Industrial Activity Land Suitability Assessment Using Delphi and AHP to Control Land Consumption

The Case Study of Bordj Bouarreridj, Algeria

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Abstract-Studies and research on land suitability for the localization of economic and industrial activities in cities are attracting academics and local policies concerned with urban planning and organization in order to make urban areas more accommodating. The current paper aims to demonstrate the ability of visualization and simulation techniques to assist planners in preserving urban real estate by combining the Delphi method with one of the multi-criteria hierarchical analysis decision-making techniques. The city of Bordj Bouarreridj in Algeria was chosen as the case study and, with the participation of experts, a set of criteria were adopted to determine land suitability. Three criteria were selected in the first phase with the use of the Delphi method. In the second phase, we applied the Analytical Hierarchy Process (AH, a hierarchical analysis method. During the third stage, the obtained results were translated into the GIS program to derive the spatial suitability map. The following are among the most important achieved results: 13.38% (521.793 km^2) of the area was regarded to be of high suitability, 67.54% (2,634.758 km^2), achieved moderate suitability, 12.94% (504,794 km^2) attained low suitability, and 6.14% (239,685 km^2) were found to be not suitable at all.

Keywords-industrial activity; Bordj Bouarerridj; land suitability; control consumption; Delphi method; AHP

I. INTRODUCTION

Both private and public sectors contribute to the increment of the area of cities. In Algeria, we find that most of the construction of industrial zones is usually at the expense of agricultural lands, which affects the land uses of cities by covering the increasing housing demand [1]. The economic transformations of cities have created factors, represented in factories and workshops, that contribute to the emergence of management and organizational problems of the territory, especially about the allocation of lands and their suitability. The planners confront a dual problem in this situation. They must create initiatives and programs that maintain ecological balance while promoting economic growth, while they must act as mediators, attempting to prevent conflict and reduce objections. Land use planning is a means of optimal allocation of land resources [2]. It is frequently utilized in the spatial allocation and characteristics of land size to scheme and arrange land usage of the studied areas. Studying and identifying land-use needs for each land-use type is critical and fundamental for evaluating land use suitability for each land mapping unit [3]. Land use suitability analyses are of considerable use in the planning of mega-cities [4]. As a result, it is critical to use a technique that allows weight estimation. One such strategy is the Analytical Hierarchy Process (AHP), which is a multi-criteria decision-making method.

The author in [5] used several variables that were related to the environmental aspect. He focused his studies on environmental indicators. In this study, the answers were obtained by experts and institutions, and the obtained data were analyzed with the AHP method, after which a map of spatial suitability was derived by the Geographic Information Systems (GIS). Authors in [6] used AHP to determine the GIS weights based on 12 variables. Their study focused on social, economic, and environmental indicators. Such methods have the largest number of variables but the participation of experts and sometimes residents is often necessary. Authors in [7] used GIS and AHP to select the best sites for urban growth in Seremban, Malaysia. Many social, economic, and environmental factors were considered to create a final land suitability map, but the notable thing in this study is that the researchers relied on the selection of factors and variables on local literature and general observations only without relying on experts or residents.

This paper presents the results obtained by integrating the Delphi approach, AHP, and GIS in analyzing the relevance of land use to economic activity to control the land consumption in urban areas. The case study area was the city of Bordj Bouarerridj.

II. MATERIALS AND METHODS

A. The Study Area

Bordj Bouarerridj is an Algerian city in the high eastern highlands. It is located in the Algerian east in the middle of two Atlas Mountains series, the Beban mountain range and the Al-Hodna mountain range with a population density of 186.4 inhabitants/hectare in 2014, according to the NSB (National Statistics Bureau). Its total area is estimated at 3901.02km^2, i.e.

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the 1/600 of the total area of Algeria. The forms of land usage vary, the land appropriateness is broad, and the degree of use is high (Figure 1).

