GIS Based Multi Criteria Decision Analysis Techniques for Urban Development Site Selection: The Case of Jijel Area, NE Algeria

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Received: 28 April 2025 | Revised: 29 May 2025 | Accepted: 8 June 2025

 DOI: https://doi.org/10.48084/etasr.11798

ABSTRACT

This study presents a framework integrating Geographic Information Systems (GIS) and Multi-Criteria Decision Analysis (MCDA) to identify suitable sites for urban development in the Jijel region in Algeria. A GIS-MCDA model was created to select suitable sites for construction and to demonstrate the effectiveness of these methods and tools to urban planners and decision-makers. Six criteria were used: slope, lithology, flood, liquefaction, swelling, and depth of the groundwater table. These criteria were then standardized and weighted. This crucial step was carried out using the Analytic Hierarchy Process (AHP) method, based on constructing a pairwise comparison matrix of the criteria. Each criterion was weighted according to its relative importance. Subsequently, six layers were created using ArcGIS Pro software. Weighted Linear Combination (WLC) was used to combine the criteria weights and produce the Building Suitability Index Layer (BSIAHP). The results of this study are presented in the form of a construction suitability map of shallow foundations classified into five groups: very weak, weak, moderate, strong, and very strong suitability. These classes represented 24.48%, 38.48%, 11.41%, 8.05%, and 17.93% of the total surface area, respectively. This map was validated by a few boreholes (control points) that were not used to create the criteria maps.

Keywords-multi-criteria decision analysis; site selection; AHP; suitability; Algeria

I. INTRODUCTION

The city of Jijel has grown rapidly due to the population growth, hence there is a need for new expansion areas. Geotechnical studies must be carried out to determine the areas which are most suitable for construction with shallow foundations. The geological environment is a complex, multi-component dynamic system that cannot be studied comprehensively during construction or other technical activities (e.g., re-sloping in the case of shallow foundations). When using the model method, it is essential to create a simplified schema of the system by including only the components of the geological environment that are crucial to engineering geology. This process includes the distribution and properties of soil and rocks, groundwater, relief features, and ongoing geodynamic processes. Selecting suitable construction sites and creating a suitability map showing the spatial distribution of land is important for ensuring a safe and efficient urban growth. This research aims to raise awareness among planners and decision-makers about using effective tools and methods such as GIS and MCDA to mitigate risks and optimize the construction site selection. Ultimately, this will enhance the practical knowledge of geotechnical mapping, urban planning, and land management. GIS is crucial for managing data by integrating subsurface information into a cohesive framework. This integration enhances the data visualization, analysis, and interpretation, facilitating better decision-making in engineering projects. Geotechnical maps occupy an essential place in GIS and their importance is high. They can serve as the basis for initial studies on various projects, such as urban and industrial construction, communication infrastructure, and hydraulic works. They will, however, make it possible to conduct this study rationally and to interpret the results [1]. Multi-Criteria Spatial Decision Support Systems (MC-SDSS) is a class of SDSS based on the combination of GIS and MCDA methods. This process is an effective and advantageous method for transferring GIS to real support systems for decision-making. The GIS and MCDA coupling provides specialists with an analytical instrument capable of supporting spatial problems [2]. The application of MCDA, particularly the AHP, in urban development site selection is a robust method for determining the land suitability for building.

Several studies have demonstrated the effectiveness of GIS as an analytical method for engineering geology. The combination of GIS and AHP has been widely adopted for land suitability analysis, considering several criteria and ensuring that the relative importance of each factor is considered during the decision-making process. This method has been directly applied to identify the suitable sites for urban development and land-use planning [3, 4]. It has also been used to improve AHP [5-7] or combine AHP with other decision support methods to improve the weighting of criteria, such as the analytical network process [8], ordered weighted averaging [9], fuzzy set [10], entropy [11], and multi-influencing factors [12].

II. STUDY AREA

The study zone is located in northeastern Algeria in the eastern portion of the Jijel area (Figure 1). The area of the study zone is 243 km^2, representing 10% of Jijel province. The province's total population is estimated at 684,933 inhabitants (2020), with a density of 286 persons/km^2. The area is situated in the geomorphological province called the Neogene Basin and is surrounded by mountain ranges in the east, west, and south, with an absolute altitude between 300 and over 1000 m above sea level. The Jijel region is characterized by a Mediterranean climate, featuring a coastal marine environment that is rainy and cold in winter and hot and humid in summer. Temperatures vary between 11 °C and 25 °C, with a yearly average air temperature of 17 °C. The relative humidity values range from 70% to 75%, and evaporation from 41 to 80 mm. The high mountains of the Babors are characterized by a large volume of rainfall during the rainy seasons, reaching 900 mm/year [13]. It is considered among the rainiest regions in Algeria.

