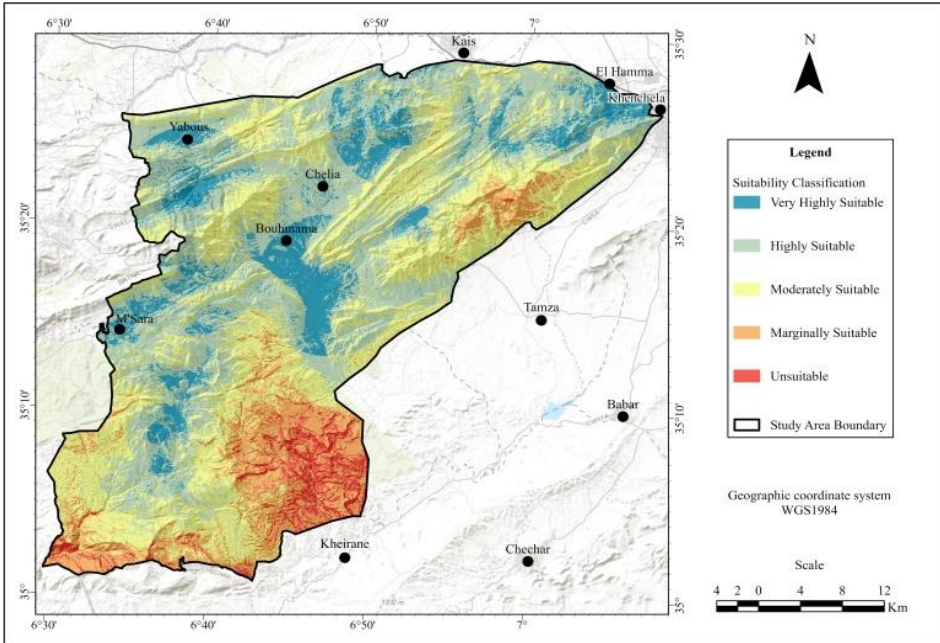


Fig. 5. Final Map of suitability analysis for tourism resort location planning

The suitability map (Map N°05) reveals the presence of five spatial categories ranging from unsuitable to very highly suitable. Most of the study area (Table N°06) is concentrated within the medium to high suitability classes, with moderate suitability accounting for 34.58%, high suitability for 37.21%, and very high suitability for 12.11%. Meanwhile, the two lower suitability categories represent approximately 16.08% of the area. The spatial distribution is clearly manifested by the clustering of the highest suitability categories near the core tourism resources, surrounding population centers, and road networks, which underscores the pivotal economic and operational role of proximity to resources, services, and accessibility in selecting resort locations.

From a topographic perspective, the unsuitable areas are mainly located in the south and southeast, where slopes and elevations increase. This indicates the influence of slope and geology on development feasibility due to higher construction costs, landslide risks, and accessibility challenges. Highly suitable areas are associated with dense vegetation cover (high NDVI), forests, and valleys that offer strong potential for ecotourism.

Regarding infrastructure, proximity to major roads and population centers emerges as a fundamental determinant for enhancing the viability of tourism projects and leveraging local markets and human resources. From a planning standpoint, the "suitable" and "very highly suitable" categories constitute clear priorities for phased planning and optimal investment in resorts while considering environmental protection mechanisms. Conversely,

the lower suitability categories warrant caution or exclusion, especially if they overlap with sensitive habitats. Therefore, essential environmental and safety considerations must be incorporated prior to any development, including wildfire risk management plans (protection zones, evacuation routes, and fuel management), monitoring air quality using AOD values for projects targeting therapeutic and natural tourism, and strict adherence to protocols when intervening to protect resources.

The map in (figure N°05) demonstrates promising potential for guiding sustainable tourism investments, emphasizing the necessity of field verification, sensitivity analysis of weighting factors, and detailed feasibility studies to ensure safe and sustainable implementation.

*Table 6. Suitability Classes by Area*

Suitability Classes	Area (Km <sup>2</sup> )	Area in %
Not suitable	58.54	3.71
Less suitable	194.95	12.37
Moderately suitable	544.58	34.58
Suitable	586	37.21
Extremely suitable	190.73	12.11

## **Discussion**

### ***Sensitivity Analysis***

A One-Factor-at-a-Time (OFAT) sensitivity analysis was conducted on the weights of the site suitability evaluation criteria. Each weight was individually adjusted (either increased or decreased) while the remaining weights were proportionally normalized to maintain overall balance. Subsequently, threshold values were calculated to determine the point at which a given criterion could surpass the one immediately above it in the ranking (Malinić et al., 2025). The figure below illustrates the obtained results.

