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THE SPATIAL MODELING OF URBAN EXPANSION. CASE STUDY MSILA

Abstract: Understanding, analysis, monitoring and modelling of urban growth evolution as a major driving force of land use, especially in developed countries, is of great importance for land managers in the process of development. This research aims to analyse the spatial modelling of urban expansion using modern technologies - Delphi and Analytic Hierarchy Process (D-AHP) hybrid model and Geographic Information System (GIS) technique for Land-Use Assessment. These techniques are used to detect the most suitable and unsuitable areas in the Msila zone. By engaging residents and experts to choose criteria for analysing urban expansion, the study showed that 80.75% of total area represent suitable lands for expansion and around 19% represent unsuitable lands. By reading the results of the study, it is clear that the total suitable lands are located in the southwestern side of the city.

Key words: urban expansion, Delphi method, GIS, analytic hierarchy process (AHP), decision-making

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Introduction

One of the important issues in urban planning is the identification of suitable sites for urban expansion (Admasu & Jenberu, 2020) of the city on a large scale in order to preserve lands, on the one hand, and to organize the city and develop, on the other hand.

The analysis of spatial modelling and suitability of urban expansion is one of the most important and effective techniques for determining the suitable sites for urban expansion (Alexander & Benjamin, 2012; Jankowski, 1995; Aburas et al., 2017). This technique is effective as it helps planners and decision-makers to analyse all data before reaching a final decision about future changes regarding land use (Bagheri et al., 2013). Identifying the relative weights of the factors used in land suitability analysis is generally difficult. Thus, the use of a technique that has a powerful capability to identify the weights of various factors is important. AHP is one of the significant techniques used in analysing issues related to spatial nature (Javadian et al., 2011).

In setting the importance of the criteria used and computing the weights of factors, GIS tools must be integrated with other methods to improve the results of land suitability analysis (Zhang et al., 2006; Phua & Minowa, 2005). The integration of GIS tools and multi-criterion decision analysis is a powerful approach for evaluating land suitability (Bagheri et al., 2013).

The references indicate that the methodology of integrating the AHP method with GIS has been used in the positioning process in several previous studies in this field. We point out as an example: the first, on Ulubey Canyon (Usak—Turkey) and its surroundings is analysed in terms of land use suitability. Resorting to GIS and the AHP, the study area is approached in terms of three land-use categories: agriculture, pasture and forest. For this analysis, topographic conditions, soil properties, climate types and lithological properties are evaluated (Cukur et al., 2019). The second article this study aims to use GIS and AHP to choose the best locations of urban growth in Seremban, Malaysia. Various social, economic, environmental, utilities, and physical factors were used to generate a final land suitability map (LSI) (Aburas et al., 2017). It was concluded that these techniques help decision-makers in preserving the ecosystem of semi-urban areas for cities, in light of what was mentioned in the two studies were based on two techniques: AHP and GIS to determine the suitable areas of urban expansion. In addition to these two studies, the Delphi method was used in this study to better define the criteria after discussion by experts.

In light of the planning problems the city of Msila, where the buildings are spread in areas unsuitable for expansion, which negatively affected the planning and development process until this percentage reaches 70% of the total buildings in the suburbs (Msila Municipality, 2010). The study aims to pre-conceptualize a digital map suitable for the urban expansion of the city according to pre-defined criteria by specialized experts (architects, MER, real estate promoters) for understanding, correction and control. The process of urbanization in the study area, depending on the integration of the Delphi method with AHP determination of its spatial areas in GIS and the assistance of technical departments (decision makers) to plan in the monitoring and control of urban expansion (Steiner et al., 2000; Cukur et al., 2019).

Through all this, the following criteria were determined: distance to the road, distance from the valley, distance from agricultural lands and vegetation cover (the forest), distance from power lines (electricity—gas), distance, including elevation and slope of the land, distance from industrial areas, and the distance from urban areas. In addition, the nature of real estate ownership has been added based on expert opinion in the field (Aburas et al., 2017). They are divided into three groups: economic, physical and service factors.