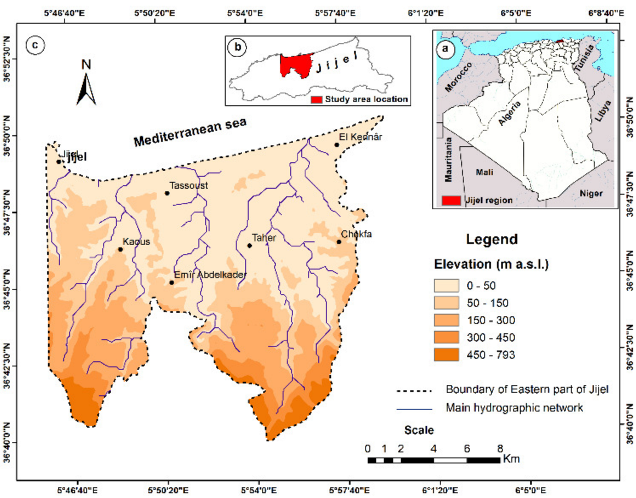

Fig. 1. Location and morphological characteristics of the studied zone: (a) location of the study zone in Algeria, (b) form and dimensions of the study zone and its location in Jijel province, and (c) hypsometric variations in the study zone.

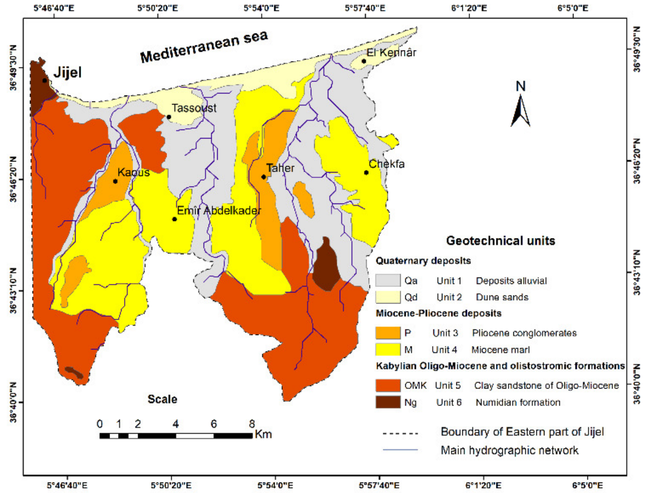

Fig. 2. Geological map of the study area.

The geological formations of the study zone are shown in Figure 2. They are composed of a substratum crystalline formed of metamorphic rocks (mainly schists, mica schists, marbles, and gneiss), a discordant sedimentary cover greso-micaceous in which blocks of flysch (olistholiths) are inserted corresponding to Kabylian Oligo-Miocene (OMK) olistostromic formations. Over this cover, the "post nappe" formations are found deposited unconformably on the other previous formations, including Miocene marls, Pliocene conglomerate, and Quaternary sands and silts [14, 15].

III. DATA AND METHODOLOGY

The current research displays the application of the GIS technique and AHP to construct an engineering geological map and determine the building's suitability areas based on the different factors. The data used in this study comprised the following elements:

- The topographic maps at a 1:25000 scale.
- The geological map of Jijel at a scale of 1:50000.
- Many geotechnical reports and studies were obtained from the public and private sectors from 2008 to 2022.

The procedure steps followed in this study are depicted in Figure 3.

Two stages were developed in this work. In step 1, spatial and non-spatial data were collected. The spatial dataset includes maps of multiple layers realized after digitization and registration according to the Universal Transverse Mercator (UTM) projection system (Zones 31, 32 and Datum: North Sahara 1959). The nature of the information at a specific point in the area is defined by the attributes of the non-space data, which are supplemental to the spatial data. The space distributions in the space and non-space data study area are important for creating geotechnical maps. The latitude and longitude (spatial data) of the positions of the boreholes in the study area were derived from geotechnical reports and studies. The Geotechnical Database was developed using Microsoft Excel with the data extracted from 1168 boreholes burrowed in the eastern part of the Jijel region (Figure 4). In step 2, six factors were extracted from the collected data using the ArcGIS Pro software. These factors were transformed into grid maps with a 30 m resolution and classified. In order to identify the weight value of each class and factor, an AHP model was approved. Finally, the final aptitude map was produced using different GIS functions.

