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Land Suitability Analysis for Physical Development Based on Natural Criteria (Case Study: Bojnord-Iran)

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ABSTRACT

Objective: Neglecting the selection of suitable land for urban and non-urban development, especially in areas with significant physical and natural challenges, can profoundly impact security, living costs, and ultimately lead to human and environmental disasters.
Methods: This research aimed to evaluate urban land suitability for physical development in Bojnord, North Khorasan, based on natural factors using the Analytic Hierarchy Process (AHP) technique. Data collection was conducted through library and field research methods, while data analysis and calculations were performed using ArcGIS and Global Mapper 16 software. The study area encompassed the entire city of Bojnord and its surrounding regions. The evaluated indicators included slope, vegetation, faults, geological characteristics, elevation, rivers, groundwater, and soil type and erosion.
Results: The findings revealed that, given the geographical and topographic characteristics of the city, only about 9% (8,804 hectares) of the available land (primarily in the northwestern and southern parts of the city) was classified as very suitable or suitable, approximately 9.98% (9,869 hectares) as moderately suitable, and 81% as unsuitable or very unsuitable.
Conclusion: Land-use planning for Bojnord requires high sensitivity, and it is crucial to incorporate the results of land suitability studies in future urban development strategies.

1. Introduction

Despite human efforts and claims of progress, natural and environmental factors continue to exert undeniable influences on human life and activities. Achieving goals and objectives without considering natural rules and conditions remains a challenge. Some scholars argue that the environment is a decisive factor in human life (Nazarian, 2009), and ignoring ecological variations and environmental potentials can lead to adverse consequences such as soil erosion, desertification, deforestation, and loss of rangelands (Jalalian & Ayubi, 2010). Therefore, identifying the productive constituents, elements, and factors within the environment is a prerequisite for any sustainable activity (Soroor et al., 2014).

The impacts of human activities on the environment, which manifest as both natural and anthropogenic disasters, have gained more attention as cities expand and support increasing population densities (Ghanavati & Goodarzi, 2013). Urban activities often result in the destruction of orchards and

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agricultural lands, encroachment on river boundaries, infringement on environmental values, and unregulated development on steep slopes (Karam & Mohammadi, 2009). These consequences have occurred even as urban development has become unavoidable, making environmental sensitivity and protection more urgent and essential than ever before (Mirkatouli & Kanani, 2010). Therefore, it is imperative that urban development occurs in areas with minimal negative environmental impacts (Karam & Mohammadi, 2009).

Bojnord, the focus of this research, hosts approximately 56% of the population of North Khorasan Province. However, the city's topographic conditions present significant challenges to urban development. Despite these constraints, city managers regard Bojnord as a regional development hub in northeastern Iran, emphasizing its potential for urban population growth and its capacity for industrial and commercial activities (Ziari, 1999; Statistics Center of Iran, 2012). To evaluate these claims, this research aimed to highlight the natural and physical challenges currently facing Bojnord and the additional bottlenecks anticipated in its future development. Addressing these challenges is essential for informed policymaking. Accordingly, the study assessed land suitability for the physical development of Bojnord using natural factors and indicators, applying the Analytic Hierarchy Process (AHP) integrated with a Geographic Information System (GIS).

2. Materials and Methods

2.1. Study Area

The spatial focus of this research was Bojnord, located at 57°20′ longitude, 37°29′ latitude, and an altitude of 1070 meters. The city is bordered by a fault to the north and southwest and by a river and several channels to the north and east (Sedaghati et al., 2022) (Fig. 1).

