ISSN Online: 2821-1936

Transactions on Data Analysis in Social Science

Journal Homepage: https://transoscience.ir

Utilizing Geographic Information System (GIS) and Analytic Network Process (ANP) in Assessing the Ecological Potential of Malayer County for Urban Development Management and Identifying Development-Friendly Areas

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ARTICLE INFO

Article History:
Received 5 July 2021
Received in revised form 16 October 2021
Accepted 13 December 2021
Available online 17 December 2021

Keywords:
Ecological potential assessment, Urban development management, ANP model, Geographic Information System (GIS), Malāyer county.

ABSTRACT

The increase in urbanization and land use for urban development without considering ecological capacities and environmental potentials leads to adverse consequences and environmental destruction. Therefore, this research aims to determine suitable areas for urban development based on the indices of the ecological development model in Iran within the Malāyer county, using a multi-criteria decision-making method based on GIS. Initially, ecological parameters, including physical and biological parameters affecting urban development, were studied and identified. Then, the Analytic Network Process (ANP) method was used to determine the weights of the criteria, and fuzzy membership functions were employed for their standardization. Finally, analyses were conducted using the Weighted Linear Combination (WLC) and ANP methods, resulting in the extraction of the ecological development potential map for Malāyer county. The results indicate that, based on the ANP method, 43% of the total area has lands with a potential of grade one, while 19% has unsuitable lands for urban development. Moreover, the findings suggest that completely suitable areas for urban development are mostly located in the northern and central parts of the region.

1. INTRODUCTION

Throughout history, humans have always been dependent on nature and relied on the environment to meet their basic needs. However, today, with the increase in population and consequently their needs, the potential of the land has been improperly utilized, and the capacity to use environmental resources has decreased [1]. The continuous growth of cities, influenced by population growth and migration, has led to unplanned constructions and significant

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http://dx.doi.org/10.47176/TDASS.2021.218

changes in the spatial structure, demanding conscious guidance and fundamental organization [2]. This uncontrolled development, coupled with land use without considering ecological differences and environmental potentials, results in adverse consequences such as soil erosion, desertification, reduction in the area of pastures, forests, and more [3]. Coordination between various sectors, including environmental conditions and the regional activity system, is essential for balanced and comprehensive urban and regional growth. Understanding these conditions in the region, its potentials, and limitations for meeting societal needs, pursues sustainable regional development. Lack of knowledge about capacities and inappropriate use of facilities, in addition to reducing efficiency in utilizing land capabilities, causes various environmental problems [4], including the destruction of the surrounding environment of cities, natural resources, and extensive areas of the most fertile and suitable lands [5], reducing biodiversity, and the potential and capability of land utilization [6]. The establishment and emergence of a city are more than anything a function of geographical conditions, as natural phenomena have decisive effects on site selection, sphere of influence, physical development, and morphological urban structure. Natural phenomena sometimes act as positive factors and sometimes as negative and inhibitory factors. In this context, suitable urban development occurs when land is used according to its ecological capacities [7]. For the preservation of resources for future generations, a balance must be struck between inherent potential and its exploitation, which is achieved through land suitability assessment. Land suitability assessment is a method used to determine the compatibility of land for a specific type of use, considering their potential and productive capacity [1]. Therefore, due to human potential and the ecological potential for future land development, ecological capacity assessment becomes doubly important [7]. Ecological capacity assessment involves evaluating the inventory and potential of the land using predetermined criteria and standards. These studies serve as a foundation for decision-making and planning for land use worldwide and are crucial for optimizing the use of ecological potential in land planning and environmental management studies aimed at achieving sustainable development [8].

Currently, the most logical approach to conducting environmental studies within the framework of regional planning is to incorporate ecological aspects into land planning and organization. In any case, for sustainable and appropriate development, land planning is essential, and the foundation of this planning is environmental capacity assessment [9]. In Iran, for land development, the ecological capacity assessment method is multifactorial, and land assessment and classification are done by comparing the ecological characteristics of environmental units and Iranian ecological models. For the assessment of ecological capacity for urban development, the fuzzy logic model with three capacity categories (suitable, relatively suitable, and unsuitable) has been proposed.

In cases where multiple criteria (qualitative and quantitative) are involved, the lack of standards for measuring qualitative criteria and the lack of a unit for converting criteria into each other complicate decision-making. To address this issue or minimize its side effects, multiple criteria decision-making (MCDM) methods are used. Therefore, to find suitable urban locations, alleviate concentration, and create balance in the environment, the multi-criteria assessment method is used, which is one of the fundamental decision-making methods in the geographic information system (GIS) and serves as a spatial decision support tool for land planning [10].

In this regard, Geographic Information System (GIS) is highly capable of managing data and providing new insights as an effective tool in environmental planning. Since the 1990s, the integrated strategy of combining multi-criteria decision-making with GIS for spatial planning issues has gained significant attention among planners. GIS, as a tool that can easily work with a vast amount of data and analyze them, appears to be a suitable platform for integration with multi-criteria decision-making methods [11]. Solving multi-criteria decision-making problems is complex, especially since the mentioned criteria often conflict with each other, and an increase in the desirability of one may lead to a decrease in the desirability of another. For this reason, methods called Multi-Criteria Decision-Making (MCDM) have been developed to help solve these problems [12]. For decision-making regarding spatial issues, the use of an integrated multi-criteria decision-making model with GIS can be highly efficient because, on one hand, it provides a solid framework for considering criteria effective in spatial issues and valuing these criteria, and on the other hand, it uses a powerful analytical tool like GIS to analyze a vast amount of data related to these criteria and adopt the most suitable decisions [11].

