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Research Article

Integrating the Analytical Hierarchy Process (AHP) and GIS to assess threats from oasis urbanization

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Abstract:

Urbanization's growing threat to oases' delicate and vital ecosystems, particularly in arid and semi-arid environments, demands immediate attention. These oases, essential to biodiversity, water resources, and indigenous inhabitants' means of subsistence in Algeria, are increasingly threatened by urbanization and climate change. To assess the threats caused by urbanization in oasis ecosystems while taking into account local characteristics and sustainability issues, a geographic information system (GIS) was combined with a hierarchical analytical process (AHP) to analyze several criteria, such as distance to agricultural areas, sands, settlements, valleys, and roads, land uses, and slope. The Analytical Hierarchy Process (AHP) was applied to determine the importance weights of each criterion. A simple additive weighting method was used to assess spatial suitability for urbanization within the study area. Each criterion was evaluated using AHP and mapped using GIS. The resulting land suitability was reported on a scale of 0 to 10, respectively, from least to most suitable sites for urbanization. The study revealed that physical factors significantly influence the deterioration of the oasis and have determined the direction and scale of urban development. As a result, 73.39 km2 of the study area is identified as the most suitable for urbanization, 91.64 km2 moderately suitable, and 50.51 km2 unsuitable.

1. Introduction

The relentless march of global urbanization, a defining phenomenon of the 21st century, is accelerating with particular intensity in arid and semi-arid regions, posing a growing existential threat to fragile oasis ecosystems [1, 2]. These oases, often described as "islands of life" within vast desert expanses, are characterized by unique biodiversity and an irreplaceable socio-economic and cultural role for local communities, notably ensuring food security and preserving ancestral knowledge [3- 5]. However, they face unprecedented pressures due to uncontrolled urban sprawl, the overexploitation of already limited water resources, exacerbated by climate change [6], soil degradation and salinization [5, 6], and the irreversible loss of fertile agricultural land to urban development [7]. In this critical context, an accurate, objective, and spatially explicit assessment of the threats induced by urbanization is imperative for guiding sustainable urban planning and effective resource management within oases. Nevertheless, the inherent complexity of dynamic interactions between urban, socio-economic, and environmental factors makes this assessment particularly challenging [5- 7]. Traditional approaches, often based on fragmented data, sectoral analyses, or subjective judgments, frequently prove insufficient to capture the multidimensional and interconnected nature of urbanization-related threats [8].Facing these challenges, the synergistic integration of