Fig. 1 - The geographical and political position of the study region

2.2. Research Design and Data Collection Methods

This study employed an analytical-descriptive approach, with Bojnord as the statistical population. The library method was utilized to gather information on the study's background and theoretical foundations, while field research comprising a questionnaire and interviews with 30 experts was conducted to collect data essential for addressing the research questions and achieving the study's objectives. The evaluated indicators included slope, vegetation, faults, geological characteristics, elevation, rivers, groundwater, and soil type along with its erosion. To analyze the data, the Analytic Hierarchy Process (AHP) technique and Geographic Information System (GIS) software were employed. The process involved the following steps to identify suitable areas for the physical development of the city:

- Stage 1: Data was obtained from relevant organizations. Certain information layers, such as the elevation layer of the study area, were acquired using Global Mapper 16 software. Landsat satellite images were utilized to delineate the current boundaries of Bojnord.
- Stage 2: The collected data was input into GIS software (ArcGIS). This included spatial information layers and various characteristics of the study area, which were organized in tabular format (Fig. 2).
- Stage 3: Since the data entered into the GIS was in vector format, it was converted to raster format to facilitate the combination of various layers.
- Stage 4: The indicators were classified and assigned scores. At this stage, all raster layers were reclassified based on their characteristics, and each class was assigned a score according to its level of importance. For instance, slope was measured using percentage or degree scales, while distance from faults was measured in meters—different units of measurement. To standardize these differences, all raster layers were assigned scores ranging from 1 to 9, consistent with the scoring system used in the AHP technique.
- Stage 5: Each selected indicator for urban physical development carried a distinct level of importance, necessitating the assignment of weights to each index. The AHP technique was employed to determine these weights.
- Stage 6: The weights obtained for each index were applied to the raster layers, and all raster layers were subsequently combined.
- Stage 7: The study area was prioritized for physical development. While most of the models and methods used in this process have been detailed in previous studies, this research briefly outlines the main methodology for clarity. The AHP technique is a robust method for addressing the complexities of multi-criteria decision-making (Soroor, 2004). Introduced by Sa'ati in 1971 as a tool for analyzing complex decision-making (Yu, 2002), the technique relies on paired comparisons and facilitates the evaluation of various conditions (Ajza Shokohi & Hosseini, 2017).

After preparing maps based on the indicators, these maps were blended and categorized into specific classes. A table of indicators and scores was compiled, allowing the integration of the AHP technique with GIS. The maps were converted from vector to raster format, and weight maps were created based on the assigned scores. Using the combined AHP and GIS framework, the maps were analyzed. Indicator priorities were determined using the preference table introduced by Sa'ati. Subsequently, the weights and consistency ratio (coefficient of stability) were calculated and verified, ensuring they met the standard threshold (less than 0.1). This set the stage for the final analysis, where indicators were combined to evaluate land suitability for physical development based on natural criteria.