The application of multi-criteria decision-making methods and GIS in various fields has received much attention from researchers. Beshati and Manouri (2017) conducted a study on the ecological capacity assessment of urban development in Sahand using the Multi-Criteria Decision-Making (MCDM) model and GIS. The results indicate that out of the total area of Sahand, identified in 1751 ecological units and covering 45,200 hectares, 3,326 hectares have the capacity for level 1 development, and 4,279 hectares have the capacity for level 2 urban development. Currently, the spatial distribution of population centers in the county is mostly in level 2 (medium) land use. This is mainly due to the average slope, relatively good soil structure, suitable drainage conditions, and favorable climatic conditions. Azar and Shirzadi Babakan (2016) evaluated the ecological capacity of urban development in Baghmalek. The results showed that, based on the final classification map, areas suitable for future physical development in Baghmalek are mostly located in the northern part. On the other hand, the southeastern and eastern directions impose more limitations on future development due to their mountainous nature. Soroush and Khaliji (2014) also assessed the ecological capacity of urban development in Tabriz using the Network Analysis Process (ANP) model. The results indicated that the eastern and central halves of Tabriz are the best places for development, while the northern and southern halves, which are close to the mountains, pose greater limitations on future development.

Javadian Kootenaei and colleagues (2014) conducted a research to develop a model for assessing the ecological capacity of urban development in Sari, utilizing the Analytic Network Process (ANP) methodology. In this study, the most significant criteria for the ecological capacity of urban development were formulated within a network structure, incorporating Geographic Information System (GIS) analysis and mapping of the study area based on the ecological capacity of urban development.

Additionally, Kanaani and collaborators (2011) carried out a study aiming to categorize urban development land use based on the ecological capacities of Mazandaran province, using a multi-criteria decision-making method grounded in GIS. The results indicated that 23% of the province's area is allocated to suitable zones, 47% to moderate zones, and 47% to inappropriate zones for urban development land use.

In the city of Malayer, due to its special importance, credibility, and administrative-political position, urban habitat development is progressing without considering the capabilities and limitations of the land. Consequently, a growing portion of the high-quality lands in this city is being converted into urban constructed areas, leading to irreversible consequences. Considering the capabilities and limitations of the region through the process of evaluating the ecological capacity of urban development becomes a suitable solution for coping with emerging environmental crises and an effective approach to achieving sustainable development goals. This is perceived as a management tool for development in the planning and decision-making stages. Therefore, the objective of the present research is to assess the ecological capacity of urban development in Malayer.

2. THEORETICAL FOUNDATIONS

2.1. Environmental Planning (Land Use Planning)

Land use planning is the regulation of the relationship between humans, land, and human activities in the land for sustainable utilization of all human and spatial resources over time, aiming to improve the material and spiritual conditions of society [9]. Ecological capacity assessment forms the foundation of land use planning [9].
Ecological Capacity Assessment: It involves evaluating each homogeneous land patch for various land uses [18]. Ecological capacity can be considered as the potential capacity of the land concerning its ecological capabilities for development [7]. Ecological capacity assessment is a process that seeks to facilitate sustainable development by adjusting the relationship between humans and nature. It is an effective step towards developing a plan for sustainable development, as it identifies ecological features in each region, allowing for coordinated development plans aligned with nature [20]. The goal of land use is to achieve economic, social, ecological, and environmental efficiency for sustainable resource utilization [19]. Therefore, the natural and human environmental capabilities encompass both existing and potential capacities of the region. These latent capacities, with careful recognition and assessment, provide a clear picture for future development [20].

2.2. Analytic Network Process (ANP) Model

The ANP process is one of the newest multi-criteria decision-making techniques introduced by Professor Saaty. This model is designed based on the hierarchical analysis process and replaces "hierarchy" with "network" [21]. The fundamental assumption in AHP is the independence of the upper-level groups in the hierarchy from all parts of the lower level and from the criteria of each level and category [22]. Many decision-making problems cannot be accommodated in a hierarchical structure due to interactions between various factors. The structure of a problem with operational dependencies allows feedback between identified clusters in the network system. Thus, the ANP method, as a generalization of AHP, introduces a feedback approach, replacing the hierarchical structure, indicating that relationships between different decision-making levels cannot be easily perceived as top-down, dominant-subordinate, or direct-indirect. For example, not only does the importance among criteria determine the significance among options in the hierarchy, but the importance of options can also affect the importance among criteria. Therefore, presenting a hierarchical structure with linear relationships from top to bottom may not be suitable for complex systems [23]. In general, the ANP method consists of three parts: the first part is the hierarchical control for the network of criteria and sub-criteria, the second part is the network of relationships between elements and clusters, and the third part is feedback between different clusters and elements within a cluster.

2.3. Interactive Multi-Criteria Decision-Making Models

To analyze and evaluate multi-criteria suitability of land, various methods exist, with Weighted Linear Combination (WLC) being one of the most common [25]. This method is chosen for its simplicity, widespread use, and ease of implementation in Geographic Information Systems (GIS). Additionally, it allows the analyst to easily apply their perspective and information regarding the importance of criteria and revisit them as needed [25]. WLC is an accumulation method that maintains the diversity of continuous and discrete factors. This requires standardizing factors to a common numerical scale, followed by combining them with weighted averages [26]. Fuzzy logic membership functions are used for standardization. Fuzzy logic theory was first introduced by the Iranian scientist, Professor Asghar Lutfi-Zadeh, to deal with conditions of uncertainty. Fuzzy logic is a multi-valued logic, meaning parameters and variables can take values between 1 and 0, and it is applicable in situations where uncertainty exists [10]. Fuzzy set theory emphasizes the concept of membership functions, indicating the fuzziness of a fuzzy set [27]. Linear functions, J-shape, S-shape, and membership functions are commonly used in fuzzy set theory [28].

3.MATERIALS AND METHODS

3.1. Introduction of the Study Area

Malayer County is located in the southeast of Hamadan Province, covering an area of 3302 square kilometers, constituting approximately 9.16% of the total area of the province. Geographically, the region is situated between 46°48' to 51°48' east longitude and 34°34' to 34°34' north latitude. About 600 square kilometers of the total area of Malayer County consists of plains, and the rest is mountainous marginal foothills, composed of the Zagros mountain ranges. Mount Lashgar Dor is the highest point in the county at an elevation of 2928 meters above sea level, while the lowest point is 1550 meters above sea level. The climate is semi-arid and cold, with a precipitation regime resembling the Mediterranean climate. According to the 1390 national census, the population of Malayer County is 287,982, with 176,748 residing in urban areas and 111,234 in rural areas, constituting 17% of the province's population [29].