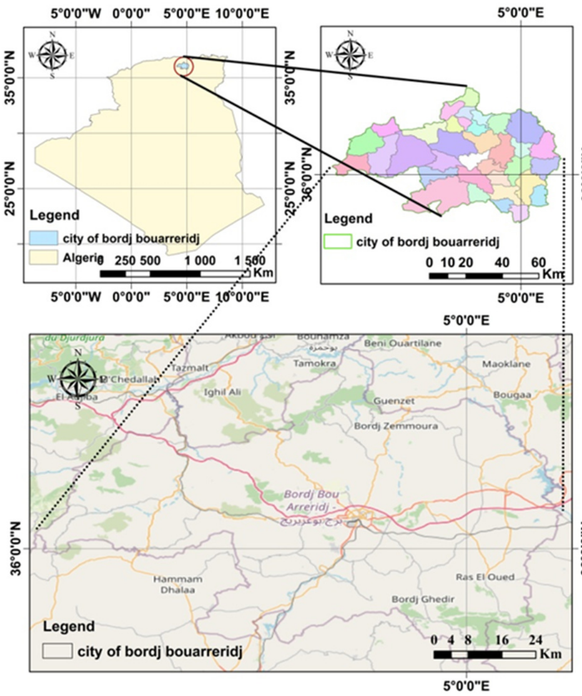


Fig. 1. The study area. Prepared by the researchers on the QGIS program, 2021.

B. Data Collection

1) Suitability Factors for Land Use for Industrial Activities

The criteria defined by the Delphi method to study the suitability of lands for economic and industrial activities, and their weights were appreciated by using the expert choice v11 program, which is an application for multi-criteria analysis through AHP. After collecting the geographical data, layers of determinant criteria, and sub-criteria were set in the open-source QGIS program. The results are displayed graphically in Figures 2-9.

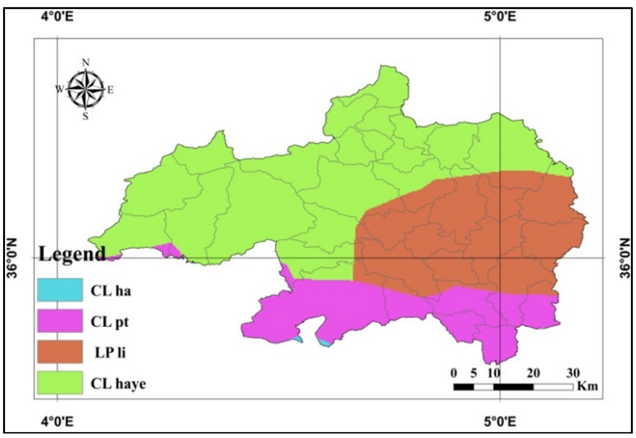


Fig. 2. Geological nature of the study area. Prepared by the researchers on the QGIS program.

2) Nature and Environment

For this factor, forest areas, hydrographical networks, and watershed basins have been identified, through the Bordj Bouarerridj city Reconstruction Plan. The suitability sub-factors were as follows (Figure 2): Forest areas: (0-5 Km), (5-9 Km), (9-13 Km), and (> 13 Km). Hydrographical network: (0-5 Km), (5-10 Km), (10-15 Km), and (> 15 Km). Watershed basins: (0-5 Km), (5-10 Km), (10-15 Km), and (>15 Km).

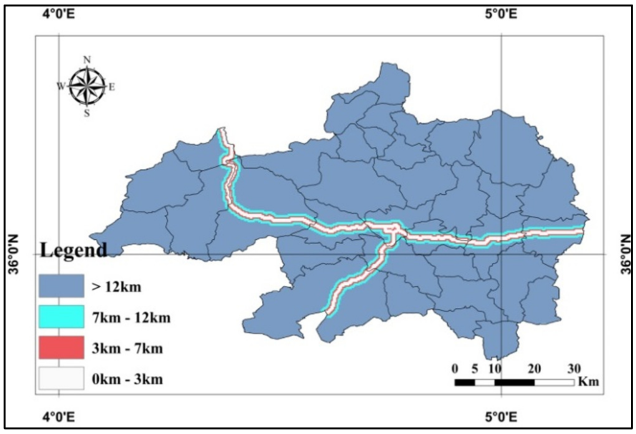


Fig. 3. Railways of the study area. Prepared by the researchers on QGIS.

