GLL
Geomatics, Landmanagement and Landscape No. 4 • 2024, 123–135

ISSN 2300-1496 https://doi.org/10.15576/GLL/194115

Research paper

Received: 24.06.2024
Accepted: 4.10.2024
Published: 31.12.2024

Analysis of constraints to urban expansion in the city of M'Sila using the Analytic Hierarchy Process (AHP) and Geographic Information Systems (GIS)

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Summary

The presented study aims to deepen the understanding of urban expansion and land resource management to meet growing urbanization needs and identify constraints associated with this phenomenon. The main objective is to propose a model that integrates the Analytic Hierarchy Process (AHP) and Geographic Information Systems (GIS) – a method recognized for addressing complex spatial issues. By defining the criteria related to the targeted objectives and by mapping attribute and geographic data at the municipal level of M'sila, we have prioritized the identified indicators, quantitatively evaluated the phenomenon, and compared various development scenarios for the studied areas. This quantitative evaluation was carried out through spatial simulation, including data intersection and multicriteria aggregation based on the AHP method, which allowed participatory modeling of factors according to their respective importance. Moreover, this process facilitated the identification of optimal land use for urbanization, while assisting specialists in choosing the most appropriate urban planning orientations and objectives for the studied areas.

Keywords

Analytic Hierarchy Process (AHP) • constraints • criteria • GIS • M'sila • urban expansion

1. Introduction

Since the early 1960s, accelerated urbanization has significantly disrupted traditional arrangements, leading to extensive spatial reconfiguration. Although urban planning documents are mechanisms for defining land use, they have many practical shortcomings [Chtouki 2011]. Addressing these issues requires new decision support tools that provide relevant information, evaluate criteria, and select among multiple proposals to facilitate the decision-making process and rationalize resource use.

According to Roy [1985], decision support aims to provide answers to questions posed by different actors in a decision-making process, relying on explicit but not necessarily formalized models. It does not always directly address the ultimate problem but often deals with specific questions from the stakeholders. However, it is crucial to ensure that the answers given also contribute to solving that problem, and that decision support remains in line with its development [Mammeri 2013].

In order to optimize the use of the budgets for infrastructure and site development, a multidisciplinary approach should be adopted and coupled with developing a tool for classifying potential urbanization zones. This involves identifying favorable land, topographic, and urban characteristics in M'sila. The use of GIS and AHP is effective for this task, helping to identify suitable sites for urbanization. The evaluation of these tools aims to select the most appropriate model for future land use, considering specific requirements, preferences, or forecasts related to particular activities [Collins et al. 2001].

This leads to systemic modeling, which, according to Thériault and Claramunt [1999], is the primary application domain for spatial analysis and geographic information systems (GIS). Integrating GIS with multicriteria analysis methods is a key and essential way of transforming GIS into a true decision support systems [Joerin 1997, Laaribi 2000, Malczewski 2004, Chakhar 2006]. This approach has been applied by several authors for site selection [Eastman et al. 1993, Lili Chaabane et al. 2002, Recatalá and Zinck 2008, Pelizaro et al. 2009, Conchita 2010, Arciniegas et al. 2011, Feizizadeh and Blaschke 2012].

2. Context, problem, and contribution

Territorial issues are spatial in nature, characterized by their multidimensional, interdisciplinary, and poorly defined aspects. They require the definition of several conflicting criteria, each with different degrees of importance, and involve the handling of a considerable amount of quantitative and/or qualitative data [Hamdadoud and Bouamran 2007].