Materials and Methods

Study Area

The city of Msila is located in the middle of northern Algeria, as it lies within the following geographical coordinates: 35°42′7″N 4°32′49″E. The city is considered as a link between the east and the west of the country and between the north and the south of the homeland. It is located in the high plateaus extending over an area of 232 km². The population is estimated at 214,669, with a population density exceeding 925 people per hectare (National Statistics Office, 2014). The city of Msila is an agricultural area, characterized by the flatness of its lands on the southern side, and mountainous on the northern side. It is the home of the largest power plant in Algeria, and includes an industrial area on the southern side of the city.

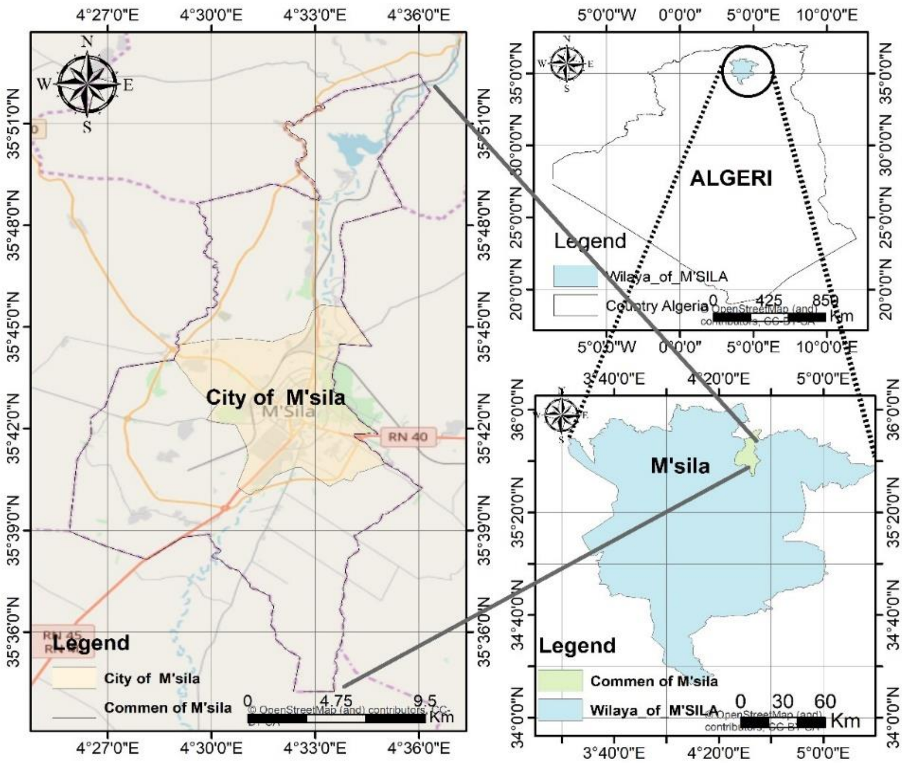

Fig. 1. Location of the Study Area - City of Msila (Dehimi & Hadjab, 2019)

Data Collection

The selection of urban expansion sites is influenced by a set of economic, environmental, and service factors. The selected criteria have been reviewed based on a comprehensive review of previous studies and expert knowledge. According to the objectives of the study, the criteria were determined by using the Delphi method to assess the suitability of the lands for urban expansion through the application of multiple analyses according to criteria for the decision-making process according to the AHP (Dehimi & Hadjab, 2019). After collecting all the maps (Appendix 1, Fig A1), we need data according to the indicators identified above and then assigning layers to the main factors in the GIS program. The factors are: distance to the road, distance from the valley, distance from agricultural lands and vegetation cover (the forest), distance from power lines (electricity—gas), distance, including elevation and slope of the land, distance from industrial areas, and the distance from urban areas, as well as the nature of real estate ownership.

Proximity to the road

Through this factor, the existing road network was determined based on road plans (Public Works Directorate of the Wilaya of Msila, 2021), and with a service range -close: up to 25 meters, average: 25–40 meters, far: greater than 40 meters.

Distance from industrial areas

The Directorate of Industry created a map of the location of the industrial zones for the Wilaya of Msila (Ministry of Industry, 2021). The distance from these areas was determined by experts to protect the population from pollution at – close: distance of less than 500 meters, average: 500-1000 meters, and far: distance of more than 1000 meters.