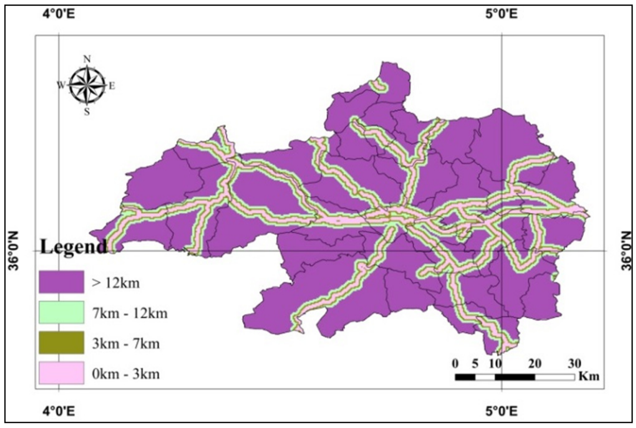


Fig. 4. Principal roads of the study area. Prepared by the researchers on QGIS.

3) Security and Protection

The relevant information was collected from the planning and reconstruction plans of the Bordj Bouarerridj state. Layers were determined in the ARC GIS program in urban tissues, archaeological areas, slopes, and geological sites according to the opinion of experts and technicians. The range of suitability for the distance from residential areas was as follows: (< 4 Km), (4-10 Km), (10-15 Km), and (> 15 Km). For slope, the range of suitability was as follows: (< 4%), (4%-8%), (8%-12%), and (> 12%). The geological nature was determined according to the permeability and type of soil.

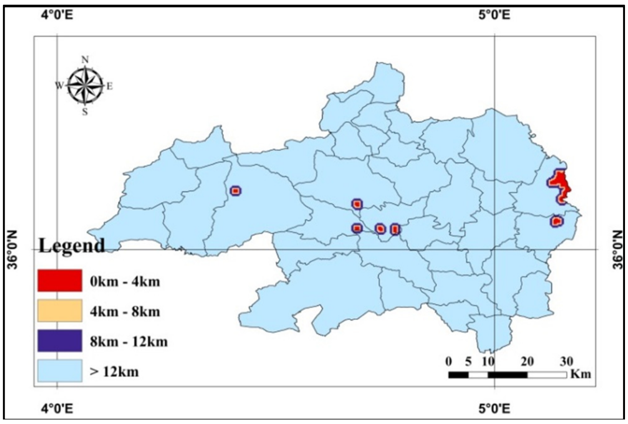


Fig. 5. Watershed basins of the study area. Prepared by the researchers on QGIS.

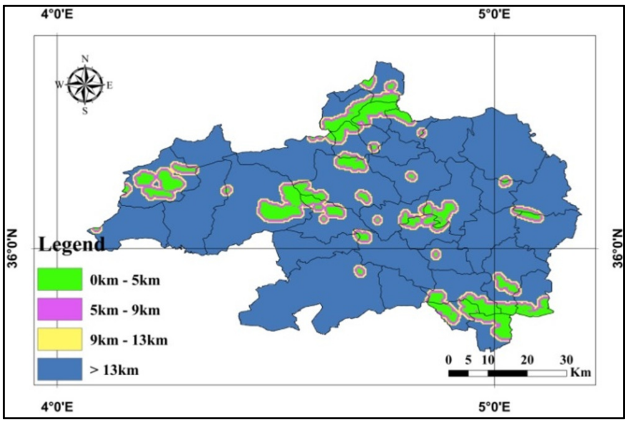


Fig. 6. Forests on the study area. Prepared by the researchers on QGIS.

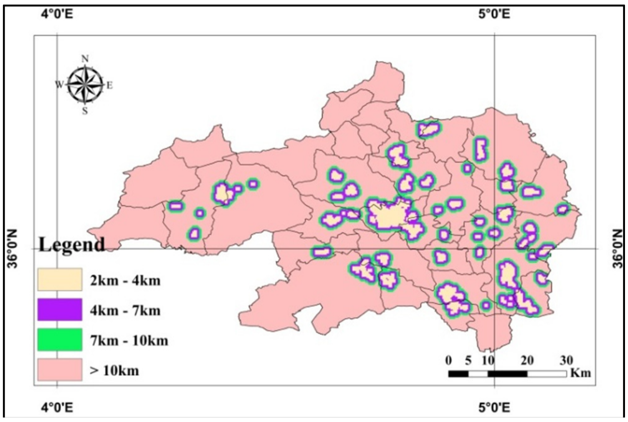


Fig. 7. Urban areas of the study area. Prepared by the researchers on QGIS.