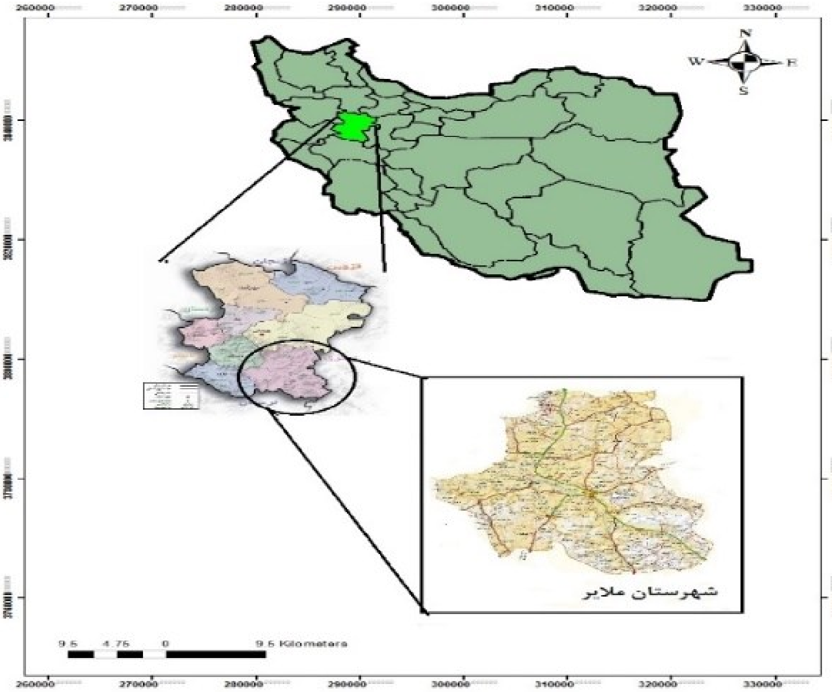


Fig. 1. The situation of the studied area

3.2. Research Methodology

In this study, the evaluation of ecological potential was conducted for the land use development of Malayer County based on the ecological model. The research has a practical objective and adopts a descriptive-analytical method. Data collection was performed through two methods: document review (library-based) and field survey. The ecological model of urban development in Iran generally indicates three categories of potential within the framework of linear programming equations. Accordingly, this research focuses on the ecological factors (physical and biological) necessary for evaluating the ecological potential of urban land use in Malayer County. These factors include physiography (slope percentage) (so), elevation above sea level (E), geographical aspect (As), wind speed (Cw), relative humidity (Ch), water flow (wc/m3), precipitation (Cp), temperature (Ct), soil depth (Pd), soil erosion (Es), soil structure (transformed) (Ps), soil texture (Pte), soil drainage (Pdr), soil granulometry (Pg), vegetation cover density (Vgo), climate, and lithology (parent rock Li).

To create the DEM map, the contour lines of the 1:25000 topographic map of the region (obtained from the National Cartographic Organization) with 10-meter contour lines were used. The climate map was prepared using meteorological data from the Meteorological Organization and interpolation operations. For soil characteristics maps, the evaluation map of resources and land capability of the region (obtained from the Soil and Water Research Institute at a scale of 1:250000) was utilized. The lithology map was derived from the 1:100000 geological map (obtained from the Geological Survey Organization). Software tools such as ArcGIS 10, SuperDecision, Excel 2013, and Idrisi were employed for data preparation.

The flowchart for executing the model is depicted in Figure 3. In the process of multi-criteria analysis, summarizing and integrating environmental criterion data becomes essential. The DEM of the region was utilized for the reclassification and classification of slope and aspect layers. Before merging maps, it is necessary to correct, edit, and digitize all layers through georeferencing, and define a coordinate system to standardize them for merger based on decision-making rules.

After preparing the criteria and extracting constraints and factors, constraints were reclassified as zero and one (based on Boolean logic) for further standardization. Constraints were determined using buffer functions for protected areas, residential areas, and rivers. Prior to merging maps in the implementation of the fuzzy model, it is crucial to assign weights to each of the factors and standardize them (fuzzy parameterization of ecological parameters). The fuzzy standardization process involves converting vector layers of criteria into raster form. Fuzzy methods and membership functions were employed for standardization.

After standardization and based on fuzzy logic, a layer was created with values ranging from 0 to 255. Otherwise, this process was carried out by pulling the layer and using membership functions. Linear functions were used to fuzzy map layers, and the positions of at least 2 to 4 points (a, b, c, and d) on the linear membership function graph needed to be determined.

To determine the weight vector of criteria, the Analytic Network Process (ANP) method was utilized. After determining the importance of each factor based on expert opinions, the Super Decision software was employed. Following factor weighting, the stages related to the integration of layers using Multi-Criteria Decision-Making (MCDM) rules were initiated to achieve areas susceptible to urban development. In summary, the process involves preparing information layers, determining weights, standardizing layers using membership functions, merging layers, and ultimately creating the final map and prioritizing between regions.

3.3. Weighting Criteria

As different criteria in decision-making matrices for land use determination do not have equal importance, knowing the importance coefficient or weight of each of these criteria is crucial for decision-making and evaluation.

3.3.1 ANP (Analytic Network Process)

The Analytic Network Process (ANP) was developed in 1971 by Saaty. Its goal is to structure the decision-making process considering a scenario influenced by multiple independent factors. This technique enhances the Analytic Hierarchy Process (AHP) as a multi-criteria decision-making tool by replacing the hierarchy with a network [33]. In the ANP analysis process, the measurement of values and relative importance, similar to the Analytic Hierarchy Process, is done through pairwise comparisons using a spectrum from 1 to 9. The steps of the ANP method are as follows:

1. Constructing the Analysis Model (Network): In this stage, criteria that are influential in the final decision and have been identified through expert consultation are connected to each other, forming a network structure.
2. Forming Pairwise Comparison Matrices and Calculating Weight Vectors: Pairwise comparison matrices for the influence of criteria and sub-criteria, considering higher levels of the network and internal relationships, are created. These matrices are used to calculate weight vectors. Once the pairwise comparisons are complete, the weight vector (W) is calculated using the method proposed by Saaty:

$$AW = \lambda_{max} W \quad (1)$$

In which λ_{max} is the largest eigenvalue of matrix A. The vector W is normalized using the $a = \sum_{i=1}^{n} w_i$. To determine the consistency of comparisons, the Consistency Index (CI) of the criteria weight is used, calculated using the following formula:

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

In general, if CI is less than 1/0, the comparison is considered acceptable.