Gas lines

This indicator was taken to preserve the safety of the population (National Electricity and Gas Company, 2021), where the distance was determined according to the easement area specified in the law as a distance range – close: less than 35 m, average: 35–60 m, far: greater than 60 m.

Power lines

This indicator was taken to preserve the safety of the population (National Electricity and Gas Company, 2021), where the distance was determined according to the easement area specified in the law as a distance range – close: less than 35 meters, average: 35–60 m, far: greater than 60 meters.

Distance from the railway

The railway is one of the obstacles to urban expansion, which is also determined by the beginning of the easement area at a distance of 75 m. We marked it as follows - close: 0-75 m, medium: from 75-150 m, far: greater than 150m.

Legal nature of the property

The legal nature of the property is one of the important factors and indicators, since the nature of the property has an effect on the type of planning and controlling it. It is related to the material side of the owner of the property, so reconstruction is not possible in areas with private ownership due to the difficulty of intervention and planning.

Proximity to the urban area

The proximity to the urban area gives great importance to the lands for their exploitation. The further we go the value is lower. We marked it as follows - very close: 0–1000 m, somewhat close: less than 1500 m, and far: greater than 1500 m.

The distance from the valley

The risk of valleys flooding, where the distance range was determined by the easement area – near: 0–20 m, average: 20–35 m, far: greater than 35 m.

Slope

Significant lows and rises are a hindrance to the expansion process for these areas. Together with the experts, we set the maximum slope at 20%, and distinguished three categories: less than 5%—from five to 10%—greater than 10%.

Agricultural and forest lands

This factor was determined according to the plans (National Agricultural Land Office, 2021). The aim of determining these lands is to preserve them from the danger of urban expansion. We marked it as follows – near: 0-1000 m, medium: from 1000-2000 m, far: more than 2000 m.

Methods

In this study, a hybrid model of the Delphi process and hierarchical analysis (D-AHP) (Bagheri et al., 2021) was applied to discover suitable and unsuitable areas for urban expansion of the city of Msila. These results are combined with GIS. This study lasted for two and a half years, and this analysis was carried out according to three important stages. In the first stage, the Delphi method was used to determine evaluation criteria with the participation of a team of experts from different disciplines who are fully aware of the area under study (planning experts, university professors, study offices, engineers in the municipality). The Delphi method was carried out in this study using a closed questionnaire (Malmir et al., 2016). After preliminary investigations 10 criteria were selected, where the grade of importance was calculated in percentage terms.

In this phase the importance level in percentage was calculated. This method is important to overcome the shortcomings of common methods by providing an opportunity for experts to review their answers. The next stage includes assessing the relative importance of the criteria through a scale developed by Saaty (2012), where the factors 1 – 9 were compared.

The third phase included mapping the specific criteria and then developing the results of the hierarchical analysis process in the GIS environment to come up with a map to identify the appropriate areas for expansion urban in the city of Msila.