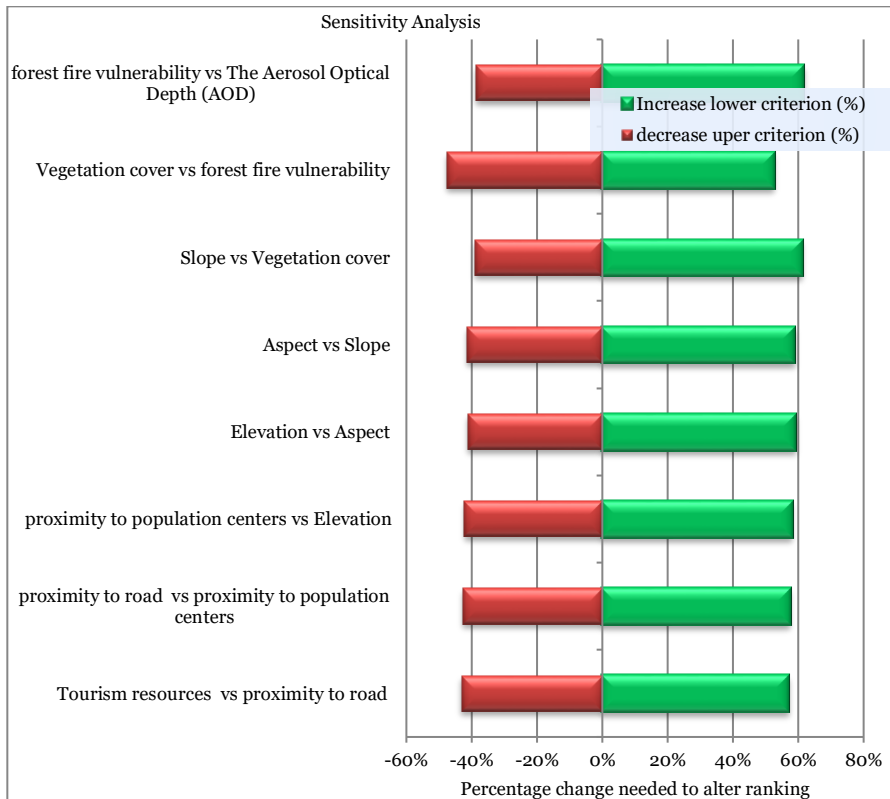


Fig. 6. Sensitivity analysis of ranking criteria

The results indicate that significant changes are necessary to alter the current ranking of the criteria. For instance, to elevate the ranking of the slope criterion above the proximity to population centers criterion, its weight must increase by +80.84%, or the weight of the population centers criterion must decrease by -44.01%. Similarly, the elevation criterion requires an increase of +56.40% to surpass the competing criterion or a reduction of -36.04% in that latter criterion. Meanwhile, the vegetation cover criterion demands an increase of +121.93% to exceed the direction criterion.

These findings point to significant weighting gaps among the criteria, with threshold values exceeding 100%, indicating that the lower-weighted criterion must more than double its weight to surpass the opposing criterion. Such substantial thresholds serve as indicators of the robustness of the criteria ordering; thus, values of P greater than 100% are not errors but rather evidence of the strength and coherence of the original preferences, as supported by many experts (Garuti & Fulcrum, 2021).

Most threshold points fall within broad ranges starting at +36.32% and exceeding 100% in some instances, meaning that minor or moderate weight changes are insufficient to shift the priority of the top criteria. Therefore, the results underscoring the importance of topographical factors and infrastructure in identifying suitable locations can be relied upon to a great extent, while maintaining some flexibility and precautionary measures when handling sensitive criteria, especially those related to security constraints.

The results of this study generally align with the broader trends in the literature regarding applications of AHP+GIS for selecting tourism and environmental activity sites, although methodological and contextual variations explain differences in the ranking and weighting of criteria. Similar studies have consistently affirmed that integrating analytic hierarchy process tools with geographic information systems provides a robust framework for weighting multiple criteria and spatially aggregating them. However, each study's results are influenced by the nature of the data used (including its sources and temporal-spatial accuracy), the methodological structure (methods of eliciting expert opinions, number of pairwise comparisons, and rescaling criteria), and local planning priorities (developmental versus environmental or security concerns). For this reason, comparing the results with previous studies reveals not only points of general agreement, such as the importance of proximity to resources and road networks, but also methodological and contextual discrepancies that highlight the sensitivity of weights to local study conditions. This underscores the need for field validation and sensitivity analysis before generalizing planning recommendations.

The priority of proximity to tourism resources stood out clearly, with the proximity to natural and cultural landmarks criterion receiving the highest weight (30.9%) in our model. This confirms that the concentration of resources and the geographic specificity of Khenchela make the location's proximity to these resources a decisive factor in its investment attractiveness. This finding aligns with previous studies that identified proximity to landmarks as a central factor in attracting tourists and enhancing economic viability (Guan & Qiao, 2013). It should be noted that differences in weight magnitudes across studies usually reflect contextual specificity: in more open coastal or urban areas, lower weights for proximity are often recorded (around 17.05% in the study by (Aditi et al., 2022)), since accessibility mechanisms and infrastructure there differ from the dispersed mountainous conditions characteristic of Khenchela province.

Road networks and connectivity also play a central role, with the proximity to roads criterion ranking second (22.1%) in our hierarchy. This aligns with findings from other studies that emphasize the importance of transportation infrastructure in site suitability assessment (Deribew, Mihretu, Abreha, & Dessalegn, 2022; Withanage et al., 2024). This regional reality reflects the heavy reliance of tourism movement in Khenchela on terrestrial roads, unlike areas possessing strong air or sea connections. Consequently, improving accessibility and infrastructure directly impacts the feasibility of any resort project.