3. Formation of the Initial Supermatrix: Based on the pairwise comparisons made in the previous stage, several matrices are created, and the relative weight of each matrix is calculated. Then, the derived weights are entered into the supermatrix, representing the interrelationships between the elements of the system.
4. Formation of the Weighted Supermatrix: To ensure that the elements of the column of the initial supermatrix correspond to their relative weights, each column is normalized so that the sum of the column equals 1. As a result, a new matrix is obtained, where the sum of each column is equal to 1.
5. Calculation of the General Weight Vector of the Converged Supermatrix: In the next stage, the supermatrix undergoes a convergence process until its elements converge, and the row values become equal. In this case, the sum of the rows of the converged supermatrix is made convergent in the following manner:

$$\lim_{K\to\infty} W^K \tag{3}$$

In this research, the Super Decision software was used to implement the ANP method and perform information analysis.

3.3.2. Multicriteria Evaluation - Weighted Linear Combination (WLC)

One of the most common techniques for multicriteria decision-making is the Weighted Linear Combination (WLC) method. Here, for integrating layers to achieve areas suitable for urban development, the method of overlapping index model or weighted linear combination was employed. In this approach, the final assessment layer was obtained by multiplying the scores of criteria by their weights [32], using the following relationship:

$$A_i = \sum w_j x_{ij} \quad , \quad \sum w_j = 1 \tag{4}$$

In the formula, A_i is the score of option i, x_{ij} is the score of option i for attribute j, and wj is the weight of attribute j. This method is the most common model in spatial multicriteria decision-making problems [12]. In the end, the final map was prepared based on the breakpoints (by taking a histogram of the number of pixels and their desirability) and expert opinions, dividing it into three classes.

3.3.3. Accuracy Determination of Evaluation Methods

3.3.3.1. Kappa Coefficient

The kappa coefficient calculates the accuracy of classification compared to a completely random classification. It means that the kappa value calculates the accuracy of classification compared to a situation where an image is classified completely randomly, as shown in equation 8. For example, a kappa equal to 75% means that the classification results are 75% better than when pixels are randomly labeled. Values between 0 to 100% represent a certain level of agreement with the classification (completely correct), and negative values indicate very poor classification results.

$$K = \frac{\text{obsaerved accuracy} - change\ agreement}{1 - change\ agreement} \tag{5}$$

The formula for calculating this coefficient is as follows:

$$\hat{K} = \frac{N\sum_{i=1}^{r} Xii - \sum^{r} X_{i+}X_{+i}}{N^2 - \sum^{r} X_{i+}X_{+i}} \tag{6}$$

In this formula, N is the total number of actual ground pixels, Xii is the sum of elements in row i, and X+i and Xi+ are the sums of elements in column i. In this study, the kappa coefficient was calculated using IDRISI 17 software.

4. RESEARCH FINDINGS

In this research, initially, the ecological potential of urban development, considering all aspects of ecological criteria, was evaluated within the borders of Malayer County as a planning and land management unit. In this regard, the preparation of physical and environmental factors was carried out. Subsequently, using Geographic Information Systems (GIS) and WLC-ANP multi-criteria decision-making models, the ecological potential of the study area was assessed based on urban development models in Iran. For the ecological parameters in the urban development model, three environmental potential categories were considered. Since the maps of these parameters were measured in different units and were not comparable directly, fuzzy membership functions were employed after preparing the initial layers. Information layers were prepared in two qualitative forms (soil texture, soil drainage, soil classification, and bedrock) and quantitative forms (slope, geographical aspect, soil depth, percentage of vegetation cover density, temperature, wind speed, and relative humidity). Fuzzy membership functions were used for standardizing continuous layers using linear membership functions in IDRISI. Linear membership functions require determining at least 2 to 4 points (a, b, c, d) on the linear membership function chart for fuzzification. Table (1) indicates the threshold values, types, and shapes of membership functions for standardizing the study factor maps. As observed, a descending linear membership function was applied to the percentage of vegetation cover density layer, an ascending linear membership function to the soil depth layer, and a symmetrical linear membership function to the elevation layer. The degree of importance for each discrete criterion was assigned using triangular fuzzy numbers, and the maps were transformed into values between 0 to 1. The vector weights of the criteria were determined using the method...

$$X = m + \frac{\beta - \alpha}{4} \tag{7}$$

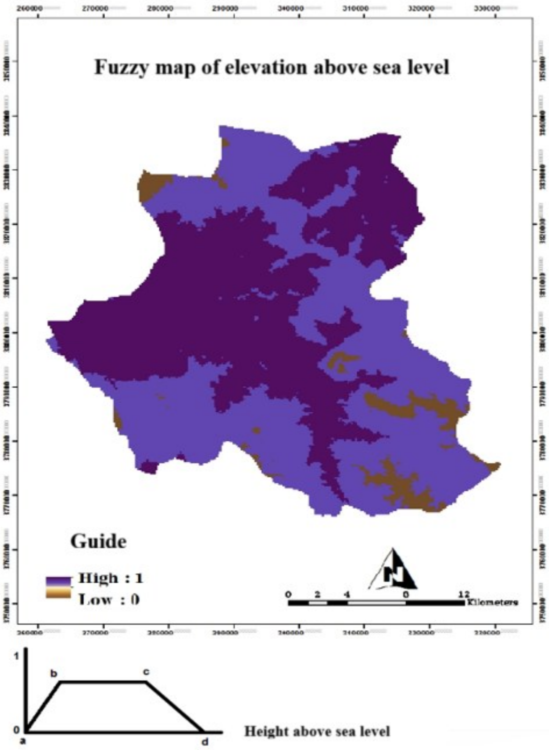
The Boolean approach is one of the simplest methods for standardizing constraints. Constraints are presented as two-valued maps, where the value zero indicates unsuitable areas and the value one represents suitable areas for development [34]. In the present study, considering the desired land use and geographical conditions of the area, four urban nodal points were considered as constraint layers, and ultimately, the final evaluation map was derived.