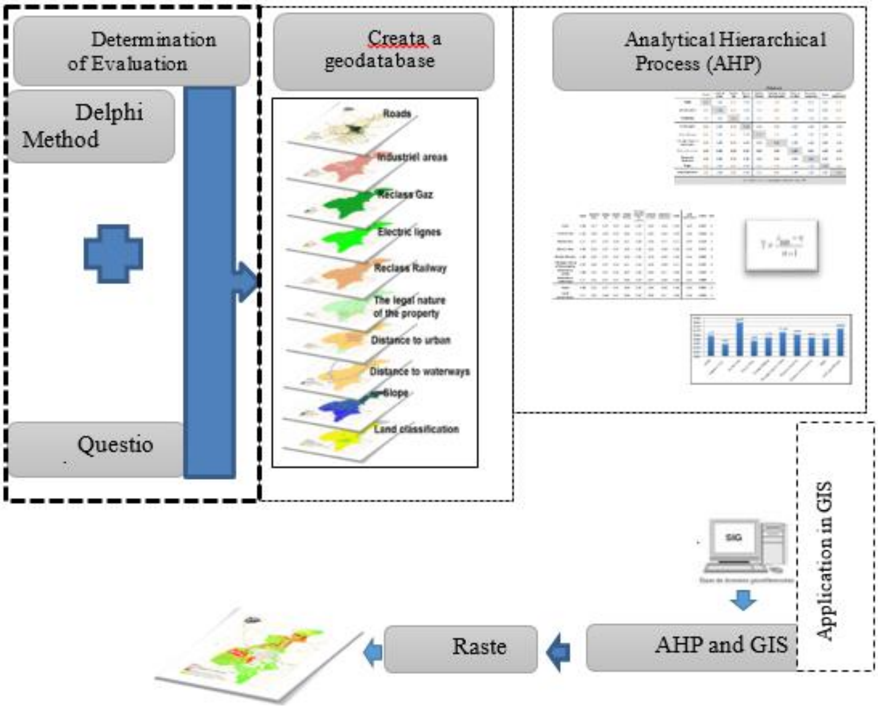

Fig. 2. The stages of creating an appropriate map for urban expansion in the semi-urban areas of the city of Msila

Delphi Method

It is a pioneering method in determining effective indicators and criteria for evaluating social or physical phenomena. The Delphi technique was initially based on guesses, judgments, and inspiration (Landeta, 2006), but later became a scientific method to extract opinions from a group of experts on a topic or question to reach consensus. Collectively through a series of questionnaires (Al Fanatseh, 2021), it can be said that the Delphi method is a frequent method for obtaining effective opinions from experts (Windle, 2004).

In our research, a group of experts from various disciplines was selected for defining the appropriate area for urban expansion of the city of Msila. The appropriate criteria for the goal is underlined, where there was a response from the experts. In the first phase, 31 criteria were identified that contribute to identifying areas suitable for urban expansion. In the second phase, the questionnaire was returned to the experts containing the criteria obtained from the first phase to be re-reviewed according to the five-point Likert scale, and then repeating the process for the third stage. In the fourth stage, the process was stopped after obtaining 10 basic criteria that were approved.

Calculating Weights Using Analysis AHP

The criteria obtained from the previous stage were included in the hierarchical analysis process in order to determine the relative weights of each criterion according to its impact on the selection of the region. AHP (Goepel, 2022; Mohammadizadeh et al., 2016) adopting the opinion of experts in this process also in capturing the degree of importance through a closed questionnaire using the degree of importance scale suggested by Saaty (Hanssen et al., 2018). It is taking into account the proportion of consistency, in order to ensure the credibility of the results obtained from the arithmetical operations, a pairwise comparison was made between the main criteria of the same level according to the Saaty method. The practical results were synthesized in Table 1.

Tab. 1. Degree of homogeneity of behaviour of outdoor spaces

VALUE	PREFERENCE LEVEL NUMERIC
1	Equal preference
3	Moderate preference
5	Strong preference
7	Very strong preference
9	Absolute preference
2, 4, 6, 8	Intermediate values between them

Source: Abediniangerabi et al., 2014, p. 62

The judgment matrices were extracted in the Equation 1, in order to form a (n × n) pairwise comparison matrix for multiple factors.

$$M = \begin{bmatrix} 1 & a1n & \cdots & a1n \\ \frac{1}{a12} & 1 & \cdots & a2n \\ \vdots & \vdots & \ddots & \vdots \\ \frac{1}{a1n} & \frac{1}{a2n} & \cdots & 1 \end{bmatrix} \quad (1)$$

It is proposed that aij = the selected factor (factor I to factor j). Then, it assumed that aij = 1/aij (Everest et al., 2020). The adjustment of the decision matrix was performed in such a way that each value was divided by the sum of the values in each column and ultimately by computing the means of the row values. This stage is also called the measurement of stability: when the matrix is fixed, the standard sum for each row gives the amount of dominance of each element over the other elements relatively, to ensure consistency within the pairwise comparison matrix, the consistency index (CI) was determined according to Equation 2 (Kamali et al., 2017).

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

In the Equation 2 maximum indicates the largest genetic value of the decision matrix, and n is a number of criteria. Accordingly, the final consistency ratio (CR) was obtained by Equation 3 to measure the CI score (Table 2).