Multi-Criteria Decision Analysis (MCDA) methods [9] and Geographic Information Systems (GIS) offers a promising and increasingly recognized pathway to assess and map urbanization threats in an integrated and spatially explicit manner [7, 10]. Among MCDA methods, the Analytic Hierarchy Process (AHP), developed by Saaty (1980), remains a benchmark for its ability to structure complex decision-making problems into a hierarchy of criteria, sub-criteria, and alternatives, and to weight these elements based on expert judgments or stakeholder preferences [9, 11]. Combined with the robust spatial analysis, data management, and visualization capabilities of GIS, the AHP-GIS approach enables the generation of vulnerability, risk, or suitability maps that facilitate informed and transparent decision-making [12].Numerous studies have demonstrated the effectiveness of the AHP-GIS approach in various contexts of environmental management and land-use planning. For example, Ayalew and Yamagishi (2005) successfully used it to map landslide susceptibility [13]. More recently, researchers like Kazakis et al. (2015) [14]. And Harkat et al. (2020) [15] have highlighted its relevance for flood risk assessment. In the field of land-use planning, the work of Barami et al. (2020) [11]. and Redjem et al. (2021) [16]. Utilized AHP-GIS to identify the most suitable areas for development. Magoura et al. (2023) also applied this approach for optimal site selection [17]. Other recent works have consolidated the use of AHP-GIS for assessing land suitability for urban expansion [18, 19], coastal vulnerability analysis, or identifying priority areas for biodiversity conservation under anthropogenic pressures [14, 20].Other research on Bou-Saâda, such as that by Mayouf (2022), spatially modeled and assessed the urban resilience of the city of Bou-Saâda, Algeria, using AHP and GIS methods to identify and map areas of low, medium, and high resilience [21]. Another approach Dechaicha (2021) used is to monitor and quantify the uncontrolled urbanization of Bou-Saâda (Algeria) between 1984 and 2020 [22]. He uses multi-temporal analysis of Landsat images and GIS to map spatial evolution and changes in land use. Also, Bouzekri (2021) applies AHP and GIS to identify areas suitable for urban expansion in M'Sila, integrating physical, environmental, and socio-economic factors [19].Recent research has also mobilized these tools regarding Bou-Saâda and its surroundings, or similar Algerian contexts. Mayouf (2022) spatially modeled and assessed the urban resilience of Bou-Saâda city using AHP and GIS methods [21]. Dechaicha (2021) quantified the uncontrolled urbanization of Bou-Saâda between 1984 and 2020 through multi-temporal analysis of Landsat images and GIS [22]. Bouzekri et al. (2021) applied AHP and GIS to identify areas suitable for urban expansion in M'Sila [19]. These local studies [23, 24] highlight a growing awareness of Algeria's need for spatial and multi-criteria decision support tools to address urbanization challenges [25, 26].However, it is crucial to note that the specific application of AHP-GIS to the integrated assessment of urbanization threats on oasis ecosystems remains relatively underexplored. Although some studies, such as those by Doulgeris et al. (2012) or Thomas et al. (2015), have addressed the impacts of urbanization on specific components of oases (water resources, biodiversity), few have adopted a holistic multi-criteria and spatial approach to assess the full range of threats. Furthermore, more recent studies confirm that oases, particularly in North Africa, face anthropogenic and climatic pressures requiring integrated assessment approaches to guide adaptation and mitigation strategies [4, 20]. The specific context of North African oases, characterized by severe environmental constraints, complex socio-economic dynamics, and a rich cultural heritage, requires rigorous adaptation and validation of the AHP-GIS approach.Bou-Saâda constitutes a relevant case study, as it is emblematic of an oasis facing rapid urbanization and growing environmental challenges [24, 27]. Unplanned urban expansion, the degradation of palm groves (the productive and ecological heart of the oasis), water pollution and scarcity, and the erosion of unique Saharan biodiversity are all threats to the sustainability of this oasis [27-30]. It is therefore crucial to develop an integrated approach to assess and map these threats to inform urban planning policies and promote sustainable resource management [21-33]. This study, therefore, aims to fill this gap by adapting and applying AHP-GIS to the assessment of urbanization threats in the Bou-Saâda oasis, taking into account local specificities and sustainability issues [34, 35].The main objective of this study is to integrate AHP and GIS to assess the threats from urbanization in the Bou-Saâda oasis. It aims to develop a vulnerability (or threat) map for urbanization, considering relevant environmental, socio-economic, and urban factors, weighted according to their relative importance. The results of this study will provide decision-makers, urban planners, and managers with an evidence-based decision-support tool to better guide planning policies, anticipate negative impacts, and protect the Bou-Saâda oasis, while proposing a methodology potentially transferable to other oases facing similar challenges.

2. Materials and methods

A. The Study Area

Bou-Saâda City, with an area of 249.98 km², is situated at the southern limit of the Hodna Depression (between the Tellian Atlas and the Saharan Atlas), a "gulf" of the Hodna Plain. The old center appeared in the oasis situated in the depression corridor located at 461–550 m absolute altitude. The mathematic position situates the city in the arid and semi-arid area with λ = 4 ° 12' Eastern Longitude; φ = 35 ° 25' Northern Latitude (Fig. 1).Bou-Saâda City is known for its semi-arid continental climate, which features cold, rainy winters and hot, dry summers. The monthly temperatures range from a minimum of 4.9 °C in January to a maximum of 40.3 °C in July. There is a difference in relative humidity between 26 % in July and 68 % in January. Precipitations are infrequent and irregular, with an annual total of about 151.1 mm.This study used a wide range of publicly available datasets, both digital and complex copy, at various scales, collected from multiple sectors of the nation. The study's data was chosen based on its suitability and availability.