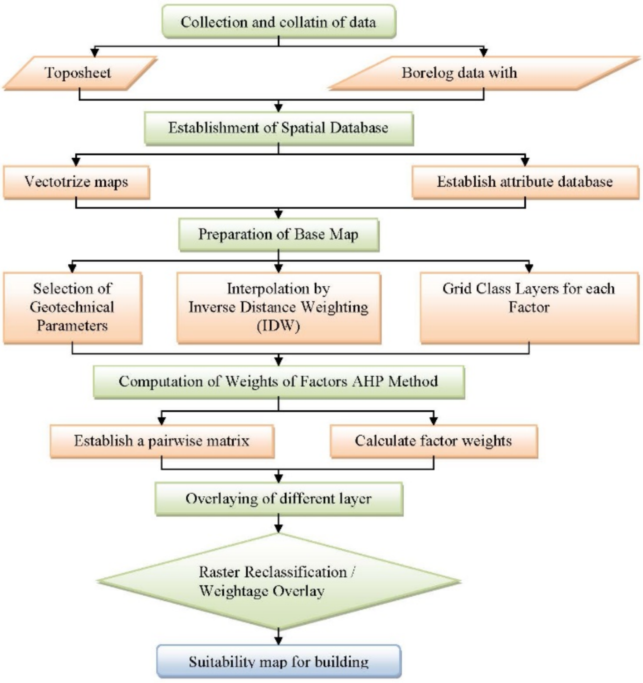

Fig. 3. Methodological flowchart of the study.

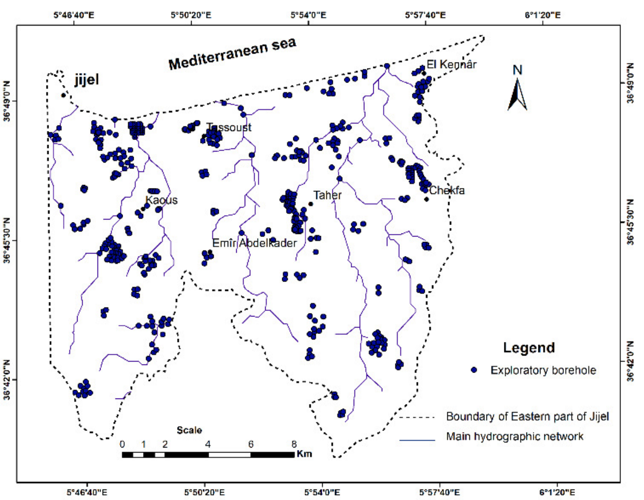

Fig. 4. Location map of boreholes.

IV. SUITABILITY MAP FOR BUILDING

A. Factors for Suitability Evaluation

To develop a suitable soil map for building, the factors included in the present study were the depth of the groundwater table, flood susceptibility, liquefaction potential, swelling, slope, and lithology. The selection of appropriate factors and the definition of the number of classes and their limit values were based on (a) review of the literature, (b) discussions with researchers, (c) suggestions from engineering geologists and planners practicing at the public sector, and (d) personal experience from previous studies. A spatial database was created using the ArcGIS Pro software, and the vector thematic layers of the factors were converted to a raster format at a cell size of 30 × 30 m.

1) Slope Layer

The construction cost on the sloping ground increases with the slope, so a gentle slope is more favorable than a steep slope. In addition, natural landslides may occur due to erosion or heavy rain on slopes. This situation can also be exacerbated by poor practices, such as backfilling at the top of a slope, concentrating water on the slope, loading the slope with a building, or excavating foot embankment slopes [7]. In this study, the slope map of the study zone was extracted from a digital elevation model created from the digitization of the contours of the topographic map after the required processing (Figure 5(a) and Table I). The surfaces with inclination values between 2° and 6° were considered the most favorable for construction, surfaces less than 2° and inclinations between 6° and 12° were considered intermediate, and inclinations greater than 12° were considered the least favorable for construction.

2) Lithology Layer

Knowing the nature of the land where a building is planned to be constructed is important because the specific characteristics of each soil determine the type of foundation suitable for future construction. The rocky ground does not require deep foundations because of its good lift, but the cost of production increases because of the necessary excavations. The lithological layer was created using the geological map corresponding to the study area. The formations are classified depending on their geotechnical engineering behavior into three categories (Figure 5(b) and Table I), namely: (i) soils constituted of sands, sands with clay, silty clay, silty sands, and recent alluvial, gravel, sand and pebbles, (ii) soils composed of quaternary terraces alluviums of ancient valleys, and continental conglomerates of Pliocene age, and (iii) hard soil-soft rocks composed of Miocene marls, flysch formation (sandstone with intercalations of clay and marl) of Kabylian Oligo-Miocene and Miocene Numidian sandstones and clays. The first category is considered the least favorable for building, the second category is the intermediate class, and the third category is the most favorable for building.

3) Flood Layer

Based on the review of existing reports about the flooding phenomena in the Jijel region, it is concluded that flooding occurs mainly during the storm periods and is caused by overflowing rivers or other watercourse plans. This phenomenon is related to the amplitude and elevation of the hydrographic network. Due to these conditions, the flood susceptibility layer of the study zone was realized, and areas with a slope of less than 2° are considered potentially floodable (Table I and Figure 5©).