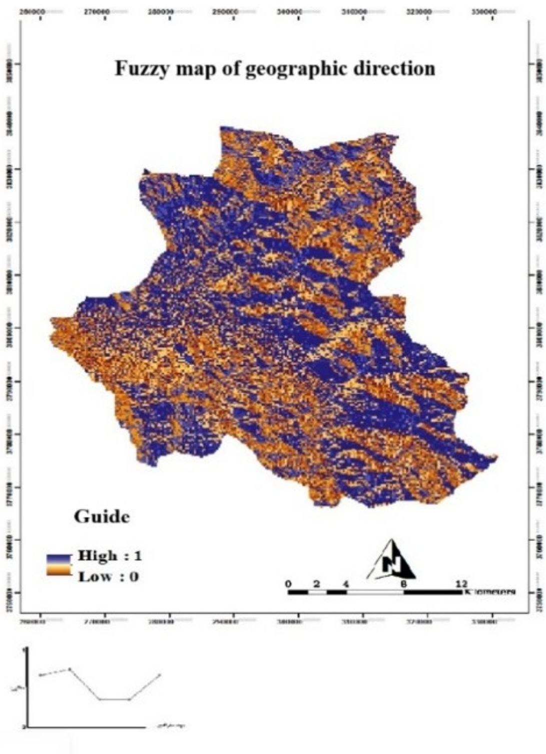
Table 1. Standardization of Continuous Criteria Using the Fuzzy Method

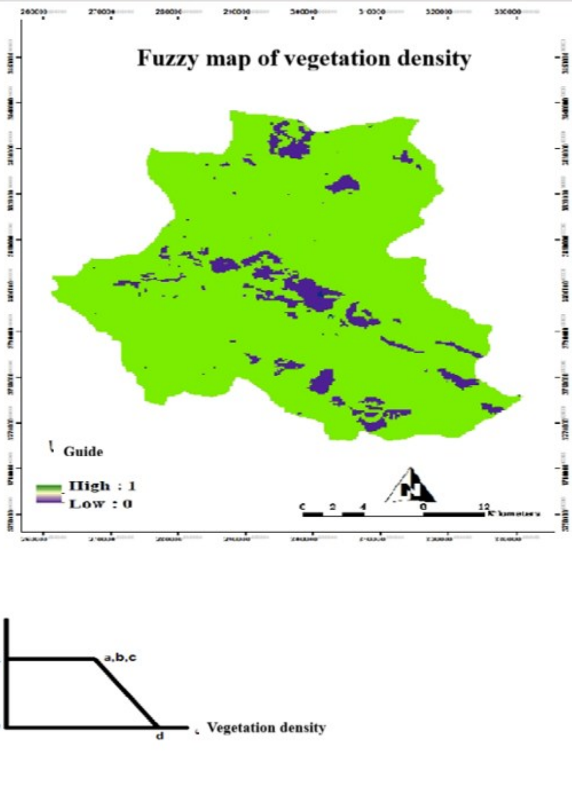
Control points				Function shape	Function type	Criterion
d	c	b	a			
3364	1900	1558	0	Trapezoidal	Linear	**Height**
-	-	150	0	Ascending	Linear	**Soil depth**
76	25	-	-	Descending	Linear	**Vegetation density**
-	-	-	-		User-defined	**Slope**
-	-	-	-		User-defined	**Direction**

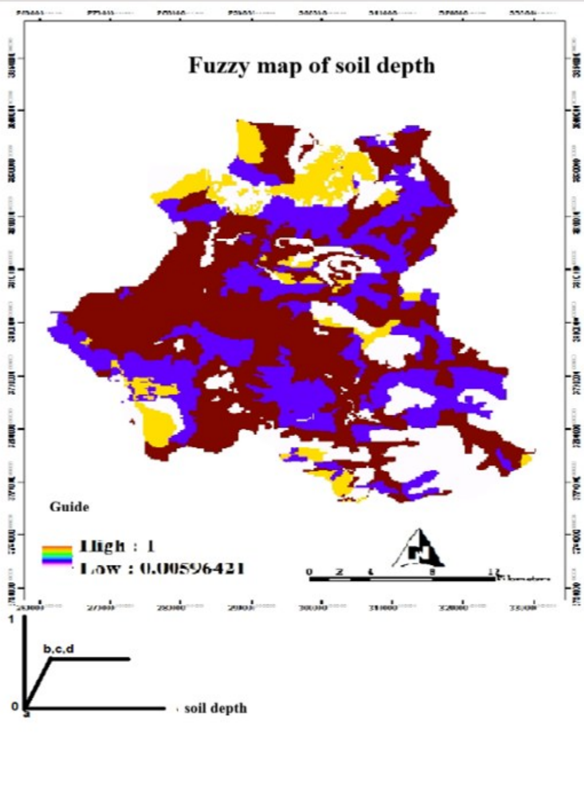
Table 2. Standardization of Soil Texture Using Fuzzy Logic

Definite numbers	Triangular fuzzy numbers	Qualitative number
0/0625	(0 ,0 ,0.25)	Very little importance
25/0	(0.25 ,0.25 ,0.25)	Low importance
0/5	(0.5 ,0.25 ,0.25)	Medium importance
75/0	(0.75 ,0.25 ,0.25)	Great importance
0/9375	(1 ,0.25 ,0)	Very important


Fuzzy map of elevation above sea level
Guide
High : 1
Low : 0
Kilometers
Height above sea level