B. Data Collection

Our study of Bou-Saâda combined AHP for criteria weighting and GIS for spatial analysis.Data for the AHP consisted mainly of judgments by experts in planning, urbanism, the environment, and local officials on the relative importance of the criteria: distance to agricultural areas, distance to sands, distance to settlements, and distance to valleys, collected via the group workshop method over weekends.The initial and crucial phase for the GIS-based spatial analysis involved comprehensive data acquisition and pre-processing. This began with gathering essential geospatial datasets for each of the seven evaluation criteria identified (distance to agricultural areas, distance to sands, distance to settlements, distance to valleys, land uses, distance to roads, and slope). Key data included Digital Elevation Models (DEMs), land use/land cover information (sourced from INCT at 1/50,000 scale and USGS Landsat 8 imagery with 30m resolution, as mentioned for the final analysis), road networks (INCT), and meticulously defined boundaries for agricultural areas, sand zones, existing settlements, and valleys. These boundaries were derived from existing cartographic products or digitized from high-resolution imagery where necessary.A critical pre-processing step was geospatial standardization. To ensure accurate spatial overlay and analysis, all acquired vector and raster layers were systematically transformed and projected to a unified coordinate system, WGS 1984 UTM Zone 31N [16, 28]. Furthermore, data formatting was undertaken to prepare the layers for the subsequent analytical steps. This included rasterizing vector data (such as road networks or area boundaries) where appropriate and ensuring all raster layers, including the DEM and derived slope, shared a common spatial resolution. This standardization ensured compatibility and consistency for their integration in the weighted overlay analysis.

C. Identification of Evaluation Criteria

Evaluation criteria were determined based on the elements that most affect the oasis' susceptibility to urbanization. Judgments were therefore made between the following seven parameters: distance to agricultural areas, distance to sands, distance to settlements, distance to valleys, land uses, distance to roads, and slope. Each criterion was then assigned to several categories and collected and prepared in a GIS environment. All layers were converted to individual raster maps. All input datasets were georeferenced to WGS 1984 UTM [16, 28].

D. Weighting Criteria

Standardizing the criteria is the process of determining each criterion's proportionate importance [9]. Tables I and II provide the comparative weight scale used in this investigation.

Table 1. *The comparison scale in ahp*

Value	Intensity of importance
1	Equal importance
3	Moderate importance
5	Strong importance
7	Very strong importance
9	Absolute importance
2, 4, 6, 8	Intermediate values between the two adjacent judgments

E. Confirmation of Consistency

To check that the transitivity of our judgment was respected, the author in [16] proposes the following mathematical formula:

$$IC = \frac{(\lambda\text{max} - \text{N})}{(\text{N} - 1)} \quad (1)$$

Where IC is the consistency index, N is the number of elements compared and is the average Saaty matrix values of the own vectors. This indicates the order of priority or hierarchy of the studied characteristics.

The consistency ratio (RC) is calculated by:

$$RC = \frac{\text{IC}}{\text{IA}} \quad (2)$$

Where IA is defined as the Random Index of a matrix of the same size presented in Table III.

F. Aggregation of Criteria

According to the hierarchical structure's confirmation, this procedure involved multiplying each factor layer by its corresponding weighting [23]. To create a summary map, the AHP approach is then applied in conjunction with the integration of the criteria cards based on their weight on the GIS software using a linear combination method of weighting.Then, the obtained geometric means were normalized, and the relative importance weights were extracted. For the decision-making problem mentioned earlier, a structural hierarchy is formed. Where CI is the consistency index, λmax is the matrix's most significant or principal eigenvalue (PEV), and n is the order of the matrix. This CI can be compared to a random matrix, the Random Consistency Index (RI), such that the CI/RI ratio is the consistency ratio, CR. As a general rule, for the matrix to be consistent, we should have a value of $CR \leq 0.1$. For this study, RI = 1.32 for n = 7 (Table 3), and $\lambda max = 7.3366$, producing a Consistency Index (CI = 0.0560) value. A CR of 4.24% (as indicated in Table II) was achieved, falling below the acceptable threshold of 10%, thereby confirming the reliability and consistency of the expert judgments used in criteria weighting. [23, 28].Validation typically involves qualitative assessment and ground-truthing for the resulting spatial threat map. This would entail presenting the map to local experts (urban planners, environmental scientists familiar with Bou-Saâda) and community stakeholders to ascertain if the identified high, moderate, and low threat zones correspond with their on-the-ground knowledge, observed urbanization patterns, and perceived environmental pressures. Sensitivity analysis can also be performed by systematically altering the weights of the input criteria and observing the impact on the final output to test the robustness and stability of the model's results, further validating the methodological approach.