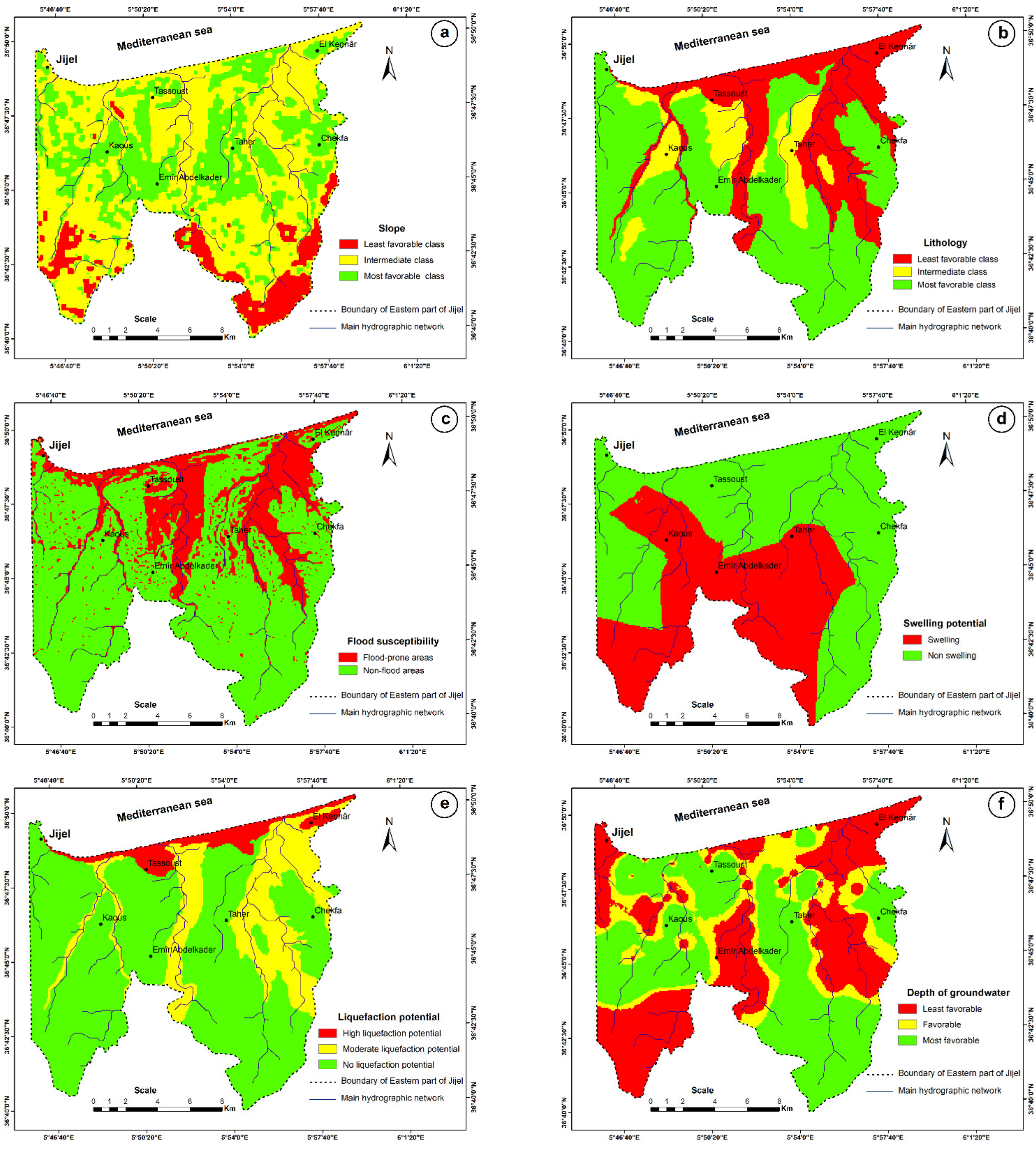

Fig. 5. The reclassified thematic layers of the parameters involved in the analysis. (a) slope map, (b) lithology, (c) flood susceptibility, (d) swelling potential, (e) liquefaction potential, and (f) depth to groundwater.

4) *Swelling Layer*

The swelling rate in soils is a function of several parameters, such as the plastic nature, the activity, the mineralogy of the soils, and the climatology. The swelling potential layer of the study zone was determined using the swelling index (Cs) of the fine fraction of the borehole data in a depth range of 0 to 2.5 m since, below this depth, the soil moisture remains constant. Soils with swelling index values greater than 0.04 are considered swelling soils, and those with values less than 0.04 are considered non-swelling soils [16]. Consequently, the swelling potential layer of the study zone was subdivided into non-swelling and swelling zones (Table I and Figure 5(d)).