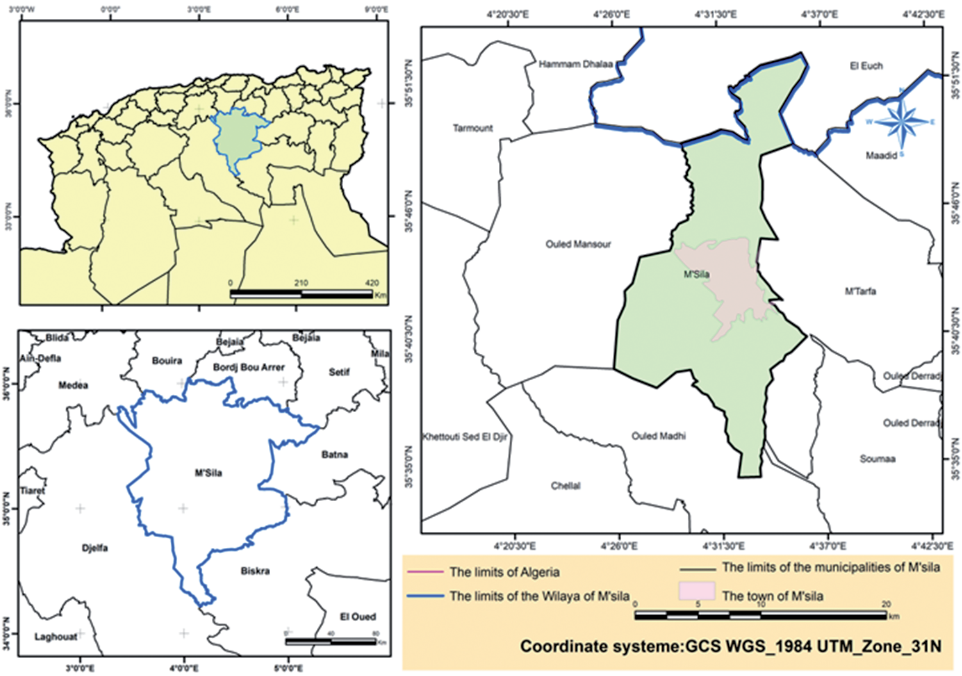
A bibliographic study in urban planning reveals a lack of integrated approaches using the AHP method to analyze land use, property protection, land status, and physical real estate characteristics. To address this, a proposed approach integrates GIS and AHP for optimized land resource planning. The study aims to develop decision support tools for managers that classify land for urban expansion and prioritize development areas within municipalities. Hierarchical multicriteria analysis is employed to rank potential urban expansion sites based on various indicators. This method involves identifying stakeholders, delineating alternatives, defining and weighting criteria, and evaluating each alternative to create decision maps for ranking and determining the best options for urban development.

The city of M'sila faces significant challenges in urban expansion, including unplanned sprawl and the absence of systematic planning, compounded by numerous natural and human obstacles. These factors call for the adoption of a structured scientific approach to urban planning. The Analytical Hierarchy Process (AHP) can be utilized to evaluate various constraints and prioritize them, facilitating organized urban planning and achieving results based on scientific principles.

3. Methodological approach

3.1. Presentation of the study area

The chosen study area is the municipality of M'sila, the administrative center of the wilaya of M'sila. This municipality is located between latitudes 35.57° and 35.87° north, and longitudes 4.43° and 4.60° east. It covers an area of 233 km², relatively small compared to the 46 other communes in the wilaya. It includes several secondary agglomerations, such as Ghezel, Boukhmissa, Mouilha, K'sob, Sidi Amara, and Mezrir. M'sila is a part of the Hodna watershed and is situated 256 km to the southeast of Algiers.



Source: Authors' own study

Fig. 1. The location of the municipality of M'sila

Thanks to its strategic geographical location, M'sila plays a central role, being a crucial crossroads between the national road RN 45, which links Bordj Bou-Arréridj to Boussaâda, and the RN 40, which links Magra to Tiaret. Such position makes it an essential hub of exchanges, facilitating the connection between the north and south of the country, as well as the interconnection between the east and west of Algeria (Fig. 1).