3. Results and discussion

GIS data sets of land use, rivers, roads, digital elevation models (DEMs), and slopes were collected for this study from the National Institute of Cartography and Remote Sensing, the urban planning and construction department.These specific criteria (Table IV) were selected based on their established importance in determining an oasis's susceptibility to urbanization. The generation and characteristics of the thematic maps for each criterion (visualized in Fig. 2, with individual results contributing to Table IV) are described below:

1) Distance to Agricultural areas

The agricultural suitability map was generated using a distance-based classification approach. Areas within a 500 m buffer of existing agrarian land were classified as unsuitable, 500–1500 m moderately suitable, and distances beyond 1500 m highly suitable for minimizing urbanization threats.

2) Distance to Settlements

To assess urbanization's impact on oases' agricultural potential, we classified the study area according to distance from urban areas (represented in the figure by a hatched pattern). The classification used distance-based thresholds (<500 m, 500 m-1500 m, and >1500 m) to define suitability categories, where closer proximity indicated higher suitability for urbanization but also greater threat to existing oasis structures.
The results show that areas are classified as suitable (<500 m), moderately suitable (500 m–1500 m), or unsuitable (>1500 m) for urbanization.

3) Distance to Sands

The spatial arrangement of sandy areas suggests their alignment along the Oued Maitar and the West-East dune current Areas classified as sandy were deemed unsuitable for sustainable urbanization due to encroachment risks.

4) Distance to valleys

Distances < 20 m, 20–35 m, and > 35 m were used to classify areas as unsuitable, moderately suitable, and highly suitable, respectively, in terms of minimizing flood risk and ecological impact from urbanization.

The map clearly shows the influence of valley networks on agricultural suitability in the oasis. The distribution of unsuitable areas closely follows the identified valley lines, highlighting the potential limitations of farming activities.

5) Land uses

Land use distribution shows an intense concentration of existing agricultural land and urban development around Bou-Saada, the northern and eastern regions, leaving a vast area of barren land. Existing agricultural land was considered unsuitable for further urbanization.

6) Distance to road*s*

The map shows land suitability for urbanization according to its proximity to roads. Highly suitable areas are those less than 500 m from a highway, moderately suitable areas are those between 500 and 1000 m, and unsuitable areas are those more than 1000 m from roads.

7) Slope

Urban suitability was determined using a slope analysis derived from a digital elevation model