TABLE I. CLASSIFICATION OF FACTORS AND SUITABILITY EVALUATION

Factor	Class	Suitability evaluation
Slope	> 12°	Least favorable
	< 2° and 6 -12°	Intermediate
	2 - 6°	Most favorable
Lithology	Sand, loamy fine sand, coarse sand, and fine gravel	Least favorable
	Coarse gravel and conglomerates	Intermediate
	Marl, sandstone, and clay	Most favorable
Flood susceptibility	Slope < 2°	Flood-prone areas
	Slope > 2°	Non-flood areas
Swelling potential	Swell index Cs > 0.04	Swelling
	Swell index Cs < 0.04	Non swelling
Liquefaction potential	Sand and loamy sand	High liquefaction potential
	Gravel and conglomerates	Moderate liquefaction potential
	Marl, sandstone, and clay	No liquefaction potential
Depth to groundwater	0 - 5 m	Least favorable
	5 - 10 m	Favorable
	> 10 m	Most favorable

5) Liquefaction Layer

Liquefaction appears only in saturated soils, so the depth of groundwater influences the liquefaction susceptibility. Liquefaction occurrences are most commonly observed at sites where the groundwater is within a few meters of the ground surface. Since liquefaction requires the development of exercise pore pressure and liquefaction susceptibility is influenced by the compositional characteristics that influence the volume change behavior. Compositional characteristics associated with high volume change potential tend to be associated with high liquefaction susceptibility. These characteristics include the particle size, shape, and gradation [17]. The layer of liquefaction potential of the study zone was determined by considering the compositional criterion. The lithology layer was reclassified to obtain the liquefaction potential layer into three classes: (i) the sandy and loamy sand was attributed to the class of high liquefaction, (ii) the gravel and conglomerates were attributed to the class of moderate liquefaction potential, and (iii) marl, sandstone, and clay were attributed to the class of no-liquefaction potential (Table I and Figure 5(e)).

6) Depth to Groundwater Layer

The depth of the groundwater table, possible groundwater rise, and the corrosive potential may cause an actual or potential risk to the engineering construction and must be considered. The stability of foundation excavations is influenced by the groundwater. To assess liquefaction, knowing the level of the piezometric surface of the water table in sediments is indispensable. Using groundwater depth data from available geotechnical boreholes, a layer representing the groundwater levels was created and reclassified into three classes: (i) depths from 0 m to 5 m were considered the least favorable, (ii) depths between 5 m and 10 m were considered favorable, and (iii) depths greater than 10 m were considered the most favorable (Table I and Figure 5(f)).

B. Weighting of the Factors

In the eastern part of the Jijel region, a building suitability map was created using the factor maps presented above. The procedure followed for urban geological mapping relies on the use of GIS. The method employed includes a multicriteria analysis and the conjunction of parametric maps by superposition. The weights of factors and the classes that express their order of priority in the decision process were previously calculated before combining factor maps. For this purpose, the pairwise comparison approach was used in the background of the AHP proposed by Saaty, based on constructing a matrix of comparison among the factors.

The first stage of the AHP is the development of the pairwise comparison matrix, where each value represents the relative sense of the importance of a factor to the others. The relative values of the two factors were set on a nine-point continuous scale (Table II). If the vertical axis factor is more influential than the horizontal axis factor, the values range from 1 to 9. Conversely, a value ranging from reciprocals of 2 to 9 is affected if it is less important. The diagonal of a pairwise correlation matrix always takes a value of 1 [18, 19].

The next step is the normalization of the pairwise comparison matrix. This consists of normalizing this matrix by column: the values of the same column are added and then each number of columns is divided by this sum. Then, the arithmetic mean of the numbers for each line is calculated. Each line corresponds to a factor; this average associated with the factor defines its weight. For each evaluation matrix, the consistency of the results was verified using the Consistency Ratio (*CR*), which is:

$$CR = \frac{CI}{RI} \quad (1)$$

where *RI* and *CI* are the random consistency Index and the Consistency Index developed by Saaty, respectively, *RI* is a constant that depends on the rank of the matrix (*n*), and *CI* is expressed as:

$$CI = \frac{\lambda_{max} - 1}{n - 1} \quad (2)$$

where λ_{max} is the eigenvalue of the matrix calculated from.

An acceptable value of consistency is a ratio of approximately 0.1 or less [18]. A consistency ratio above 0.1 includes revisions to matrix ranking, as specific factor rankings have been treated incoherently.