The municipality of M'sila is bordered by:

- to the north, the municipality of El Ach (wilaya of Bordj Bou Arréridj),
- to the south, the municipality of Ouled Madhi (wilaya of M'sila),
- to the east, the municipality of El Mtarfa and Maadid (wilaya of M'sila),
- to the west, the municipality of Ouled Mansour (wilaya of M'sila).

3.2. Evolution of population growth

In 1966, the municipality of M'sila had 35,377 inhabitants. This population grew at a rate of 4.04%, reaching 52,600 inhabitants in 1977. From 1977 to 1987, the growth rate began to decline steadily. Despite this decrease of growth rate, the population continued to grow substantially (the growth rate dropped to 3.55%, bringing the population to 75,516 inhabitants). Between 1987 and 1998, a slight – by 0.46% – decrease in population was observed, resulting in 73,026 inhabitants. Then, from 1998 to 2008, the growth rate decreased to 2.5%. Thus, estimates for 2023 are based on these trends, pending the results of the 2022 General Population and Housing Census (RGPH). Table 1 and Figure 2 illustrate these census data.

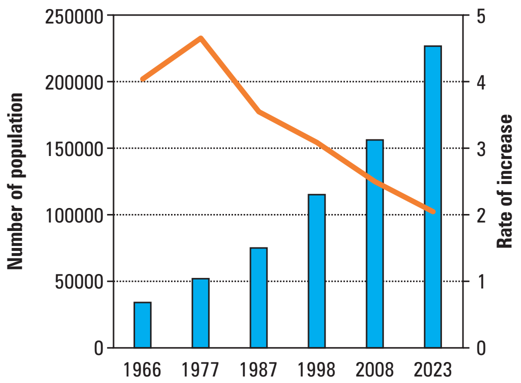


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Fig. 2. Population growth

Table 1. Population growth

Years	Number of population	Growth rate [%]
1966	35 377	4.04
1977	52 600	4.65
1987	75 516	3.55

1998	115 490	3.09
2008	156 647	2.5
2023	226 871	2.05

4. Materials and methods

The study's materials include data and software. The approach requires the integration of spatial data, 1: 50,000 scale topographic maps, satellite images, and alphanumeric data on land use, topography, demographics, infrastructure, and land occupancy. Collecting this information enabled the creation of a Spatial Reference Database (BDRS). The software used to process this data and establish a geographic information system includes ArcGIS, Global Mapper, SAS Planète, and Google Earth (GIS) of the study area. Figure 2 illustrates the data used and the processing carried out to extract the essential information for the multi-criteria analysis.