(DEM). Slope gradients were classified into three categories: <5 % (highly suitable), 5-10 % (moderately suitable), and >10 % (unsuitable for extensive urbanization).Uncontrolled urbanization is considered one of the significant challenges facing Algerian cities, given the harmful effects on the environment and the problems caused by this type of spatial growth. Agricultural and natural areas are at risk from the excessive expansion of the built-up regions [19]. The Bou-Saâda palm grove suffers from the combined adverse effects of physical and anthropogenic factors undermining its sustainability [17]. On the physical level, the critical scarcity of water resources, accentuated by climate change, more frequent droughts, and soil degradation, are weakening the oasis ecosystem. At the same time, anthropogenic factors and intense demographic pressure [25] on the outskirts of the oasis are accelerating this decline. This combination of environmental stress and socio-economic pressures is making palm grove plots less productive and economically less attractive for farming, encouraging their abandonment or sale for construction, which has led directly to rapid and often uncontrolled urbanization, nibbling away at this agricultural and heritage area [24, 25].The Bou-Saâda territory's urbanization suitability classification identified 73.39 km² (29%) as "Highly Suitable," 91.64 km² (37%) as "Moderately Suitable," and 50.51 km² (20%) as "Unsuitable," alongside the existing 34.44 km² (14%) urban area. This distribution highlights areas for carefully managed expansion and significant portions of the oasis ecosystem that are either urbanized or highly vulnerable.Spatially, "high and extreme vulnerability" (corresponding to "Unsuitable" or lower "Moderately Suitable" zones) is concentrated in Bou-Saâda city's north and center. Conversely, areas to the south (near El Hamel and Oulteme) show higher suitability (lower threat scores), potentially offering comparatively fewer direct threats if expansion is strictly controlled. Lower suitability near Maarif and Ouled Sidi Brahim likely reflects proximity to sensitive agricultural lands or dunes.The AHP-derived criteria weights (Table II & Table IV) confirm the critical threats facing Saharan oases. "Distance to Agricultural areas" (29.6%) and "Distance to Sands" (20.1%) emerged as the two most influential factors. This finding is profoundly significant for Bou-Saâda, as it highlights that the primary threats stem from the direct loss of productive agricultural land (the lifeblood of the oasis) and the encroachment of desert sands, a process often exacerbated by inappropriate land use changes on the oasis fringes. The importance given to "Land uses" (11.3%) and "Distance to Settlements" (11.9%) further reinforces that the nature of existing land and proximity to current urban sprawl are key drivers of vulnerability. The comparatively lower weights assigned to "Slope" (8.0%) and "Distance to roads" (7.4%), while still relevant, suggest that while these factors influence the ease and direction of development, the existential threats to the oasis's core ecological and agricultural functions are of greater concern in this specific AHP model.The methodological approach of combining AHP and GIS for land suitability assessment or vulnerability mapping is well-established in various contexts [16, 21]. Many studies globally have utilized this combination for urban expansion planning, landslide susceptibility, and flood risk assessment (Ayalew & Yamagishi, 2005; Kazakis et al., 2015; Harkat et al., 2020). The findings of this study, particularly the significant influence of physical and proximity factors, resonate with these broader applications. For instance, Bouzekri et al. (2021), in a study on M'Sila, Algeria (a nearby region), also found physical, environmental, and socio-economic factors integrated via AHP-GIS crucial for identifying urban expansion suitability.Findings on the paramount importance of agricultural land preservation and sand encroachment align with fundamental oasis sustainability challenges, as noted for Bou-Saâda by Chehat [29], Benderradji et al. [27], and Meddour et al. [26]. The significance of "Distance to Settlements" is consistent with urban sprawl theories [16] and observations by Dechaicha [22] in Bou-Saâda. While direct quantitative comparison across oases is challenging, protecting agricultural cores and managing desert interfaces is a common theme in emerging oasis sustainability research [26].The results suggest considerable non-urbanized land (combining "Moderately Suitable" at 37% and "Highly Suitable" at 29% of the total area) for potential future growth, contrasting with some oases with minimal expansion options. However, the 20% "Unsuitable" land underscores the critical need for strict protection zones.While the surface areas obtained are specific to the Bou-Saâda context, the overall structure of the results is consistent with observations from other work assessing urbanizability in cities or regions facing similar pressures. These results, therefore, underline, in line with current research, the vital importance of multi-criteria spatial analysis in guiding planning in the face of the challenges of urban expansion, particularly in vulnerable environments.Areas of high and extreme vulnerability to urbanization threats are located in the north and center of the city of Bou-Saada. There, population density is very high, requiring adequate planning, and local authorities should seek optimal solutions (Table 5).The map demonstrates a clear spatial pattern in suitability. Areas to the south of Bousaada, encompassing regions near El Haml and Oulteme, tend to have higher suitability, whereas the areas near Maarif and Ouled Sidi Brahim seem to have a lower suitability (fig. 3)The map provides a valuable visual representation of spatial suitability within the study area. By clearly communicating the distribution of suitable and unsuitable locations, this thematic map is a powerful tool for informed decision-making in land use planning and resource management.While this study provides valuable insights, certain limitations should be acknowledged. The AHP weighting, although validated for consistency (CR = 4.24%), depends on the expert group's judgments and perspectives. While sourced from reputable national and international agencies, the GIS data has inherent scale and accuracy limitations (e.g., 30m resolution of Landsat imagery). A more dynamic assessment incorporating future climate change projections or detailed socio-economic drivers (beyond proximity to settlements) could offer further refinements. Future research could focus on:

- Ground-truthing the threat map with detailed field surveys and comparison with recent, high-resolution imagery.
- Conducting sensitivity analyses by varying AHP weights to test the robustness of the suitability classifications.
- Integrating socio-economic vulnerability indicators alongside the physical threats.
- Developing future urbanization scenarios based on different policy interventions and assessing their potential impacts using this baseline threat map.

In summary, the study's main focus on proximity-based and biophysical criteria, with a comparatively low level of explicit socioeconomic considerations, is a significant shortcoming. Although the AHP's expert opinions inadvertently take into account certain socioeconomic factors, the model would benefit from the methodical inclusion of quantitative information on infrastructure costs, land tenure, population density, and economic activity. By including such factors, planning would be better aligned with local socio-economic reality and offer an even more comprehensive grasp of urbanization hazards and suitability.

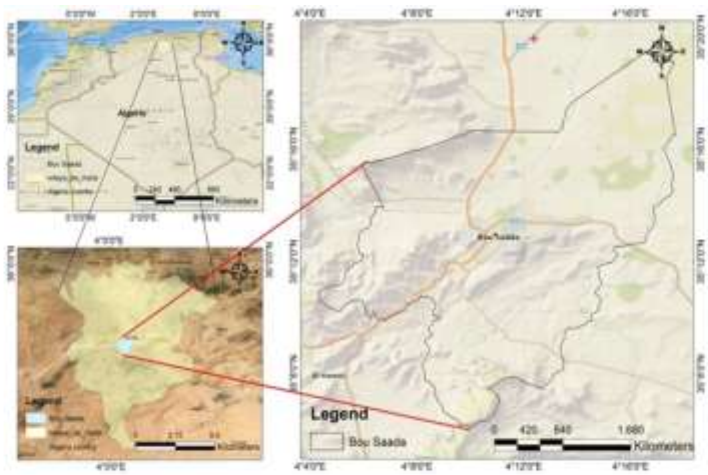

Figure 1. *Study area.*

Table 2. *Square matrix of the pair-wise comparisons of various criteria*

Criteria	1)	2)	3)	4)	5)	6)	7)	Weight		Rank
Land uses	1,00	2,00	2,00	0,50	1,00	0,25	1,00	0,113	11.30%	**5**
Slope	0,50	1,00	1,00	0,33	0,50	0,50	0,50	0,074	7,40%	**7**
roads	0,50	1,00	1,00	0,25	1,00	0,50	0,50	0,080	8,00%	**6**
sands	2,00	3,03	4,00	1,00	1,00	0,50	2,00	0,201	20,10%	**2**
Settlements	1,00	2,00	1,00	1,00	1,00	0,33	1,00	0,119	11,90%	**3**
Agricultural areas	4,00	2,00	2,00	2,00	3,03	1,00	3,00	0,296	29,60%	**1**
valleys	1,00	2,00	2,00	0,50	1,00	0,33	1,00	0,117	11,70%	**4**
PEV (λ)= 7,3360 **CI** =0,0560 **RCI**=1,32 **CR**=4,24%										

Where:

PEV: is the Principal Eigenvalue
CI: is the Consistency Index
RCI: is the Random Inconsistency Indices
CR: is the Consistency Ratio