4) *Economic Determinant*

For this factor, we considered all the main roads and structured railway lines of the case study. The data were collected from the planning and reconstruction plans of Bordj Bouarerridj in 2018. The range of suitability was determined by the experts as follows: (0.5-4 Km), (4-10 Km), and (> 10 Km) (Figures 3, 4).

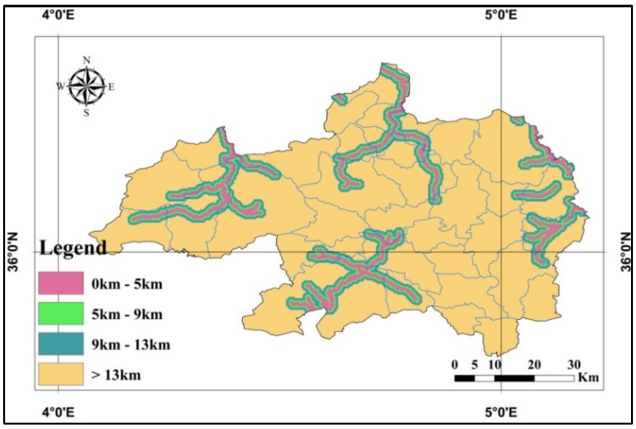


Fig. 8. Water ways of the study area. Prepared by the researchers on QGIS.

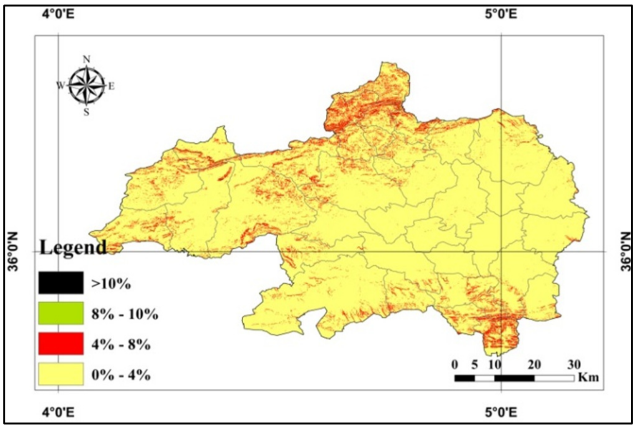


Fig. 9. Slopes of the study area. Prepared by the researchers on QGIS.

C. *Methods*

Industrial site selection is a spatial decision problem. Such problems typically involve a large set of feasible alternatives [8]. Land suitability for industrial activities is a somewhat complicated process considering the data and characteristics that distinguish them. Therefore many possible alternatives must take as well as appropriate multi-faceted and often conflicting standards, such as economic, environmental, climate, social, etc. The Delphi method is often applied to define the evaluation criteria as a way of structuring the method of collective communication to affect the complex problem of extracting and studying the influential factors to seek out the most appropriate sites. The suitability of lands for industrial activities in urban areas is determined by calculating the degree of importance of the percentage of significant value [9]. After, we used the AHP method which is used to solve complex decision problems [10]. That decision-making tool depends on reliable measurement and thorough evaluation to present suitable lands for economic activities [11]. It also serves as a helpful tool for capturing both subjective and objective assessment measures for checking the consistency of the evaluations and thus reducing bias in decision making [12]. This study is based on the AHP and through interactive computer programs (expert choice v11) [13]. The computer uses a hierarchical framework of criteria and comparisons between them to establish the criterion weight. The additive transformation function of the weighted summation technique is applied to get a final score for each choice. Expert Choice Network accepts no restriction on the size of the decision issued in this scenario. The DM's preferences on criteria are represented by cardinal weights [14].

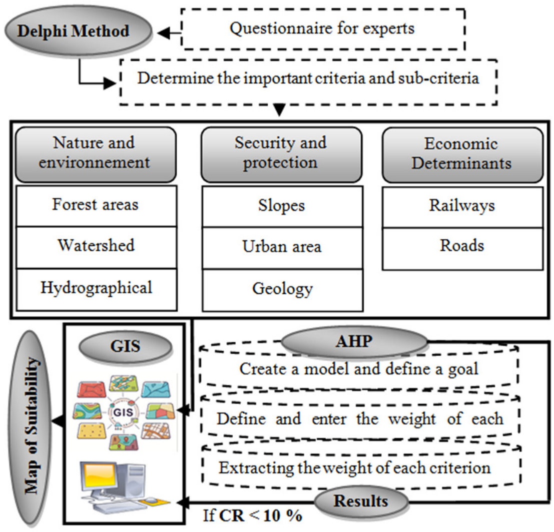


Fig. 10. The analysis used for this research.