TABLE II. THE VALUES OF RI AND THE SCALE OF RELATIVE IMPORTANCE BETWEEN TWO PARAMETERS [18, 19]

Intensity of importance	Definition	Discretion
1	Equal importance	Two activities contribute equally to objective
3	Weak importance of one over another	Experience and judgment slightly favor one activity over another
5	Essential or strong importance	Experience and judgment strongly favor one activity over another
7	Demonstrated importance	An activity is strongly favored and its dominance demonstrated in practice
9	Absolute importance	The evidence favoring one activity over another is the highest possible order of affirmation
2, 4, 6, 8	Intermediate values between the two adjacent judgments	When compromise is needed
1/9 - 1/8 - 1/7 - 1/6 - 1/5 -1/4 - 1/3 - 1/2 - 1 - 2 - 3 - 4 - 5 - 6 - 7 - 8 - 9 ◄ Less importance — More importance ►		

n	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15
RI	0	0	0.52	0.89	1.11	1.25	1.35	1.40	1.45	1.49	1.51	1.54	1.56	1.57	1.58

TABLE III. THE PAIRWISE COMPARISON MATRIX FOR ASSESSING THE WEIGHTS OF CLASSES

Factor	Class	*C1*	*C2*	*C3*	Weights W_i
Slope	> 12°	1			0.0738
	< 2° and 6 -12°	1/3	1		0.2828
	2 - 6°	1/7	1/5	1	0.6434
Lithology	S, ML, CL, SW, SP, SM, SC, GM, GC	1			0.0964
	GW, GP, Conglomerates	1/3	1		0.2842
	Marl, Sandstone, C	1/5	1/4	1	0.6194
Flood	Slope < 2°	1			0.1250
	Slope > 2°	1/7	1		0.8750
Swelling	Cs < 0.04	1			0.1250
	Cs > 0.04	1/7	1		0.8750
Liquefaction	S, ML, CL	1			0.0567
	GM, GC, GP	1/3	1		0.2946
	Marl, sandstone, C	1/9	1/7	1	0.6486
Depth to groundwater	0 - 5 m	1			0.0738
	5 - 10 m	1/3	1		0.2828
	> 10 m	1/7	1/5	1	0.6434

An AHP Excel template was developed. The AHP method enables the parameters to correlate and derive the weights allocated to each factor separately. It was applied to two objectives in the current study: (1) to weigh the classes of all factors and (2) to obtain the final weights of the various factors. The pairwise correlation matrix required in elaborating the suitability map was created primarily for each factor on the one hand, and between the different factors of the other part, in its horizontal and vertical axes were defined the judgments of class and factor (Tables III and IV). The results of the *CR* values are shown in Table V. These matrices have a tolerable level of consistency because the *CR* values are all less than 0.1. Liquefaction, flooding, soil, and depth to groundwater are important parameters that influence the suitability for construction, whereas slope and swelling are of low importance. It is necessary to recognize that the recommendations of the experts practicing at the public sector services from the Jijel region and the experience personally acquired were used to determine the affected value to each class for the factors.

TABLE IV. PAIRWISE COMPARISON MATRIX FOR ASSESSING FACTOR WEIGHTS

Factor	*F1*	*F2*	*F3*	*F4*	*F5*	*F6*	Weights W_i
Liquefaction	1						0.3464
Swelling	1/5	1					0.0579
Lithology	1/3	3	1				0.1856
Depth to groundwater	1/4	2	1/2	1			0.1037
Slope	1/6	1	1/4	1/3	1		0.0490
Flood	1	4	1	1/3	1/5	1	0.2574

C. The Overall Suitability Index

Once the weighting procedure is carried out for the classes of the different parameters and the latter (Table IV), the second step for determining the suitability index values for construction is to combine the different thematic layers with their respective weights. ArcGIS software offers multi-criteria analysis tools through overlay tools and map algebra. The WLC algorithm, which exists among weighted superposition tools, was used [6, 20, 21]. Combining these factors with their weights using the WLC method produces a synthesis of the results in the form of suitability maps. The WLC technique is the most frequently used process in multi-attribute spatial decision-making. The building suitability index is calculated using:

$$BSI_{AHP} = \sum_1^n X_{ab} * W_b \quad (3)$$

where BSI_{AHP} is the building suitability index, n is the number of factors, W_b is the weight of factor b, and X_{ab} is the weight of class a in parameter b.

TABLE V. RESULTS OF CI, RI, AND CR FOR EACH FACTOR

Factor	*n*	λ_{max}	*CI*	*RI*	*CR %*
Liquefaction	3	3.0813	0.0406	0.58	0.07
Swelling	2	2.0000		0	
Lithology	3	3.0867	0.0433	0.58	0.07
Depth to groundwater	3	3.0655	0.0328	0.58	0.06
Slope	3	3.0761	0.0328	0.58	0.06
Flood	2	2.0000		0	