Fuzzy map of geographic direction
Guide
High : 1
Low : 0


Fuzzy map of vegetation density
Guide
High : 1
Low : 0
Vegetation density


Fuzzy map of soil depth
Guide
High : 1
Low : 0.00596421
soil depth

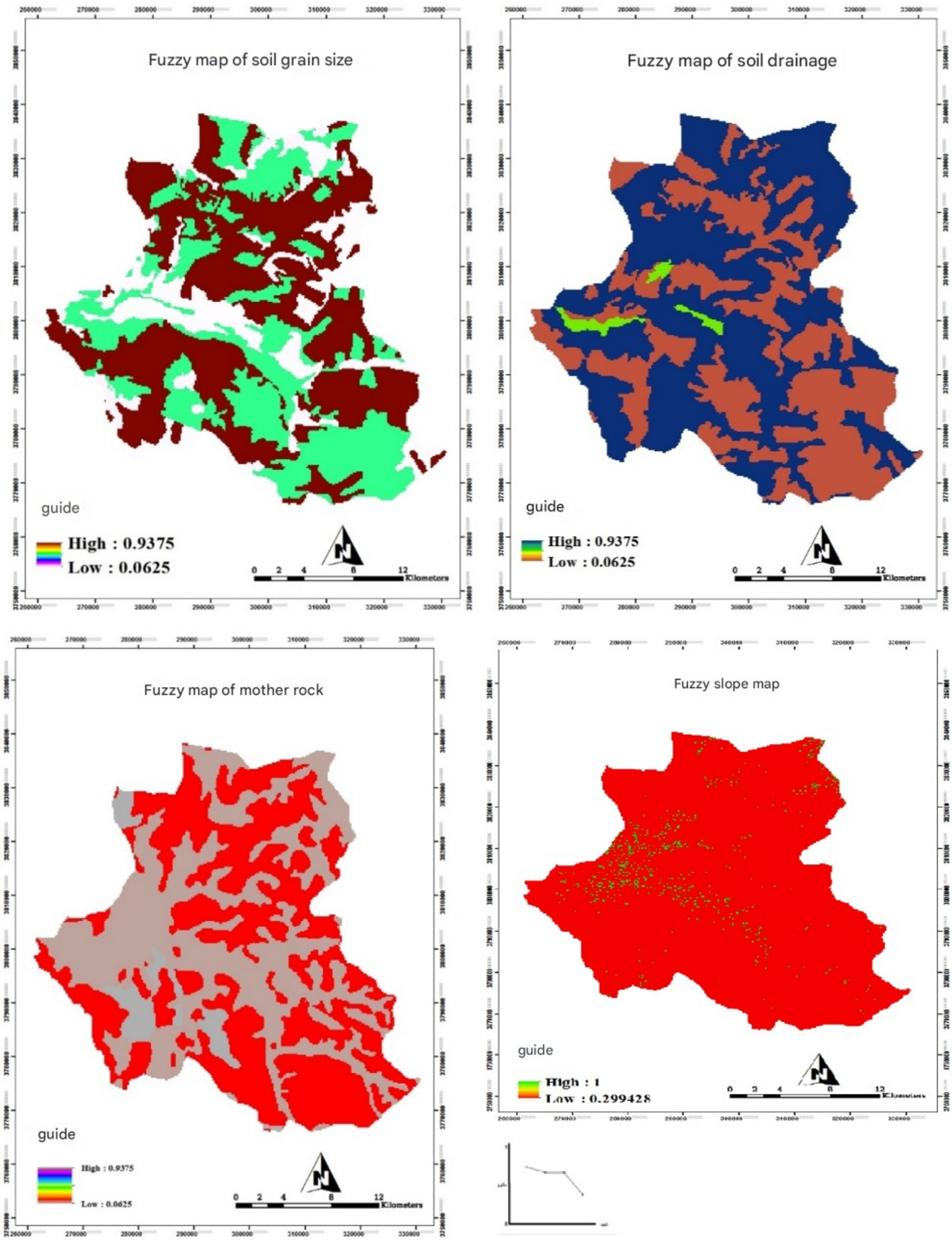


Fig. 2. Fuzzy Ecological Maps of the Study Area

4.1. Weighting Criteria

Since the decision matrix has various criteria (indicators) that do not have equal importance in land use determination, knowing the importance coefficient or weight of each of these criteria is essential in decision-making and evaluation [32]. In this research, the ANP method was used to determine the weights of the criteria. In this stage, the criteria that are effective in the final decision are connected to each other, forming a network structure in the ANP model.

Next, the criteria were weighted using the ANP method with the help of a questionnaire and the opinions of experts (12 experts). The obtained results were then entered into the ANP model, and the table of super criteria weighting matrix, super non-weighting matrix, and the table of super limit matrix were prepared. Finally, the final weights of the criteria (Table 3) were obtained using the ANP method. According to this table, slope and precipitation have the highest weights among the factors influencing the evaluation of ecological potential for urban development.

Table 3. Final weights of criteria

Criteria	Rainfall	Discharge	Temperature	Relative humidity	Wind speed	Vegetation cover	Elevation	Direction	Slope	Soil texture	Soil grading	Soil drainage	Parent rock	Soil depth	Soil erosion
Final weight	**0.39**	**0.21**	**0.09**	**0.03**	**0.19**	**0.06**	**0.28**	**0.29**	**0.42**	**0.21**	**0.08**	**0.16**	**0.21**	**0.24**	**0.07**

4.2. Combining Criteria

As mentioned earlier, the Weighted Linear Combination (WLC) method is one of the most common techniques in multi-criteria decision-making. Therefore, after dimensionless scaling and determining the weight vector of the criteria, the WLC method was used for combining layers in the Idrisi environment. For this purpose, the standardized map of each factor was multiplied by its weight, and finally, the sum of all factors in the constraint map was calculated. The resulting map (Figure 3) represents a layer with a spectrum of different desirabilities for pixels (0 to 255), where higher desirability indicates a higher degree of ecological potential, and lower desirability indicates a lower degree for urban development. In the final step, after preparing the fuzzy potential map, for better management and classification of information, the threefold classification of urban development was performed using the histogram of this map (Figure 4) and determining the break points (Figure 5).