D. Delphi Method

The Delphi method is a consensus method that aims to find general agreement among an expert panel on a specific research topic [15]. It is considered a way for organizing the group communication process to facilitate group issue solving and model building. Its principal area of application has remained that of technical forecasting [16]. In this research paper, we relied on 15 experts of various disciplines, namely geology, urbanization, economics, and law, who are familiar with the research topic and close to the decision-making authorities. Our questions were presented to them in four stages. After the first stage, we sent an anonymous summary of the resume of the experts' outlook of each previous stage and its reasoning [17]. This gradually led to the convergence of viewpoints and after the questionnaire's results were obtained. Through the questions posed to the experts and based on their opinions, criteria of approval for each standard set of sub-criteria were set. After this, the AHP series pyramid was analyzed to determine the weights of the main indicators and the sub-criterions in Expert Choice v11 software.

E. Hierarchical Analysis Process

AHP is a Multiple-Criteria Decision-Analysis (MCDA) technique used in solving various decision-making problems [18-20]. It is suitable for the evaluation of complex multi-attribute alternatives [21], because it is considered one of the most effective and easy procedures [22]. The AHP model has been applied to determine weights and ranks of all the subcategories [23]. The AHP methodology may tolerate inconsistency according to pair-wise comparison by given a measurement of evaluation inconsistency. This measurement is among the most essential parts of the priority determination process. The higher the consistency ratio, the assessment result becomes more inconsistent [24]. After the hierarchy creation, the relative importance of all resolution elements is captured and detected through binary comparisons. The Expert Choice is a decision-oriented program that provides support to decision-makers by organizing information with regarding to the complexity of a multi-solution problem into a hierarchical model consisting of objective, potential scenarios, agents, and alternatives. The priorities are determined along with the comparison matrix. We begin with a matrix that is consistent and has known priority p_i. p_i/p_j is used to compare alternatives i and j which is multiplied with the priority vector p results [25]:

$$\begin{bmatrix} p_1/p_1 & p_1/p_2 & \cdots & p_1/p_n \\ p_2/p_1 & p_2/p_2 & \cdots & p_2/p_n \\ \vdots & \vdots & \ddots & \vdots \\ p_n/p_1 & p_n/p_2 & \cdots & p_n/p_n \end{bmatrix} \begin{bmatrix} p_1 \\ p_2 \\ \vdots \\ p_n \end{bmatrix} = n \begin{bmatrix} p_1 \\ p_2 \\ \vdots \\ p_n \end{bmatrix} \quad (1)$$

Or grouped:

$$A\vec{p} = n\vec{p} \quad (2)$$

where $\vec{p}$ is the prioritization vector, n the matrix dimension, and A the matrix of comparison.

The author in [13] proposed a Consistency Index (CI) because priorities are only relevant if they are generated from coherent or close-to-consistent matrices, which is related to the eigenvalue method [26]:

$$\text{CI} = \frac{Maks\ eigenvalue - n}{n-1} \quad (3)$$

$$Maks\ eigenvalue = \sum wi.ci \quad (4)$$

The Consistency Ratio (CR) is calculated to measure the consistency of the solution [27], and it is obtained by (5). The Random Consistency Index (RI) is shown in Table I [28].

$$\text{CR} = \frac{\text{CI}}{\text{RI}} \quad (5)$$

TABLE I. RANDOM CONSISTENCY INDEX.

n	1	2	3	4	5	6	7	8	9	10
RI	0	0	0.58	0.90	1.12	1.24	1.32	1.41	1.45	1.49

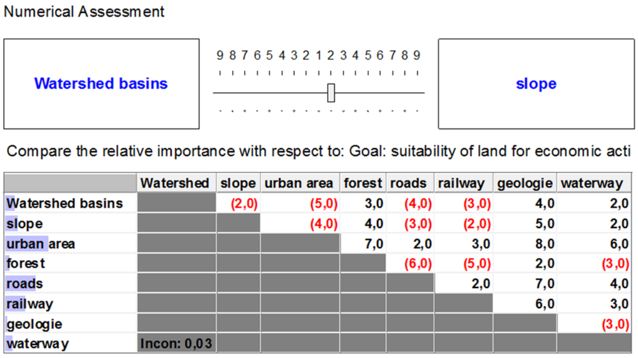
If CR ≥ 10% the data are considered inconsistent. If CR < 10% we have data consistency and the matrix is considered as having an acceptable consistency [25].