Tab. 2. Random indicators

n	3	4	5	6	7	8	9	10
RI	0.58	0.9	1.12	1.24	1.32	1.41	1.45	1.49

Source: Saaty, 1977

In the Equation 3, RI is a random harmony index. Its value is related to the dimension of the matrix established by Saaty (1982). If CR exceeds 0.1, evaluation should be repeated to improve consistency.

$$CR=CI/RI \quad (3)$$

In our study, we extracted the consistency ratio (CR = 0.06) which is less than (0.1) from the values of Saaty in the first hierarchical level of AHP, which means that the measurement of the distribution between factors was acceptable and consistent (Shokati & Feizizadeh, 2019; Abediniangerabi et al., 2014).

Integration of Geographic Information Systems (GIS) and Analytical Hierarchy Process (AHP)

The AHP model and multi-criterion models provide an objective assessment of the relative weights of each factor (Martine, 2012).

The structure of the integrated GIS and AHP urban sprawl model in Figure 2 shows the process of preparing analytical layers for factors affecting land suitability, which is the first part of the process of creating land fit mapping using the GIS environment (Bunruamkaew & Murayama, 2011; Mobaraki et al., 2014). Moreover, the reclassify tool is used to convert used layers into an integer or floating-point lines based on common metrics of ground fit. Then the calculator is used to calculate the weights of each layer based on AHP procedures.

Results and discussion

To achieve a more intuitive, realistic and comprehensive model result, we relied, in this research, on the Multiple-Criterion Decision Analysis (MCDA) (Greene et al., 2011) approach using AHP in order to extract a map to assess the suitability of the expansion the city.

Matrices of pairwise comparison were implemented for each of the main factors and sub-factors through a questionnaire that included experts with a background controlled by several economic, services, and physical influences, and in line with the goals of the decision-makers in order to develop the city. The questionnaire scores are applied to each of these elements in the degree of significance for Saaty" in the matrices to be converted into weights according to the Comparison of Indicators with AHP:

Tab. 3. Comparison of Indicators with AHP

	Roads	Industrial areas	Reclass Gaz	Electric lines	Reclass Railway	The legal nature of the property	Distance to urban	Distance to waterways	Slope	Land classification	Weight	Rank
Roads	1.00	3.00	0.50	1.00	1.00	2.00	1.00	0.50	1.00	0.50	0.097	5
Ind. areas	0.33	1.00	0.33	1.00	1.00	1.00	0.50	0.50	0.50	0.50	0.058	10
Recl. Gas	2.00	3.00	1.00	2.00	2.00	2.00	2.00	2.00	2.00	0.50	0.158	1
El. lines	1.00	1.00	0.50	1.00	1.00	0.50	0.33	1.00	1.00	1.00	0.074	9
Recl. Railw.	1.00	1.00	0.50	1.00	1.00	0.50	2.00	1.00	1.00	1.00	0.09 0	6
Prop. Leg.	0.50	1.00	0.50	2.00	2.00	1.00	2.00	1.00	2.00	1.00	0.114	3
Dist. Urb.	1.00	2.00	0.50	3.00	0.50	0.50	1.00	2.00	1.00	1.00	0.104	4
Dist. Water	2.00	2.00	0.50	1.00	1.00	1.00	0.50	1.00	1.00	0.50	0.089	7
Slope	1.00	2.00	0.50	1.00	1.00	0.50	1.00	1.00	1.00	1.00	0.086	8
Land class.	2.00	2.00	2.00	1.00	1.00	1.00	1.00	2.00	1.00	1.00	0.130	2
	PEV (λ) = 10,7556 CI = 0.0840 RCI=1,49 CR=5.63%											

Calculating the weights by choosing the suitability of the lands for the urban expansion of Msila municipality reveals that the proximity to the roads evaluated by the experts is the most important factor at 13.3%, followed by the proximity to the urban area at 12.7% because it is related to the proximity of public services, then the inclination and the slope angle at 12.4%, Since most municipal lands are flat. After that, agricultural and forest lands by 11.3% come to be preserved, as well as the type of legal nature of the property by 10.6%, power and gas lines by 9.6%, electricity by 7.3%, and the railway by 7.3%. Finally, the factor of industrial zones by 5.7%, as the proximity to these areas has many drawbacks and that is because of the pollutants it causes, according to experts' opinion. Moreover, the consistency ratio calculated in pairwise comparisons is CR = 0.06 (value <0.10) indicating that the experts' core judgment is very reasonably consistent (See again Equation 3).