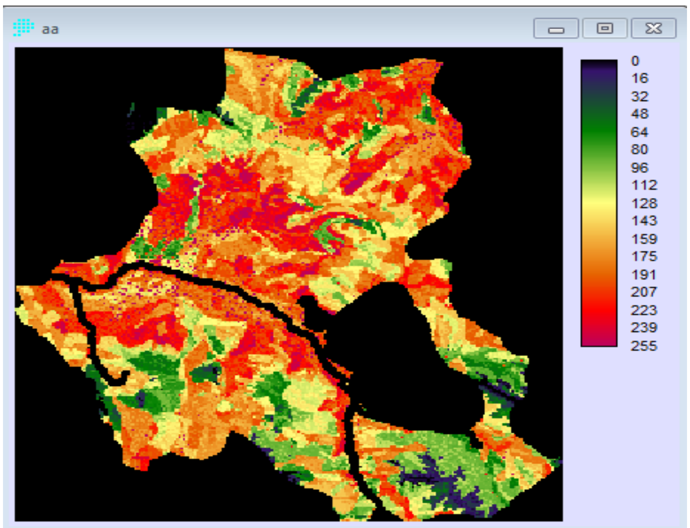


Fig. 3. Final Urban Development Land Use Map using ANP Method

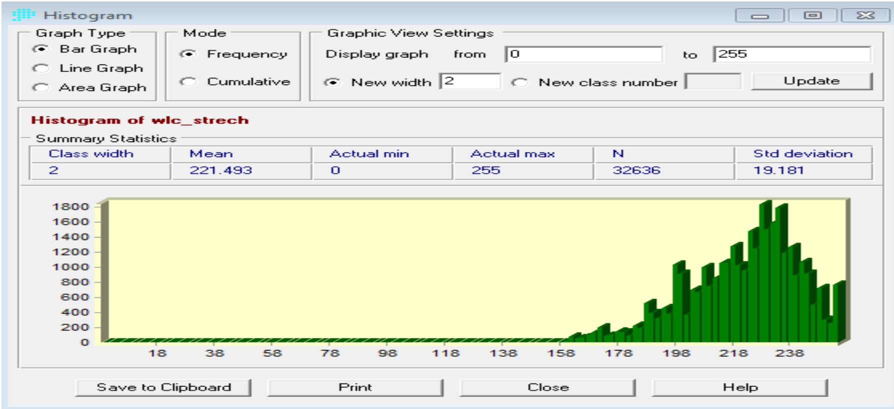


Fig. 4. Histogram of Data Distribution using ANP Method

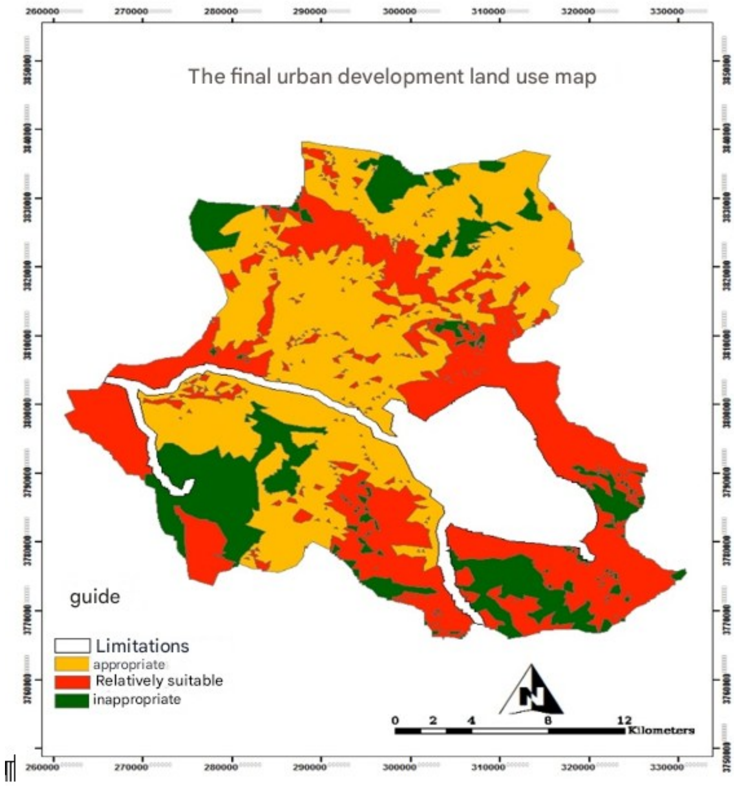


Fig. 5. Final Land Use Map using ANP Method

5. DISCUSSION AND CONCLUSION

One of the responsibilities of regional management is directing the use of lands based on predictive potentials. In many parts of our country, this aspect has been overlooked, leading to the improper use of lands [35]. Awareness of how to use land can prevent the waste of land resources. Ecological potential models provide insight into the suitable land use for a specific area, offering suggestions for land use based on ecological factors [36]. The importance of ecological potential assessment is evident, as developing land without suitable ecological potential not only fails to improve the environmental conditions of the area but can lead to further environmental degradation [37].

Appropriate urban development is achieved when land is used in proportion to its potentials and capabilities. Identifying the potentials and capabilities of the land before settling and assigning urban activities is crucial [7]. In this study, the ANP method, combined with GIS, was employed to assess the ecological potential for urban development in the Malayer county region, taking a comprehensive approach to ecological factors. The combination of multi-criteria decision-making models and GIS software (Idrisi) was used for land use zoning. The ANP model was utilized in the weighting process, providing an effective solution for group decision-making and determining the final weights of criteria influencing urban development. The results of the ecological potential assessment indicate that the study area possesses all three levels of potential (suitable, relatively suitable, and unsuitable) for urban development (Figure 5). The southeastern points and some southern parts of the study area are limited in terms of drainage, soil texture, soil structure, and vegetation cover density, indicating unsuitability for urban development. As demonstrated, slope is a crucial factor in urban development. Based on the area's topography, suitable slopes for urban development (slopes of 0-12%) cover most of the northern, central, and western parts, while the southern strip towards the southeast and specific areas in the north are considered unsuitable due to mountainous terrain and steep slopes. Suitable elevation for development also covers the majority of the region, mainly in the north, central to west, determined using a triangular linear membership function. The normalization of continuous criteria such as vegetation cover density, soil depth, and precipitation was performed using fuzzy logic and linear membership functions. In the weighting process, the ANP model, with the assistance of questionnaires and expert opinions (12 experts), was employed. The obtained results were then entered into the ANP model, producing the supermatrix of criterion weights, non-weighted supermatrix, and limit supermatrix. Finally, the final weights of criteria (Table 3) were obtained using the ANP method. According to this table, slope and precipitation have the highest and lowest weights, respectively, among the factors affecting the ecological potential assessment of urban development. The integration of criteria is essential in decision-making, especially in land-use planning. The Weighted Linear Combination (WLC) method was used in this study after normalizing and determining the weight vector of criteria. Standardized maps of each factor were multiplied by their weights, and the sum of these products was calculated for all factors to produce the restricted development map. The resulting map (Figure 3) represents a layer with a spectrum of desirabilities for different pixel values (0 to 255), where higher desirability indicates higher development potential, and lower desirability indicates lower potential. The final fuzzy potential map was then classified into three urban development categories (Figure 5) using histogram analysis and breakpoint determination.