4.1. Hierarchical multicriteria analysis for urban planning

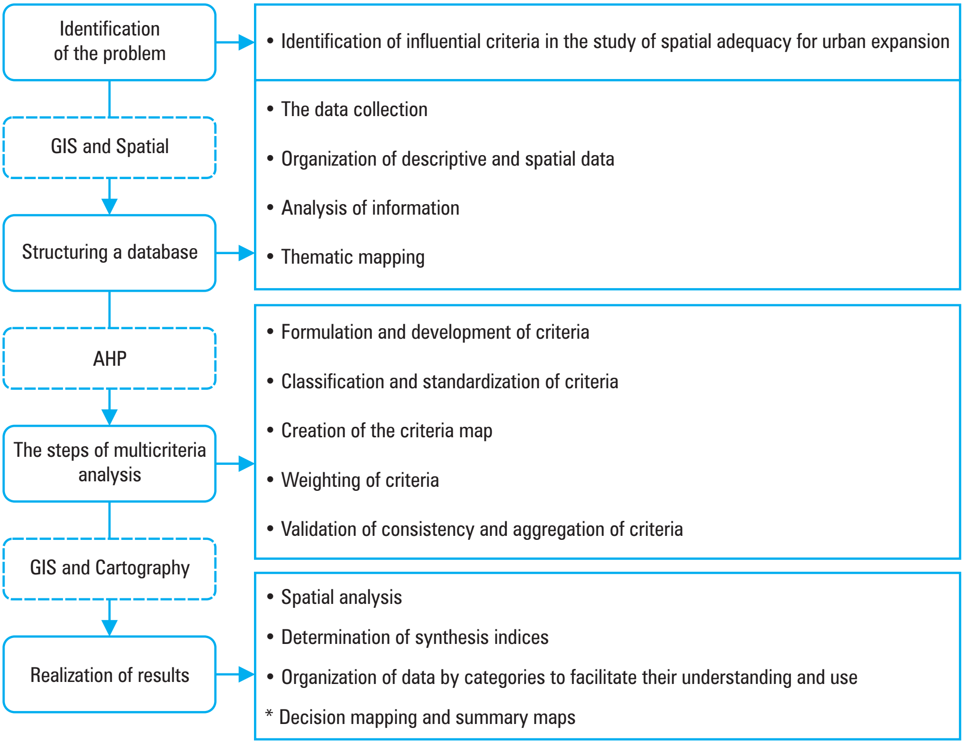
The methodology for optimizing the use of land resources in urban planning combines GIS for structuring data, cross-referencing information layers, and analyzing spatial issues with the Analytic Hierarchy Process (AHP) for evaluating and weighting decision criteria. The AHP method [Saaty 1980] was applied to develop a comprehensive land use map suitable for urbanization. This method has been proven effective in various fields, such as the study of potential land use transformation [Figueiredo 2001], the management of the alluvial plain of the Saint-Charles River in Quebec [Martin et al. 2003], and the selection of parcels for new housing construction [Marinoni 2005]. The process includes problem identification, spatial data modeling, hierarchical analysis, criteria aggregation, and presentation of results in decision maps, as shown for the municipality of M'sila.

4.2. Criteria representation and spatial data modelling

In the AHP process for determining areas suitable for urban expansion, criteria such as land use, land status, topography, military and industrial zones, high voltage power lines, technical landfill centers, valleys, and roads were evaluated for their relative importance. These criteria were prioritized through pairwise comparisons, and the results were aggregated to identify the most favorable areas for urban expansion. The process involved structuring the collected data into a spatial reference database for the study area, as shown in Figure 3.

4.3. Categorization and standardization of evaluation criteria

The process of standardizing the criteria aims to make different factors comparable by expressing them on a common scale. Once the criteria for evaluating areas suitable for urbanization are identified, it is necessary to determine the suitability level of each spatial unit using these criteria. Each criterion generates a map that assesses the level of suitability for urbanization. These suitability levels are then ranked according to the relative importance of each criterion, resulting in a series of maps that will be aggregated to obtain a final map.



Source: developed by the researcher following the decision-making process with the hierarchical analysis of Saaty [1980]

Fig. 3. Integration process of GIS and the AHP method for spatial decision support

In our study, as mentioned earlier, nine sub-criteria have been selected and ranked according to their importance. We used the weighted sum method, standardizing the factors on a scale from 0 to 10 to represent the suitability for urbanization of each area in the study zone. The criteria used in the hierarchical analysis were processed with the values assigned to them according to Saaty's classification.

The AHP (Analytic Hierarchy Process) method involves comparing elements at the same hierarchical level to determine their relative importance in solving the problem. The criteria established in this multicriteria hierarchy serve to evaluate the relevance of the objective using specific indicators for managing expansion constraints in an urbanization context. These indicators represent the various options available to achieve the project's final objective.