F. Geographic Information System (GIS)

GIS is a process of mapping and integrating computer-founded information with the ability of data layer management to make appropriate decisions by combining geographical information layers [29]. Data combined with an application of GIS provide alternative, flexible and scalable means [30]. The availability of digital data archives since 1987 enables the quantitative and qualitative assessment of land use patterns [31]. Accordingly, several studies have been conducted emphasizing the adoption of Delphi, AHP, or a combination of these methods, with GIS for modeling and analyzing spatial suitability [32]. It assists decision-makers to assign priority weights to decision criteria, evaluate the suitable alternatives, and visualize the results [33].

III. RESULTS AND DISCUSSION

This research relied on a MCDA using the AHP analysis to study the suitability of land use for economic activity in order to control the consumption of urban land involving the opinions of experts in the field. Eight criteria were used to quantify the suitability for economic and industrial land use, namely urban areas, slopes, forest areas, hydrographical network, watershed basins, geology, roads, and railways. A comparison matrix was implemented between the main factors and subfactors and paired-wise comparison was conducted between the sub-criteria of the same level [34]. Afterwards, the weight of each determinant was extracted (Figure 11).


Numerical Assessment

Watershed basins — 9 8 7 6 5 4 3 2 1 2 3 4 5 6 7 8 9 — slope

Compare the relative importance with respect to: Goal: suitability of land for economic acti

	Watershed	slope	urban area	forest	roads	railway	geologie	waterway
Watershed basins		(2,0)	(5,0)	3,0	(4,0)	(3,0)	4,0	2,0
slope			(4,0)	4,0	(3,0)	(2,0)	5,0	2,0
urban area				7,0	2,0	3,0	8,0	6,0
forest					(6,0)	(5,0)	2,0	(3,0)
roads						2,0	7,0	4,0
railway							6,0	3,0
geologie								(3,0)
waterway	Incon: 0,03							

Fig. 11. Results of AHP among main and sub criteria.

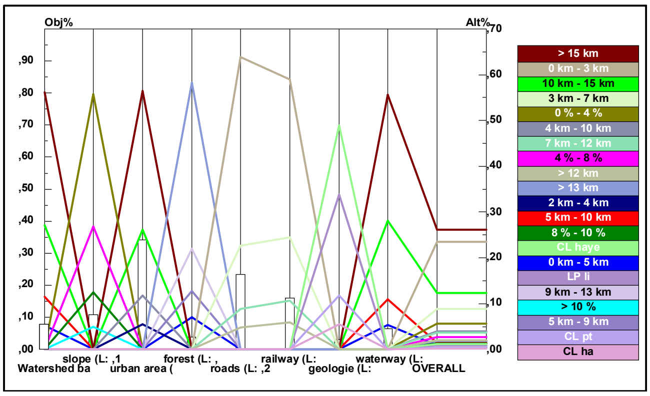


Fig. 12. Performance sensitivity for nodes.

The proportion of consistency was less than 10%, which means that the distribution between the factors was acceptable.

TABLE II. AHP KEY CRITERIA RATING

criteria	weight	rating
Road	0.2265	2
Railway	0.1531	3
Geology	0.237	8
Hydrographical network	0.571	6
Watershed basins	0.0726	5
Slope	0.1015	4
Forest	0.0318	7
Urban area	0.3338	1

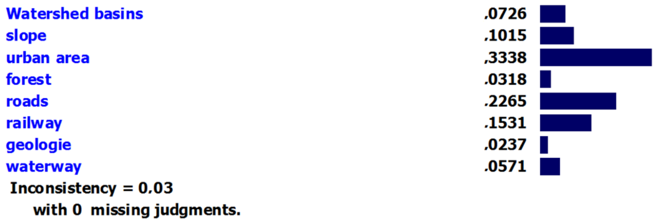


Fig. 13. Priorities with respect to goal.