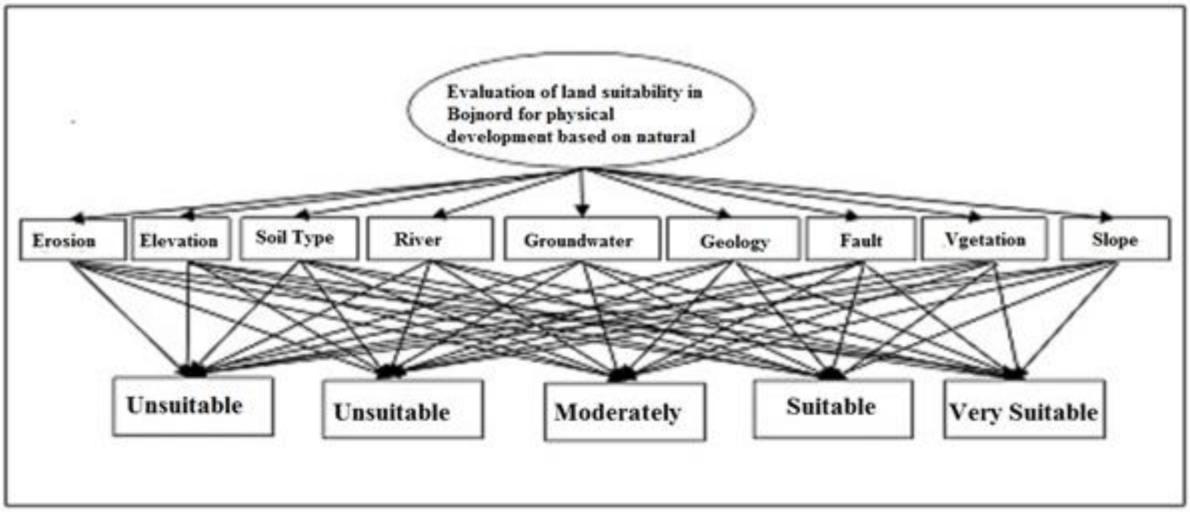

Fig. 2 - The model for determining land suitability for physical development based on natural criteria (Theoretical principles)

3. Results

3.1. Analysis of the Information

In line with the main objective of the research, the findings were categorized into the following classes:

A. Zoning the Study Region Based on Slope

Slope plays a critical role in land use policies and significantly increases vulnerability by influencing the development processes of neighboring geomorphological phenomena. These features perpetuate the dynamics of creep, landslides, and erosion, thereby directly or indirectly impacting natural and human activities (Taghvaei et al., 2013).

As mentioned earlier, reverse scoring was applied to the slope layer. The classification and scoring of the raster slope layer were conducted across five groups, the results of which are displayed in Fig. 3. According to this figure, the highest priority (score of 9) was assigned to lands with slopes of 0–3˚, followed by a score of 5 for lands with slopes of 3–5˚. Consequently, lands with the first and second slope priorities are located in the southwestern area and a section of the northeastern part of the current city limits. Lands with lower priorities (third and fourth) or no priority at all are distributed across other urban areas.

B. Zoning the Study Region Based on Topography

Topographical features are among the most important factors influencing urban development. Topography is a critical consideration in numerous urban planning issues, including determining routes for water and gas pipelines, among others (Jabbari et al., 2010). Additionally, high elevations and mountainous terrain pose challenges for movement and transportation.

Reverse scoring was also used for the classification and scoring of the elevation layer. The highest priority was given to lands with elevations ranging from 800–1000 meters, while lands with elevations exceeding 1750 meters were deemed unsuitable. The most favorable elevations, which hold the highest priority, are located northeast of Bojnord’s surrounding area. These are followed by lands with elevations of 1000–1250 meters, which cover a substantial portion of the study region, particularly within the current city limits and the surrounding northeastern areas (Fig. 4).