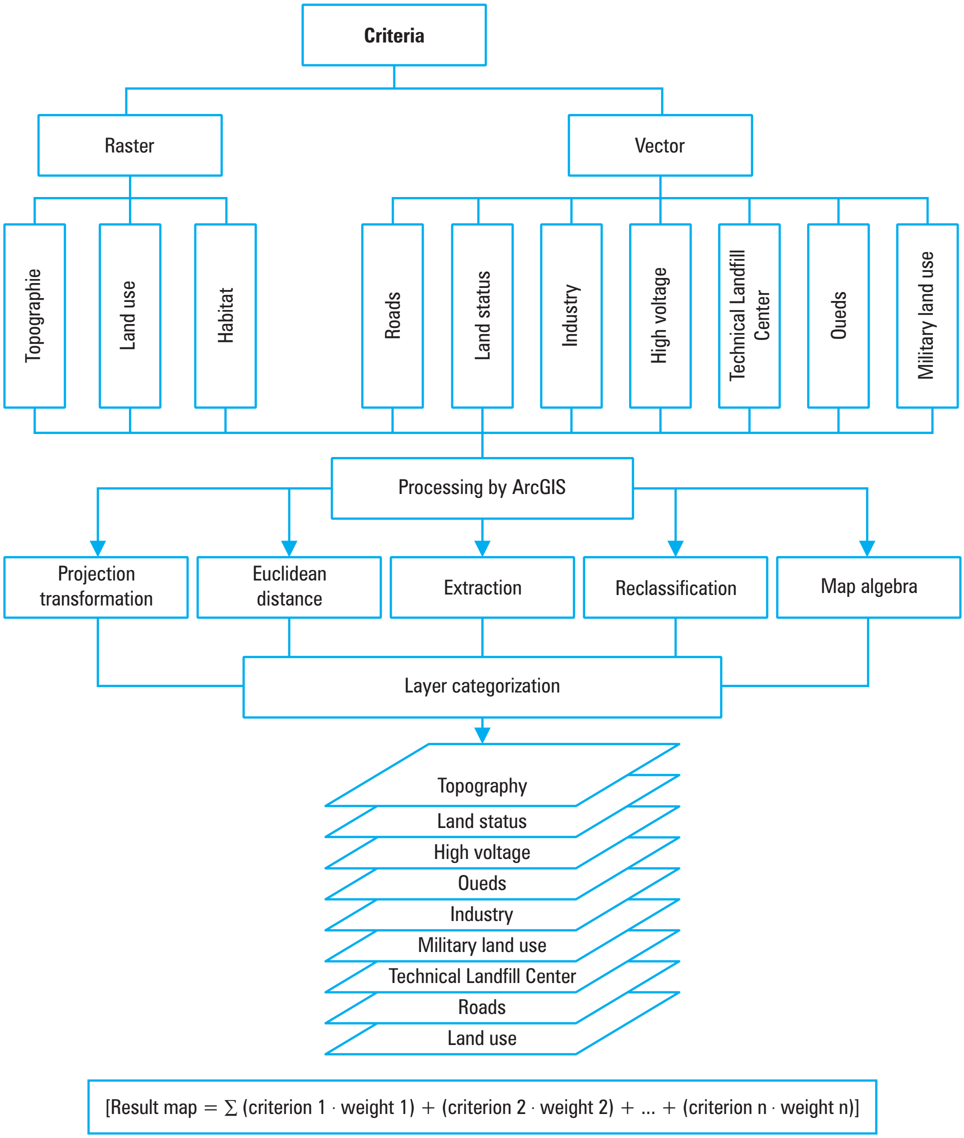


Fig. 4. Flowchart of data structuring and processing

At the end of the comparison process, a square matrix is obtained where each element ranges from 1/10 to 10. The diagonal elements on the matrix are always equal to 1, while the off-diagonal elements express the relative perception of the importance of one characteristic compared to another.