V. RESULTS AND DISCUSSION

The suitability map for building obtained by the conjunction of the six factors was classified using the equal interval method into five classes: very weak, weak, moderate, strong, and very strong (Figure 6). The very strong suitability class for building occupies an area of 59.48 km^2, corresponding to 24.48% of the overall area (Figure 7). It includes the Miocene marls, Oligocene sandstones and clays, and Numidian formation. This area is distinguished by slopes greater than 2°, groundwater depth greater than 5 m, and non-liquefiable and non-swelling soil. The strong class covers an area of 92.66 km^2, corresponding to 38.13% of the overall area, and is found to be different from the previous class owing to the presence of a lower water table (levels at 5 m). As the first class, the strong class mainly comprises Miocene marls. However, it is distinguished by the local presence of the Pliocene-Quaternary conglomerates and coarse gravel with clay matrix. The moderate class occupies an area of 27.73 km^2 (11.41% of the overall area). It comprises marl, sandstones, and fine to coarse gravel with a Quaternary ancient alluvial terraces clay matrix. The main characteristics are non-swelling and non-liquefiable sedimentary formations with slopes of less than 12° and a water table of less than 10 m. The weak class occupies a 19.46 km^2 surface area, corresponding to 8.05% of the total surface. The main formations of this area are marl, sand, and silty fine sand, which are liquefiable and swelling. Slopes greater than 2° characterize this area, and the ground depth is less than 5 m. The fifth class, which corresponds to the very weak class, covers an area of roughly 43.38 km^2, bringing an average of 17.93%. It consists of Quaternary formations containing fine gravel, coarse gravel, sand, and fine sand silty. Slopes are less than 12°, and the water table level is less than 5 m. In this area, these sedimentary formations are liquefiable and floodable.

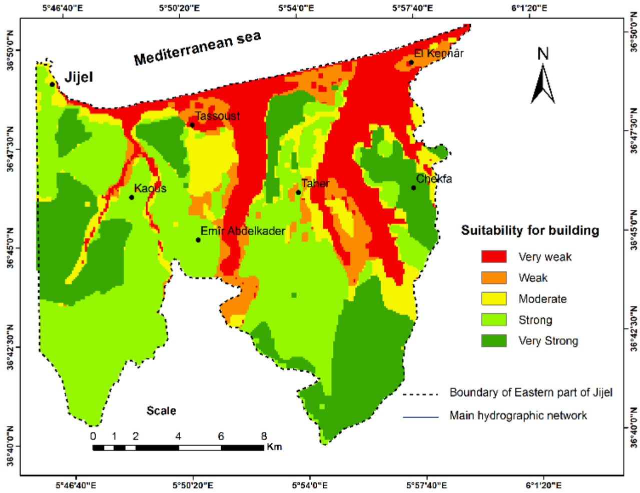

Fig. 6. Suitability area for the building of shallow foundations in the eastern part of the Jijel region.

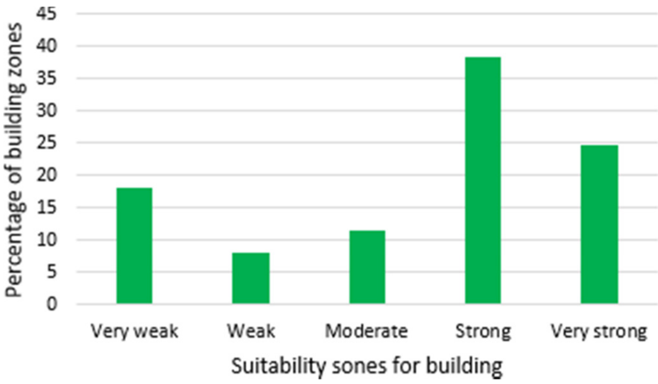

Fig. 7. Histogram showing the percentage of suitability zones building with the AHP methods.

The suitability map for building was validated by 60 boreholes (checkpoints) that were not included in establishing the criteria maps (Figure 4). To do this, the present study used the validation method based on the Receiver Operating Characteristic (ROC) curve and the Area Under the Curve (AUC). The ROC curve has a convex profile largely individualized from the diagonal line (Figure 8). The AUC value is 0.826, indicating high accuracy [22]. It is concluded that this model is representative and can be generalized to the Jijel region and regions similar to the study area.

The obtained map (Figure 6) shows that the areas of high suitability for building are located mainly in the western and southern parts of the study zone. However, the low suitability for building areas are situated along the main wadis (Nile, Djendjen, Mencha) and the coast. Given the tourist characteristics of this coastal region, public authorities have developed planning policies that respond specifically to these tourist peculiarities. In fact, of the 19 Tourism Expansion Areas (TEAs) defined by public authorities in the Jijel region, five TEAs are located in the studied zone. These five TEAs are Casino (0.73 km^2) and Adouane Ali (1.16 km^2), representing the eastern extension of Jijel City, Tassoust (3.91 km^2), Bazoul (1.09 km^2), and El-Kennar (4.80 km^2) along the coast. Given the orientations of this tourism planning policy and the results obtained in the context of this study, it is noted that the coastal areas least suitable for development and construction correspond to the main TEA in this portion of the Jijel area.