So, according to the justifications for each criterion in terms of its importance mentioned during the classification process and the weighting of these factors according to the previous table, the weighted matching process available in GIS will be carried out within the spatial analyser applications.

The final results of the final suitability map reveal that the potential sites of urban expansion have elements characterized by the land system and land condition that can be easily occupied and close to serviced areas or roads, and fit well with the weights resulting from the criteria after weighing the marital comparison.

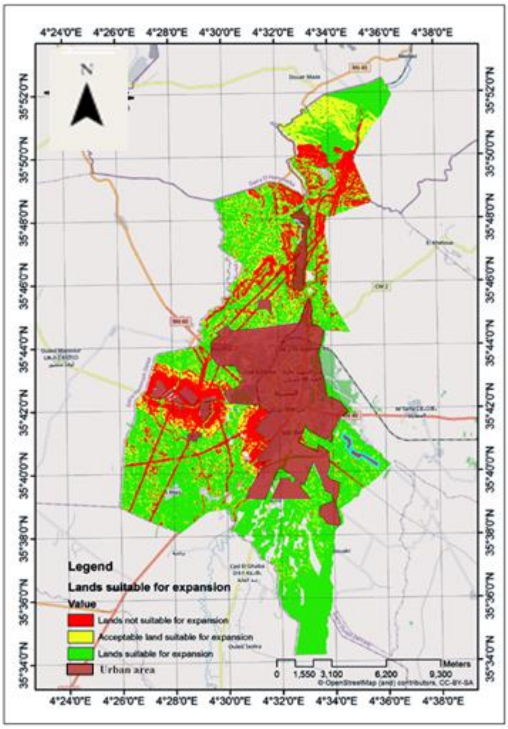

Fig.3. Areas suitable for expansion in the city of Msila

The final map (Fig. 3) shows three classes of lands, each with a certain proportion, as follows:

- Land suitable for expansion: the best areas suitable for urban expansion, that are located in the south and west of the city as they are flatlands, most of which are unfit for agriculture, vacant, and close to the city centre and thus close to services, and are state lands located almost on the western side of the city. The category represents 56.09% with an area of 94.55 km^2. This category meets the conditions or spatially appropriate criteria for expansion according to the predetermined conditions.
- Acceptable land suitable for expansion: representing a total area of 41.58 km^2 or 24.66%. This is because some of those lands are uneven and far from the city and services centre.
- Land not suitable for expansion: That represents areas located near industrial areas, power lines, and valleys, which poses a threat to the population. This category also contains agricultural lands, whose area is estimated at 32.46 km^2, or 19.25%.

To reconfirm our results, the analysis should reveal the extent of the suitability of the land, which was obtained because of some isolated factors or whether it affirms the general agreement of the criteria and weights that have greater use. From this perspective, the multi-criterion evaluation with spatial reference helped us highlight the cadastral entities, on which we must focus efforts for the rational development of the urban expansion of the studied area. Accordingly, the procedure of multi-criterion grouping, based on the calculated weights for the ten criteria according, enables us to distinguish three disparate spatial units displayed on the final summary map.

Mapping of the various criteria involved in determining urbanization priorities based on a multi-criterion assessment and spatial analysis only provides a relative assessment of the different criteria, although it gives an assessment of the suitability of the land in the municipality of Msila.

Criteria-based spatial analysis procedures for determining the suitability and selection of sites have already been proven. In fact, the results obtained are correct and their reliability depends upon the data and information used through field observation.

Finally, the results of this study can contribute to users and decision makers rather than being archival data; to develop better land management and use strategies in the urban expansion of the city, in order to preserve the safety of the city's residents, on the one hand, and to preserve agricultural and forest lands on the other.