4.4. Verification of consistency

In Saaty's pairwise comparison method, consistency relies on maintaining transitivity in our judgments. The Consistency Index (CI), defined by the mathematical formula (1), assesses the reliability of comparisons in terms of consistent judgments. A higher Consistency Index indicates less consistency in the judgments expressed in the comparison matrix, and vice versa.

$$\mathrm{IC} = \frac{L_{\max} - n}{n - 1} \tag{1}$$

Table 2. Comparison matrix and relative weights of the evaluation criteria

Criteria	1.00	2.00	3.00	4.00	5.00	6.00	7.00	8.00	9.00	10.00	**Weight**
1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	12.09
2.00	0.25	1.00	3.00	3.00	4.00	4.00	4.00	3.00	4.00	7.00	23.20
3.00	0.25	0.50	1.00	3.00	2.00	2.00	2.00	4.00	4.00	8.00	15.41
4.00	0.14	0.13	0.20	1.00	4.00	4.00	7.00	6.00	7.00	8.00	17.53
5.00	0.17	0.25	0.20	0.25	1.00	3.00	3.00	3.00	6.00	7.00	10.42
6.00	0.17	0.20	0.17	0.14	0.50	1.00	1.00	4.00	4.00	6.00	7.12
7.00	0.17	0.20	0.17	0.14	0.20	0.50	1.00	1.00	3.00	5.00	4.82
8.00	0.17	0.14	0.13	0.13	0.14	0.14	0.25	1.00	4.00	5.00	4.22
9.00	0.14	0.13	0.13	0.17	0.14	0.20	0.20	0.14	1.00	6.00	3.08
10.00	0.13	0.20	0.13	0.25	0.13	0.14	0.20	0.20	0.14	1.00	2.10
Total	2.58	3.74	6.11	9.08	13.11	15.99	19.65	23.34	34.14	54.00	100.00

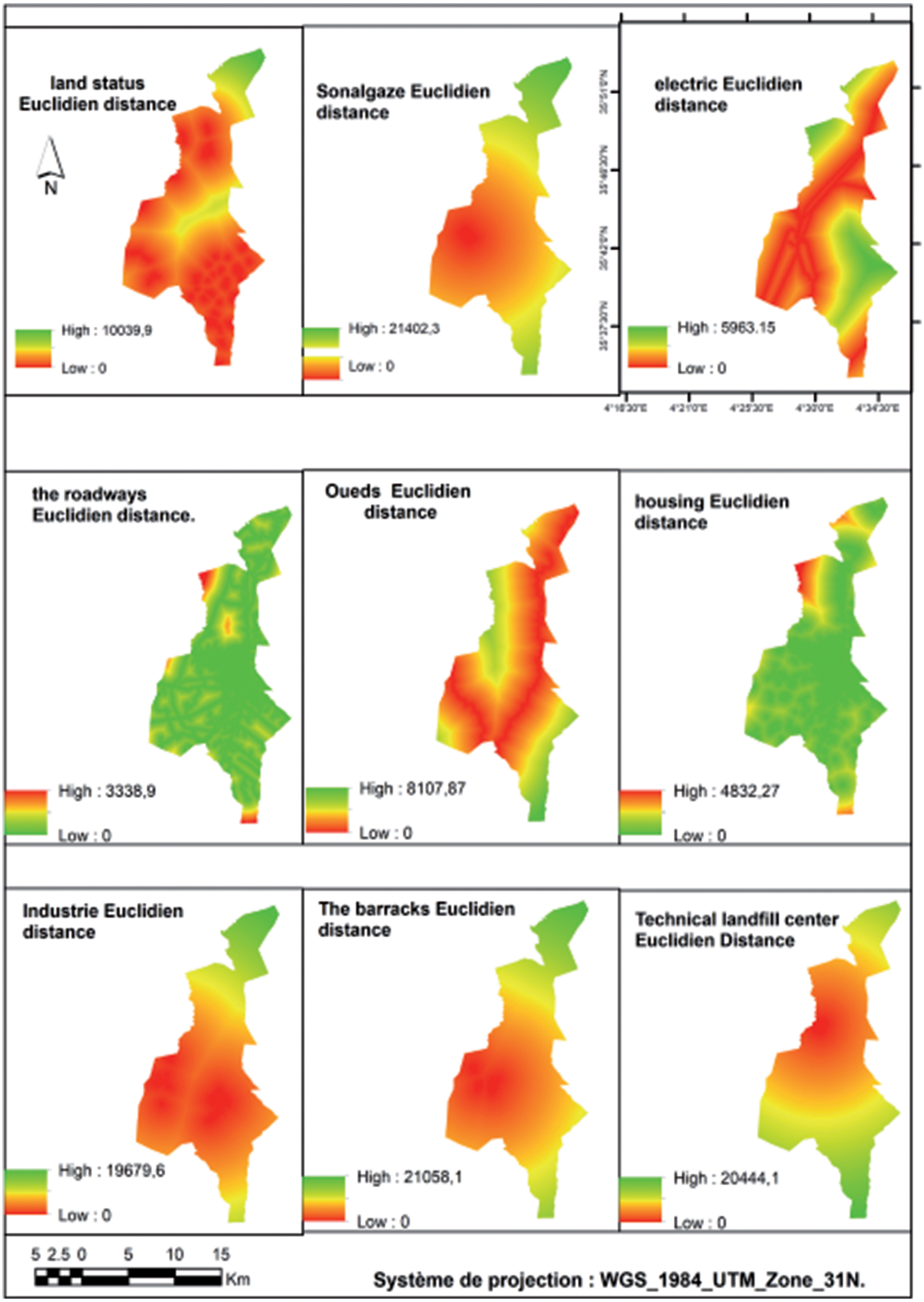
1 = Topography; 2 = Classification according to proximity to the road network; 3 = Land status; 4 = Land use; 5 = High voltage power lines; 6 = Industrial and military zones; 7 = Barracks; 8 = CET; 9 = the Wadis; 10 = Classification according to distance from urbanized areas.