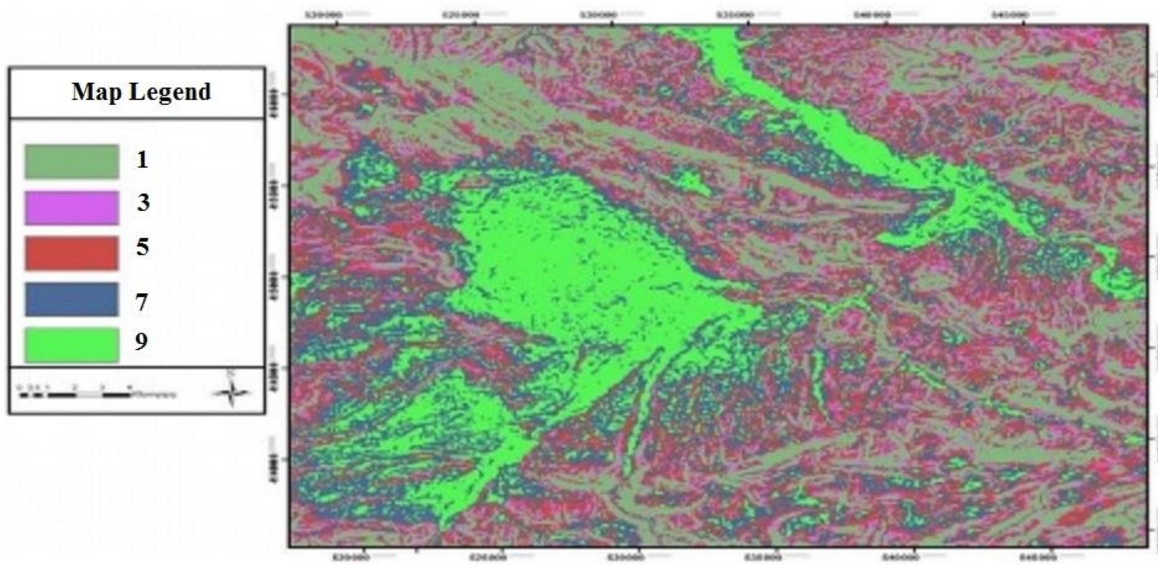

Fig. 3 - Classifying and reassigning scores to the slope layer (research findings, 2016)

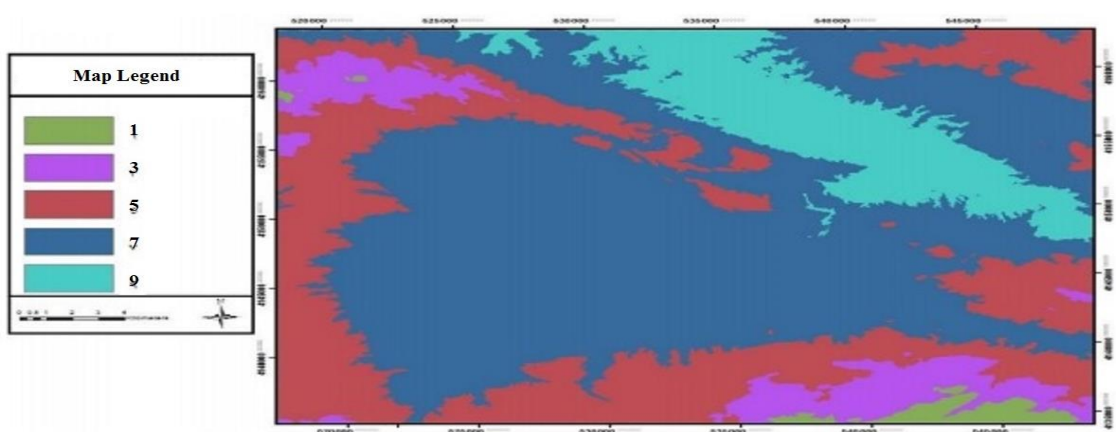

Fig. 4 - Classifying and reassigning scores to the elevation layer (research findings, 2016)

C. Zoning the Study Region Based on Water Resources

The primary water resources in Bojnord include its rivers, several deep wells, springs, and qanats. To analyze these resources, the layers representing the wells, qanats, and springs were merged into a single layer. The density function was then applied to convert this merged layer into raster format. This process facilitated the identification of areas with the highest water resource density (Table 1 and Fig. 5).

D. Zoning the Study Region Based on Vegetation

The vegetation layer was initially converted into raster format using the polygon-to-raster conversion rule. Subsequently, the layer was classified and assigned scores based on vegetation type to reflect its influence on land suitability (Table 2 and Fig. 6) (Mohamadi, 2016).

Table 1: Classifying and giving scores to the layer of water resources

Prioritization	Zoning based on access to water resources	Scores
First priority	0- 0.014	9
Second priority	0.014-0.048	7
Third priority	0.048-0.091	7
Fourth priority	0.091-0.146	3
Fifth priority	0.146-0.222	2