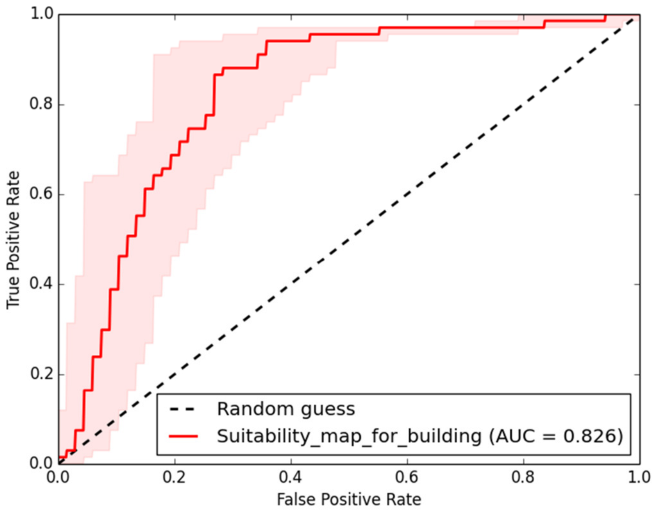

Fig. 8. ROC curves and AUC analysis for the model of suitability map for building.

Chekfa City is located in an area with very strong building suitability, attributed to geological formations characterized by lithologies that are not influenced by the liquefaction and swelling phenomena. It is also located in an area where the water table is relatively deep. Moreover, the cities of Jijel, Kaous, and Emir Abdelkader are located in areas that are highly suitable for building. These areas are distinguished from the Chekfa area by a shallower water table level. The city of Taher and its present extensions are in areas of moderate and strong suitability for buildings with less favorable lithology and relatively shallow water table levels. Localities with slopes of less than 2° represent areas with moderate suitability for building and are at greater risk of flooding. The cities of Tassoust and El Kennar, which are closer to the coast, are found in areas with weak suitability for building. The entire area between these two cities is exposed to flooding risks and liquefaction. This area is characterized by low slopes that favor flooding. Lithologically, this zone consists mainly of sandy formations that are susceptible to liquefaction.

Given these results, it would be preferable to direct the expansion of these cities towards the areas most suitable for construction. This approach would help avoid the loss of human life and material damage caused by natural hazards while reducing the construction costs. The risk associated with liquefaction and flooding is mainly developed in coastal areas, whereas soil swelling is much more sensitive in the central and southern parts of the study zone. The possible extensions of the cities of Jijel, Kaous, and Emir Abdelkader can be done without tangible and expressed risks. Conversely, it is preferable to orient the extension of the city of Tassoust, particularly towards the west.

VI. CONCLUSIONS

This study aims to provide planners with better knowledge of the geological-geotechnical conditions in the eastern portion of the Jijel area to enable them manage the soil use and occupation based on the guidelines proposed in this methodology. In conjunction with multi-attribute analysis, Geographic Information Systems (GIS) offers territory management opportunities by incorporating all sustainable management parameters. The multi-criteria assessment combines a group of criteria to create a simple suitability map for a particular category. Six factors were chosen to make the building suitability map: slope, lithology, flood susceptibility, liquefaction potential, swelling potential, and groundwater table depth. The weight values were determined by the Analytic Hierarchy Process (AHP) method for each factor and class and analyzed by the Weighted Linear Combination (WLC) method. With this analytical method, the conjunction of factors was done by multiplying each factor by its weight, followed by adding the results to obtain a suitability map. The map obtained was divided into five suitability groups, which specified that the strong and very strong suitability zones include about 62.61% of the overall area. In contrast, approximately 25.98% of the area is classified as having weak and very weak suitability zones, and 11.41% is moderately suitable. Ultimately, the map was confirmed with 5% of the total boreholes (checkpoints) not included in map creation.

The results of the study indicate the huge benefit of GIS combined with Multi-Criteria Decision Analysis (MCDA) for the identification of the appropriate areas for building. Nonetheless, the pertinence of the evaluation results is influenced by several parameters, namely, possible input data failure, database quality, treatment, and exploitation data in this system. Assessing the weight of the different factors is one of the main priorities to be realized; though rationally contestable, the method of weighing utilized in this research can be rather arbitrarily used and completely depends on expert opinions. The analysis results are particularly sensitive to the weightings assigned to the various factors, and any changes in them significantly influence the results. In addition, these maps do not exclude more detailed geotechnical studies, but can be used to make decisions and guide development actors in areas favorable for construction.

ACKNOWLEDGMENTS

The authors acknowledge that classifying different factors mainly depends on expert judgment, resulting in an arbitrarily used weighting method that may introduce subjectivity. Future work should explore more objective and standardized approaches for factor classification, ensuring consistency and reducing the bias in the evaluation process.

The authors want to acknowledge the journal editor and anonymous reviewers for their constructive comments. They would like to thank the directors and staff in the directorates of public works, town planning, building, hydraulics, planning, and regional growth for their valuable information and for allowing them to obtain most of the data required for this work.

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