5.1. Results and Interpretation:

The discussion of the results involves the categorization of areas into three classes: suitable, relatively suitable, and unsuitable for urban development. The analysis indicates that the study area is capable of supporting all three levels of urban development potential. The southern and southeastern parts, with slopes less than 12%, elevation between 1700-401 meters, loamy to loamy-clay soil texture, erosion-resistant, soil depth between 150-26 cm, and vegetation cover density less than 25%, were classified as having the highest potential (suitable) for urban development, covering 43% of the land area. The parts with slopes between 15-1/12%, elevation below 400 and above 1700 meters, sandy and sandy-loamy soil texture, soil depth between 50-26 cm, and vegetation cover density less than 50% were classified as having the second-highest potential (relatively suitable) for urban development, representing 38% of the study area. Areas with steep slopes (>15%), heavy sandy and loamy soil with severe erosion, shallow soil depth, and geological characteristics like marl, schist, and floodplains were considered unsuitable for urban development, covering 6% of the area. The analysis shows that the study area has a significant portion suitable for urban development, but it also highlights challenges in certain regions due to factors like protected areas, rivers, and mountainous terrain. Overall, the examination of urban development obstacles in this research indicates that the southern and southeastern urban spaces face limitations due to factors like protected areas, rivers, and mountainous terrain. These conditions pose challenges to future development, making these areas less desirable for urban expansion. The study also identifies regions that are entirely suitable for urban development, primarily in the northern, central, and western sections of the study area. By devising appropriate development strategies and directing settlements and activities toward suitable lands, urban centers can expand while preventing the use of inappropriate lands. This approach ensures more sustainable use of the region's resources and environmental protection.

5.2. Comparison with Previous Studies:

Comparing the results with similar studies indicates that the developed model effectively categorizes the study area based on its ecological potential for urban development. In a study by Badranejad et al. (2016) on the ecological potential assessment of rural urban development in the Tarem watershed, they found that the most limiting factor is slope, with the highest relative weight assigned to it. Thus, central areas with slopes less than 8-12% and sparse vegetation cover, including low-density pastures and sparse forests, were identified as the most suitable areas for development [38]. Similarly, Nozomfar et al. (2016) assessed the ecological potential of urban development in Urmia County using ANP and GIS. The results revealed that the zoning of the county based on ecological potential includes five classes, ranging from unsuitable to entirely suitable. The highly suitable areas cover 13% of the county, primarily located in the eastern part, with excellent potential for urban development. Unsuitable areas, covering 18%, are found in the southern, mountainous, and western parts of the county [39].

6. CONCLUSION

In conclusion, the study successfully employed the ANP method combined with GIS to assess the ecological potential for urban development in the Malayer county region. The results provide valuable insights for land-use planning, directing urban activities, and preventing urban expansion into unsuitable lands. The ecological potential assessment categorizes the study area into three classes: suitable, relatively suitable, and unsuitable for urban development. The developed model effectively considers various ecological factors and provides a comprehensive view of the region's potential for urban development. It also highlights challenges in certain regions due to factors like protected areas, rivers, and mountainous terrain. By applying appropriate development strategies and directing activities toward suitable lands, the region can achieve sustainable urban development while preserving environmental quality. Overall, the study contributes to the field of ecological potential assessment for urban development, providing a valuable tool for decision-makers and planners.

Table 4. Area of land capability classes obtained through the ANP method

WLC method		Method / Classes
Area (percentage)	Area (square kilometers)	
43	1113/11	Suitable
38	956/32	Fairly adequate
19	480/95	Inappropriate
100	2550/38	Plural

For the purpose of evaluating the accuracy and compatibility of the executed method, the Kappa coefficient was utilized using cross-tabulation tables (Crosstab module) in the Idrisi software, as well as field visits. The Kappa coefficient indicates the overall agreement of the produced map with the ground reality or another map, with higher values approaching unity indicating greater consistency. Since the land suitability model for urban land use is applied for the first time in the study area, there is currently no comparative method to assess its validity. Therefore, field studies and expert opinions from regional specialists were used in this regard. To assess the accuracy of the model (evaluation map), a number of control points (10 points) were randomly selected across the region's surface, and the quality of different capability classes was examined at these control points. The accuracy output percentage for the ANP model is reported as 78%. The results of controlling the classes of the urban development model in this study, while confirming the decision-making model of the Analytic Network Process (ANP) in the study area, indicate that the ANP method is the most suitable for evaluation. It provides a more accurate ecological land assessment and better alignment with the ground reality. Nevertheless, one of the objectives of land use models is to predict new urban locations, and one powerful technique for determining suitable points for urban development in the region is the combined WLC-ANP method. The necessity of considering future perspectives and drawing the future development scenario directs tendencies in planning and rational exploitation of resources towards the potential and capacity of the regions. The inappropriate pattern of land use and drastic changes in land use have led to environmental crises. Therefore, given the status of the country's natural resources, any planning related to the establishment of industrial, agricultural, national, and regional development activities must be carried out with an orientation toward the potential and capabilities of the land, within the framework of environmental capacity. This should take into account the principles of sustainable development, emphasizing balanced and continuous development.

Transparency Statement

The data supporting this study are available upon reasonable request to the corresponding author, subject to ethical and confidentiality considerations.

Acknowledgments

We would like to express our gratitude to all individuals who contributed to this project.

Declaration of Interest

The authors declare that they have no competing interests.

Funding

This research received no specific grant from any funding agency, commercial, or not-for-profit sectors.

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