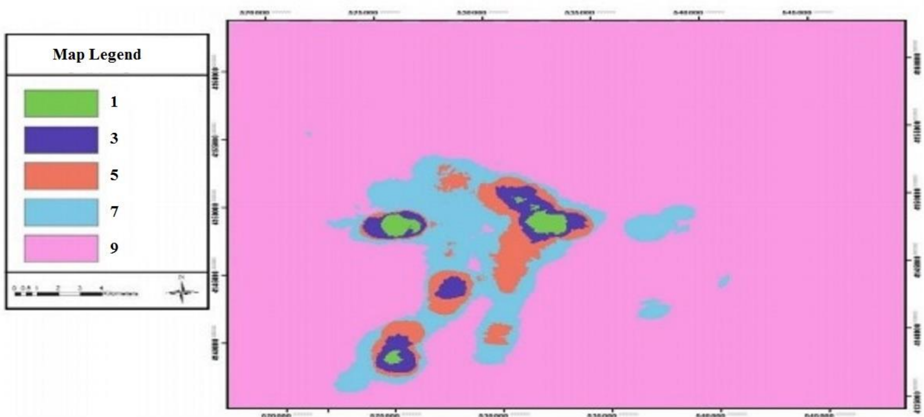

Fig. 5 - Classifying and reassigning scores to the layer of groundwater resources

Table 2: Classifying and giving scores to the vegetation layer

Prioritization	Zoning based on access to water resources	Scores
First priority	Built-up areas	9
Second priority	Low-density rangelands	7
Third priority	Moderately vegetated rangelands	5
Fourth priority	Densely vegetated rangelands	3
Fifth priority	Sparse forests, planted forests, rained and irrigated cultivation	1

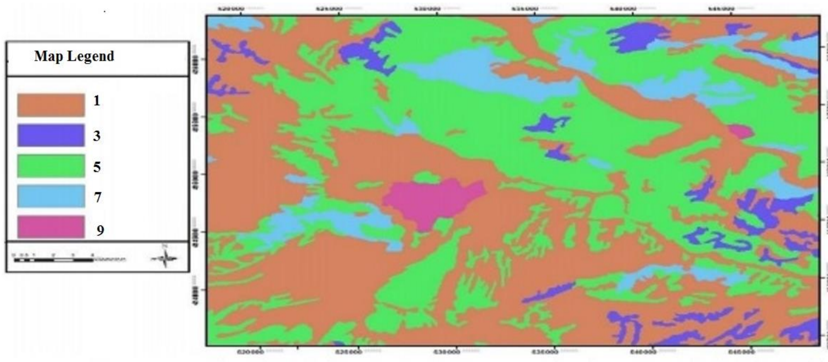

Fig. 1 - Classifying and reassigning scores to the vegetation layer

E: Zoning the study region based on distance from faults

In urban studies, it is crucial to consider fault zones, as land use must be evaluated with respect to fault lines (Barbarian et al., 1992). Therefore, examining the role of faults is vital in determining land suitability. As is customary, reverse scores were applied to the data concerning this factor (Table 3 and Fig. 7).

Table 3: Classifying and giving scores to distances from the faults

Prioritization	Zoning the study region based on vulnerability to earthquakes	Scores
First priority	+6000	9
Second priority	5000-6000	7
Third priority	3000-40000	5
Fourth priority	1000-2000	3
Fifth priority	0-1000	1