4.5. Euclidean distance in ArcGIS

The combination of the AHP method and Euclidean distance in ArcGIS provides a systematic and quantitative approach to identifying areas suitable for urbanization. By integrating multiple criteria and their respective importance weights, this method enables a precise and objective evaluation of the potential of each zone, thereby facilitating decisions regarding urban development. Map number 2 illustrates the Euclidean distances for each criterion.

5. Results and discussion

The combined use of Analytic Hierarchy Process (AHP) and Geographic Information Systems (GIS) facilitated the assessment of land potential for urbanization. The process involved modeling information layers, raster conversion, calculating criteria weights



Source: Authors' own study

Fig. 5. The Euclidean distances of the urban extension constraints of the municipality of M'sila

through AHP, and integrating these weights into a GIS for aggregation [Result map = Σ (criterion 1 · weight 1) + (criterion 2 · weight 2) + … + (criterion n · weight n)].

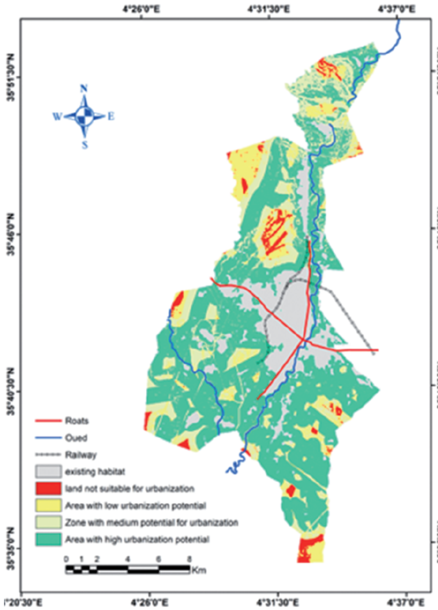
The final outcome is a map indicating the most suitable areas for urbanization. Proximity to the road network is the most critical factor (23.2%), followed by land use (17.53%) and land status (15.41%). The Consistency Ratio (CR = 0.02) confirms the consistency of expert judgments.