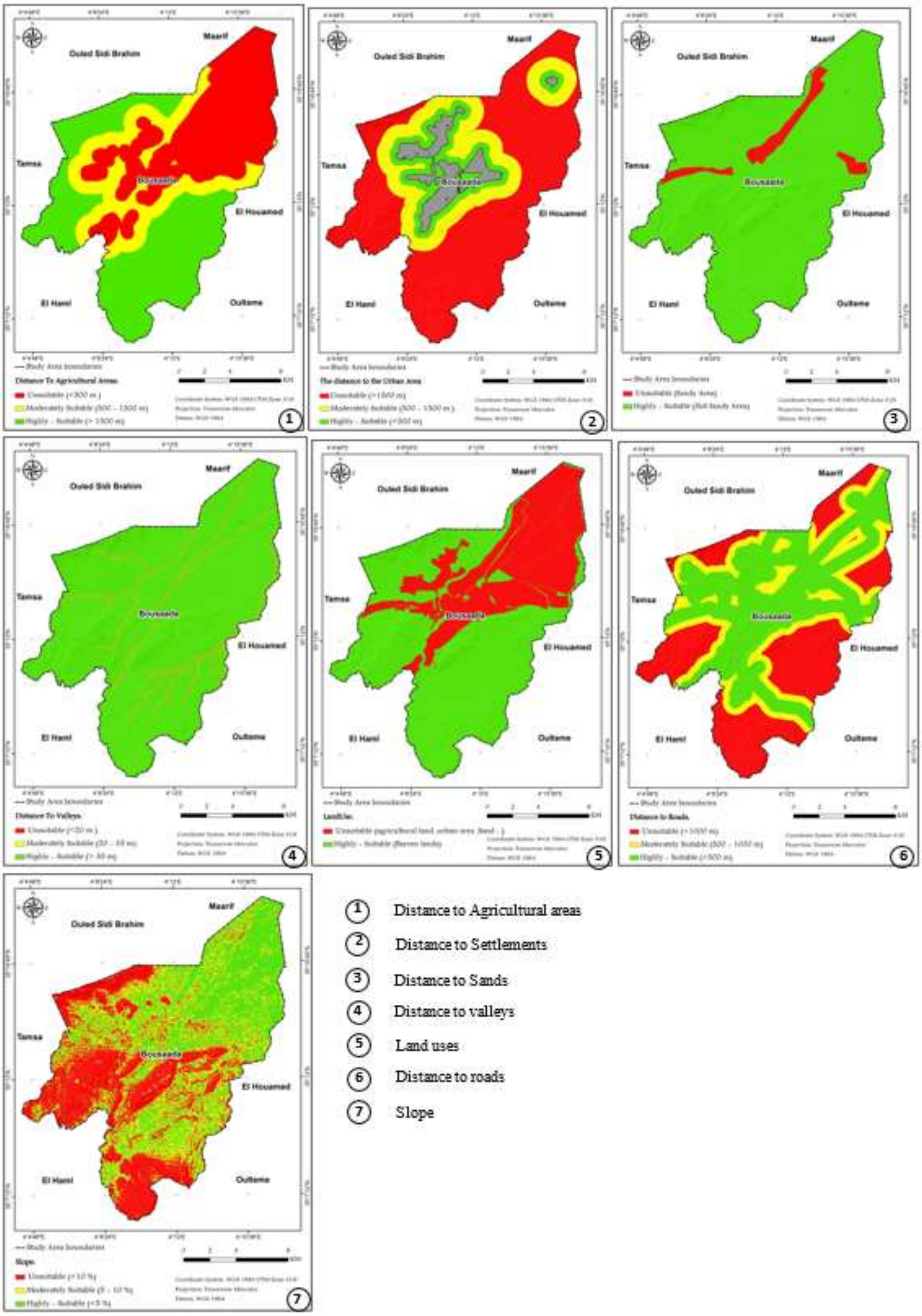

***Figure. 2.** Thematic map of the various factors applied in the study area.*

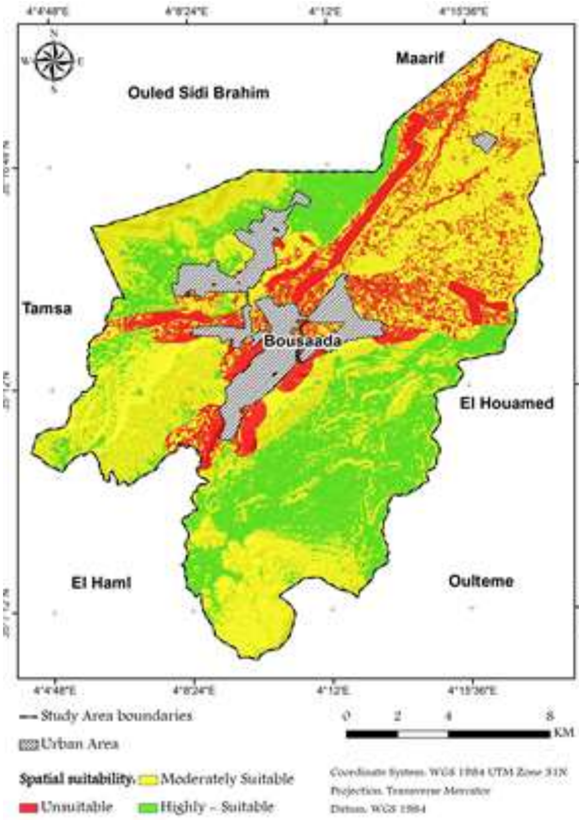

Figure. 3. *Predicted urbanization of Bou-Saada Oasis*

Table 3 *Random inconsistency indices (rci)*

N	1	2	3	4	5	6	**7**	8	9
RI	0	0	0.58	0.90	1.12	1.24	**1.32**	1.41	1.45

Table 4. *Pairwise comparison results*

Criteria	Weights of criteria	Sub-criteria	weights	Rank
Distance to Agricultural areas	29.6	<500 m	4.93	8
		500m-1500m	9.87	4
		>1500 m	14.8	2
Distance to Sands	20.1		20.1	1
Distance to Settlements	11.9	< 500 m	5.95	5
		500-1000 m	3.97	10
		>1500 m	1.98	14
Distance to valleys	11.7	<20 m	1.95	15
		20 m-35 m	3.90	11
		>35 m	5.85	6
Land uses	11.3		11.30	3
Distance to roads	07.4	<35 m	4.93	7
		>35 m	2.47	13
Slope	08.0	<5%	4.00	9
		5%-10%	2.67	12
		>10 %	1.33	16
Total	100 %	/	100 %	/

4. Conclusions

In this study, different data from various parameters were obtained and prepared in a GIS environment.

Then, we used AHP to establish the relative importance of each criterion. The results showed that agricultural areas, sand creep, and housing proliferation were the most important among the studied criteria. Physical factors significantly influence the deterioration of the oasis and have determined the direction and scale of urban development and the expansion of urban land in this case study. At the same time, the least important criterion was proximity to roads and slopes.

This study shows the overall spatial suitability for urbanization of the Bou-Saâda oasis, integrating various factors such as distance to urban areas, roads, slope, soil types, and valleys. The territory of Bou Saâda is classified into three categories: highly suitable areas with 73.39 km2, moderately suitable areas with 91.64 km2, and unsuitable areas with 50.51 km2.