Based on the previous hierarchical analysis of the suitability of land use for economic and industrial activity, the role of GIS comes in the form of a model that summarizes all stages of work in the ARC GIS. We compiled all the pre-defined standard maps in GIS via Raster calculators with each standard multiplied by the weight generated by the AHP and Expert Choice to produce a suitable land use map. (Figure 14).

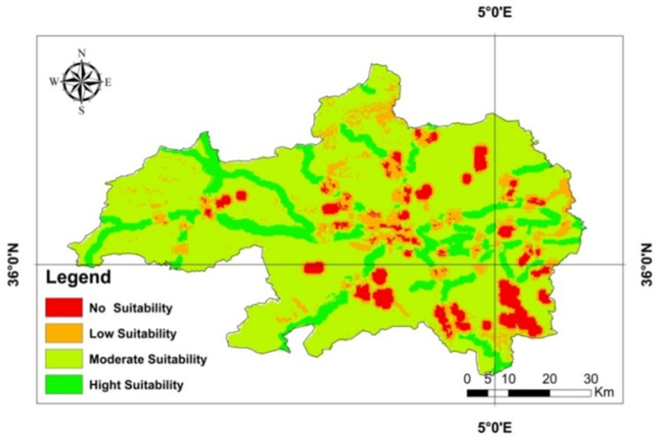


Fig. 14. The produced land suitability map for for economic and industrial activity regarding the Bordj Bouarerridj area. Prepared by the researchers on the QGIS program.

The final map gross weight was calculated by raster calculation using (6):

$$SL = (ROw * ROr) + (RWw * RWr) + (Gw * Gr) + (WWw * WWr) + (WAw * WAr) + (Sw * Sr) + (Fw * Fr) + (Uw * Ur) \quad (6)$$

where SL is the suitability of land use for economic and industrial activity, w is the weight of each criterion, r is the classification of each criterion, RO stands for road, RW for railway, G for geology, WW for waterways, WA for water, S for slope, F for forest, and U for urban areas.

Through hierarchical analysis the proportion of land-use suitability for economic and industrial activity in the city of Bordj Bouarerridj was:

- 13.38% of the total area with a total surface area of 521.793km^2 achieved high suitability.
- 67.54% of the total area with a total surface area of 504.794km^2 achieved moderate suitability.
- 12.94% of the total area with a total surface area of 2634.758km^2 achieved low suitability.

- 6.14% of the total area with a total surface area of 239.685km^2 was not suitable.

The results are summarized in Table III. In the final map (Figure 14) of the city of Bordj Bouarerridj' suitability of land usage for industrial activities, we note that the areas that achieved high suitability according to the AHP are the areas that are away from the urban tissues and near the road.

TABLE III. PERCENTAGE OF AHP STANDARD.

Classes	Area (km^2)	%
High suitability	521.793	13.38 %
Moderate suitability	2634.758	67.54 %
Low suitability	504.794	12.94 %
No suitability	239.685	6.14 %
Total	3901.023	100 %

IV. CONCLUSIONS

In this study, we utilized Delphi methodology and AHP and GIS technologies and a strategy was developed to assess the land use for economic activities and thus be able to manage the land consumption of metropolitan areas. The case study of this research was the state of Bordj Bouarerridj. A group of experts defined a set of criteria that helped determine the suitability of regions for economic activity. The AHP hierarchical analysis method was used to extract land-appropriate measures through the Expert Choice program. The consistency ratio was 0.03, which is less than 0.1, and therefore is considered favorable.

After using the AHP method, spatial analysis of the study area was carried out, with the creation of a geographical database of the criteria specified by the experts in GIS environment by creating a model using all accounted data to extract an appropriate map of land use for economic activity.

We can conclude by saying that the combination of the Delphi method and the hierarchical analysis using Expert Choice software in GIS environment is a practical scientific method that gives accurate results in determining the land use suitability for economic activity, according to the defined criteria. However, these criteria remain variable factors because they depend on the specificities of each region. The produced map may be adapted to identify regions for future housing development, evaluate the worth of a property, and assist decision-makers in achieving balanced urban development.

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