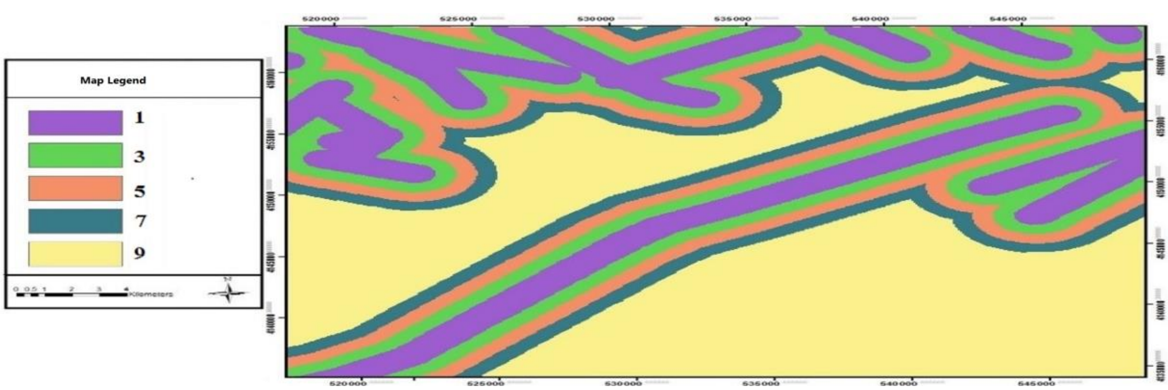

Fig 7: Classifying and reassigning scores to the layer of distance from faults

F: Zoning the study region based on distances from the rivers

Natural disasters resulting from river flooding, along with the harmful environmental effects caused by river pollution and contamination along riverbanks, are significant challenges faced by cities and residential areas (Jabbari et al., 2010:40). In this study, areas located more than 3000 meters from rivers were given the highest priority, followed by areas at distances of 2000–3000 meters, which were assigned the second priority. Areas within 1000 meters of rivers were given the lowest priority (Fig. 8).

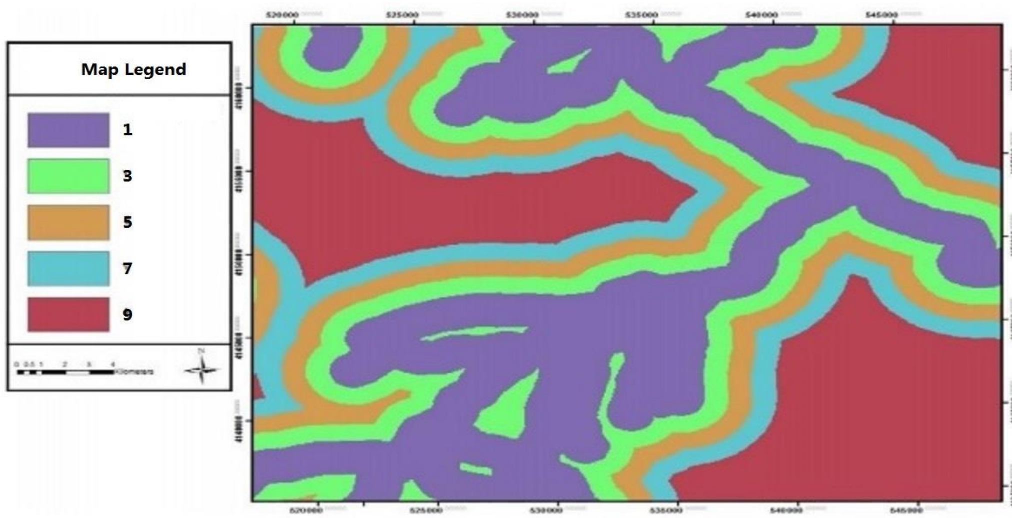

Fig. 8 - Classifying and reassigning scores to the layer of distance from the rivers

G: Zoning the study region based on soil type

The results of studies carried out in relation to zoning the soils in the study region are presented in Table 4 and Fig 9.

Table 4: Classifying and giving scores to soil type

Prioritization	Soil type	Scores
Fourth priority	Deep and fertile soils	1
Third priority	Relatively deep soils	3
Second priority	Moderately deep soils	5
First priority	Very shallow soils	7