Proximity to roads plays a crucial role in urban stability, reducing infrastructure costs and ensuring homogeneity between existing residential areas and new expansion zones. Our findings are consistent with the municipal urban planning proposals for expansion zones that meet all the analyzed criteria. The final maps, numbered 3 and 4, resulting from the hierarchical analysis using AHP and GIS, identified a spatial suitability model for the future urban expansion of M'Sila city. It reveals that most suitable urbanization zones are located in the northern and northwestern parts. These areas, predominantly state-owned, are unsuitable for agriculture, far from industrial zones, close to the road network, and surround the city.

- Areas with high urbanization potential, representing 48.88% of the total land, are ideal for expansion and host numerous planned urban projects for the short and medium term. These lands are primeareas for urban extension.
- It is noteworthy that areas with moderate urbanization potential occupy a significant portion of the total area, emphasizing their importance in urban planning.
- Urban expansion presents challenges in every city worldwide, and M'Sila is no exception. There exists a proportion of lands unsuitable for urbanization, representing a small fraction due to natural and human-related factors.
- The application of Saaty's AHP enables informed and structured decision-making, facilitating effective and sustainable urban planning.

Table 3. Surface areas according to land type

Zone	Type	Surface [km^2]	Surface [%]
1	Area not suitable for urbanization	13.99472332	6.104783794
2	Area with low urbanization potential	43.81725311	19.11397965
3	Area with medium potential for urbanization	68.62740326	29.93667325
4	Area with high urbanization potential	102.802536	44.84456331



Source: Authors' own study

Fig. 6. Areas suitable for urban expansion using the AHP method, municipality of M'sila

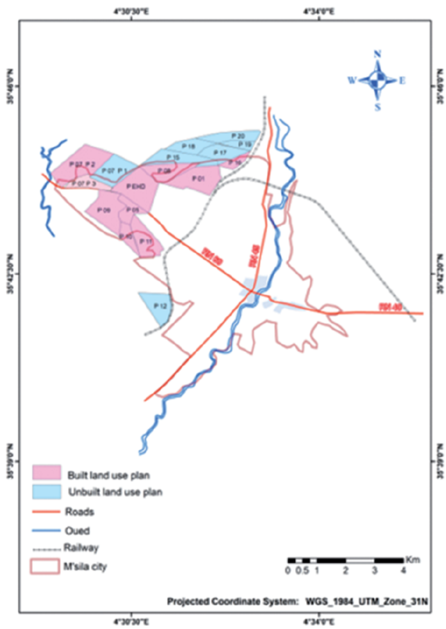


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Fig. 7. Land use plans roposed for medium and long term

6. Conclusion

The development of a model for evaluating land mobilization in urban planning relies on Saaty's method. This model integrates factors that reflect the perception of urban expansion, utilizing a multi-level hierarchical structure. To enrich our model, we have integrated the Geographic Information System (GIS), which enablies thematic modeling of information and classification of results on maps. This integration provides a spatial representation of land, topographic, and urban components.

Our methodology considers these components to construct an overall synthesis index. Four categories of indices were spatialized within the GIS and weighted using the multicriteria hierarchical method to produce a comprehensive decision map for land use planning.

This approach offers several advantages. Firstly, it provides a simple and flexible tool for land management, allowing for in-depth analyses and a clear understanding of land resource planning processes to meet urbanization needs. Secondly, it serves as a valuable resource for local authorities and urban planning services, offering flexibility and adaptability to various contexts and applications.

By integrating GIS and the multicriteria hierarchical method, our model efficiently visualizes and analyzes different land use options. This facilitates decision making by identifying the most suitable areas for urban expansion, taking into account land, topographic, and urban constraints. Moreover, the flexibility of our approach enables its application to diverse urban contexts and project types, making it highly versatile and scalable.

This methodology thus provides a solid foundation for thoughtful and well-informed urban planning, allowing for better anticipation of future challenges and optimization of available land resources.

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