Conclusion

The spatial analysis system constitutes a blueprint and a general index of GIS by conducting a comprehensive assessment of the suitability of the lands for urban expansion in any area, and a hybrid system was used in this study that combines the Delphi method with GIS-AHP techniques to discover the most suitable and inappropriate areas. For urban expansion in the Msila region and this system formulates the decision-making process as a goal through which planning policies can be improved to reach satisfactory results. The assessment that was later used in the GIS environment to extract a final map showing the suitability of the areas for urban expansion through three categories. First, a category suitable for expansion, which represents 56.09% of the total area, this category meets the conditions and criteria appropriate spatially (proximity to the road, from the city centre, and away from agricultural lands and valleys). Second, a less suitable category represents an area of 24.66% of the total area and comes in the second category due to its need for modifications and technical interventions. Finally, a completely inappropriate category is agricultural lands and lands that pose a threat to the population and represent 19.21% of the total area.

In the end, decision makers can refer to this paper and use it as a reference in choosing the best sites for urban expansion, and evaluating the trends of expansion currently taking place, with the possibility of generalizing this model to several other regions according to their data and conditions.

Conflicts of Interest: The authors declare no conflict of interest.

Appendix 1

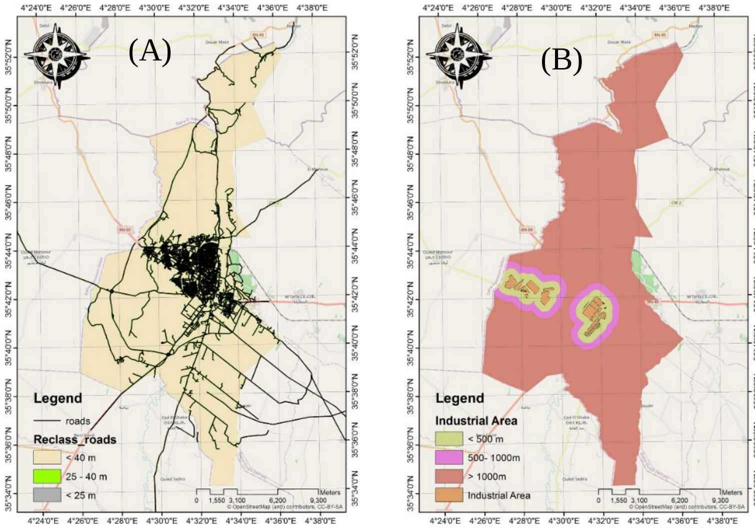

Fig. A1. A: Proximity to the road; B: Distance from the industrial areas

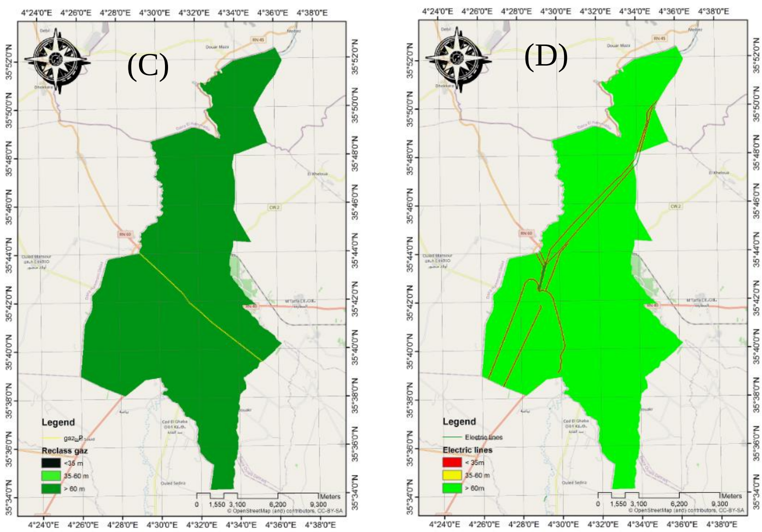

Fig. A1. C: Distance from the gas pipe; D: Distance from the electricity lines

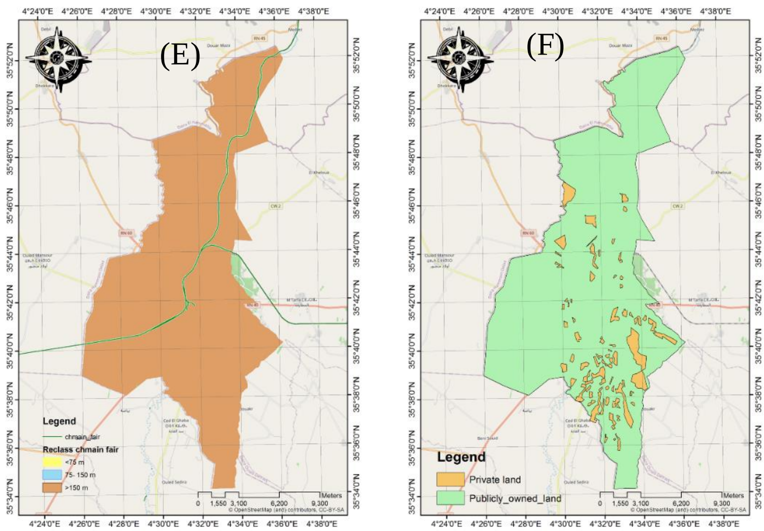

Fig. A1. E: Distance from the railway; F: Legal nature of the property

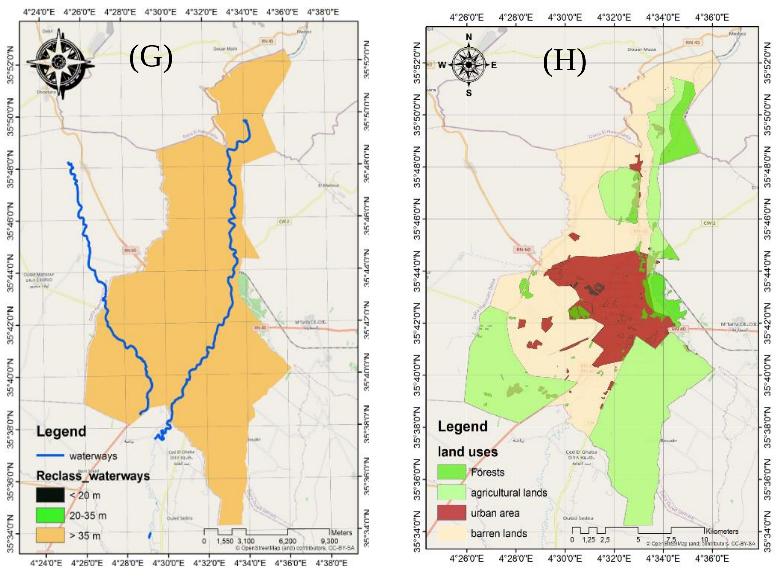

Fig. A1. G: Distance from the valley; H: Agricultural and forest land

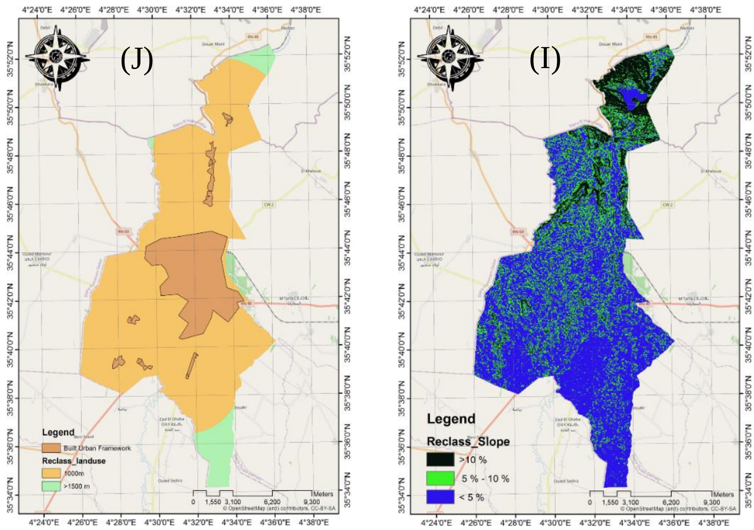

Fig. A1. J: Distance from the urban area; I: Slope

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