Thus, the practical priorities in our study align with the goal of blending economic viability with environmental preservation, as economic criteria (roads, population settlements, resources) received higher weights than some environmental variables such as NDVI (7.4%), fire susceptibility (2.9%), and AOD (1.8%). This balance contrasts with studies dedicated to ecotourism, which may assign greater importance to forests and air quality (Yerik & Danny, 2022; Zhang et al., 2020), but here it reflects a methodological choice that considers operational continuity and accessibility alongside environmental conservation.

Topographic variables also emerged as decisive factors; the results underscored the significance of slope and elevation (slope 11.0%, elevation 5.1%), consistent with literature noting that ease of construction and accessibility are essential factors, especially in mountainous areas (Kerebeh, 2020). Although slope aspect carried a smaller weight (3.2%), attention to it remains consistent with the requirements for designing tourism facilities linked to climatic conditions and solar radiation (Aditi et al., 2022).

From a safety perspective, the relatively low weights for forest fire susceptibility and air quality index do not diminish the importance of these variables. Local wildfire incidents in the Aures region (widespread impacts in 2021; (Rahmani & Benmassoud, 2019; DJABRI et al., 2023)) highlight the necessity of incorporating them as proactive planning criteria, potentially increasing their weight in environmentally sensitive scenarios.

Methodologically, study's reliance on up-to-date sources and data (such as AW3D30 digital elevation models, Sentinel-2 imagery for NDVI extraction, MODIS AOD data via Google Earth Engine, and Open Street Map data) supports the quality of results and aligns with best practices in current literature that encourage integrating multiple data sources to enhance the accuracy of suitability conclusions. The low consistency ratio in the AHP matrices (CR = 4.9%) further strengthens reader confidence in the derived weights and stands as methodological evidence of the acceptability of the pairwise comparisons used.

Finally, this study reaffirms a common conclusion in the literature: proximity to resources and road connectivity are the principal determinants of resort site suitability, while the weight proportions reflect local particularities and planning priorities.

## **Conclusion**

This study aimed to assess the suitability of potential sites for establishing tourist resorts in the Wilaya of Khenchela, eastern Algeria, by integrating Geographic Information Systems (GIS) with the Analytic Hierarchy Process (AHP) methodology. A range of tourism, economic, topographic, and environmental criteria were analyzed to identify the most suitable sites aligned with sustainable tourism development requirements. The analysis results revealed a clear spatial variation in the region's potential, with the majority (71.79%) of the study area falling within moderate to suitable categories, reflecting strong investment potential. Particularly, areas near natural landmarks such as Mount Chelia, Hammam Essalihine, and dense forests emerged as highly suitable due to their ease of access, aesthetic value, and favorable environmental characteristics, enhancing their attractiveness for resort development.

Conversely, some areas were classified as less suitable or unsuitable due to steep slopes, high fire risk, or remoteness from infrastructure networks. These findings emphasize the need for precise site-level planning, adopting preventive measures to ensure sustainable utilization of natural resources.

These results underscore the importance of objective, spatially based approaches such as the integration of GIS and AHP to support tourism planning and investment decision-making. For Khenchela, this approach provides a practical framework to guide resort development toward the most suitable areas while maintaining ecological balance and preserving cultural heritage.

Notably, the methodology applied in this study is adaptable to other tourism regions, especially those with similar natural and topographic characteristics to Khenchela. It can be refined by incorporating additional criteria that consider local specificities, such as biodiversity, environmental sensitivity, and landscape visual appeal, as well as relying on more detailed data from high-resolution remote sensing technologies or specialized field surveys. Moreover, integrating this methodology with advanced analytical tools and modern techniques, including artificial intelligence and computational modeling, could enhance its capacity to support decision-making and direct tourism investments toward the most suitable

sites, ensuring more effective sustainable tourism development. This study aimed to evaluate the suitability of potential sites for establishing tourist resorts in the Wilaya of Khenchela, eastern Algeria, by integrating Geographic Information Systems (GIS) with the Analytic Hierarchy Process (AHP). Various tourism, economic, topographic, and environmental criteria were analyzed to identify the most suitable locations aligned with sustainable tourism development. The analysis revealed significant spatial variation, with 71.79% of the study area classified as moderately to highly suitable, indicating strong tourism investment potential. Areas near natural landmarks such as Mount Chelia, Hammam Essalihine, and dense forests showed high suitability due to accessibility, aesthetic value, and favorable environmental conditions.

Conversely, some areas were deemed less or unsuitable due to steep slopes, high fire risk, or distance from infrastructure. These findings highlight the need for careful site-level planning and preventive measures to ensure sustainable resource use.

The methodology is applicable to other tourism regions with similar natural and topographic characteristics and can be enhanced by including additional local-specific criteria such as biodiversity, environmental sensitivity, and scenic quality. Employing higher-resolution remote sensing data and advanced analytical tools like artificial intelligence and computational modeling may further improve decision support for sustainable tourism investment.

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