This thematic map illustrating spatial suitability, derived from a rigorous multi-criteria methodology, provides a valuable decision-support tool for public authorities, particularly in the region surrounding the oasis of Bou-Saada. The map enables informed land-use policy direction by clearly and precisely visualizing the areas most suitable for a given use (whether agriculture, controlled urbanization, or environmental protection). For example, the areas surrounding the Bou-Saada oasis could be subject to increased environmental protection due to the high importance of the ecosystem in this area. Policymakers can prioritize investments, identify zones requiring special attention, and develop sustainable development strategies based on a thorough understanding of the potential and constraints of each portion of the territory, with particular consideration for the fragile oasis ecosystem. This multi-criteria approach ensures that economic, social, and environmental issues are considered, fostering more robust decisions tailored to local realities, including preserving and conserving the vital oasis environment of Bou-Saada.

Author Statements:

- **Ethical approval:** The conducted research is not related to either human or animal use.
- **Conflict of interest:** The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper

- **Acknowledgement:** The authors declare that they have nobody or no-company to acknowledge.

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- **Data availability statement:** The data that support the findings of this study are available on request from the corresponding author. The data are not publicly available due to privacy or ethical restrictions.
- **Use of AI Tools:** The author(s) declare that no generative AI or AI-assisted technologies were used in the writing process of this manuscript.

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