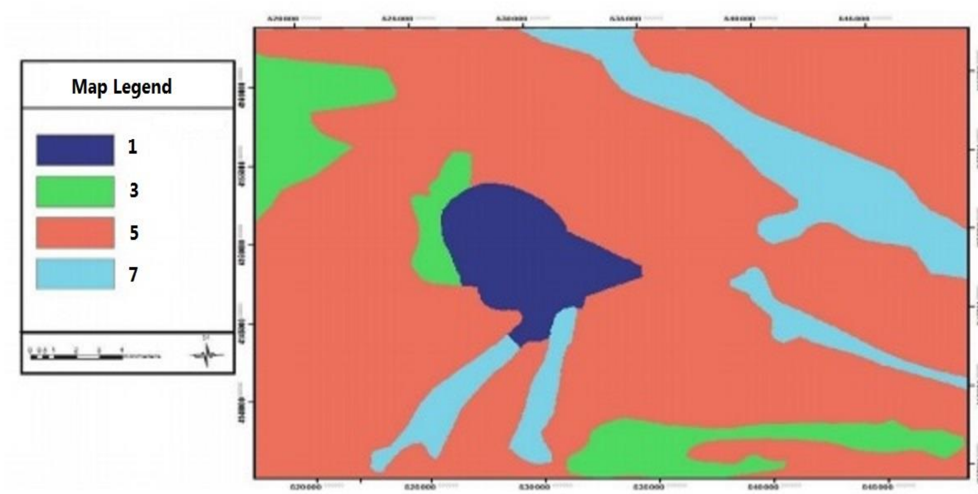

Fig. 9 - Classifying and reassigning scores to the soil layer - Reference: Research Findings, 2016

H: Zoning the Study Region Based on the Intensity of Soil Erosion

This factor was classified and scored based on three priorities: moderate, slight, and very slight intensity of erosion, as shown in Fig. 10.

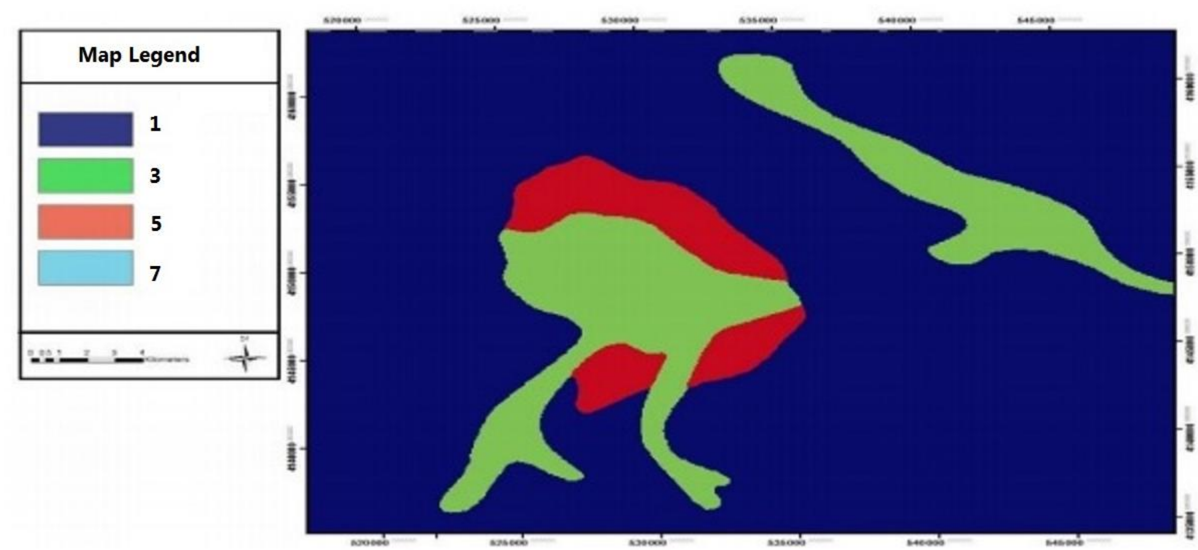

Fig. 10 - Classifying and reassigning scores to the intensity of soil erosion - Reference: Research Findings, 2016

I: Zoning the Study Region Based on Geological Formations

Geological formations provide resistance to earthquakes, support for urban infrastructure excavation, and capacity for wastewater disposal. Additionally, these formations' susceptibility to mass movement must be considered. Development on weak geological formations carries a higher risk, as these formations are more vulnerable and less resistant to the vibrations produced by earthquakes (Jabbari et al., 2010). The conditions described above were assigned scores, as shown in Table 5 and Fig. 11.

Table 5: Classifying and giving scores to geological formations

Prioritization	Geological formations	Scores
First priority	JkKsj.Jl.Ksn.Ksr	1
Second priority	Kat.Ktr.Ku	3
Third priority	Mur	5
Fourth priority	Peps	7
Fifth priority	Qft1.Qft2	9

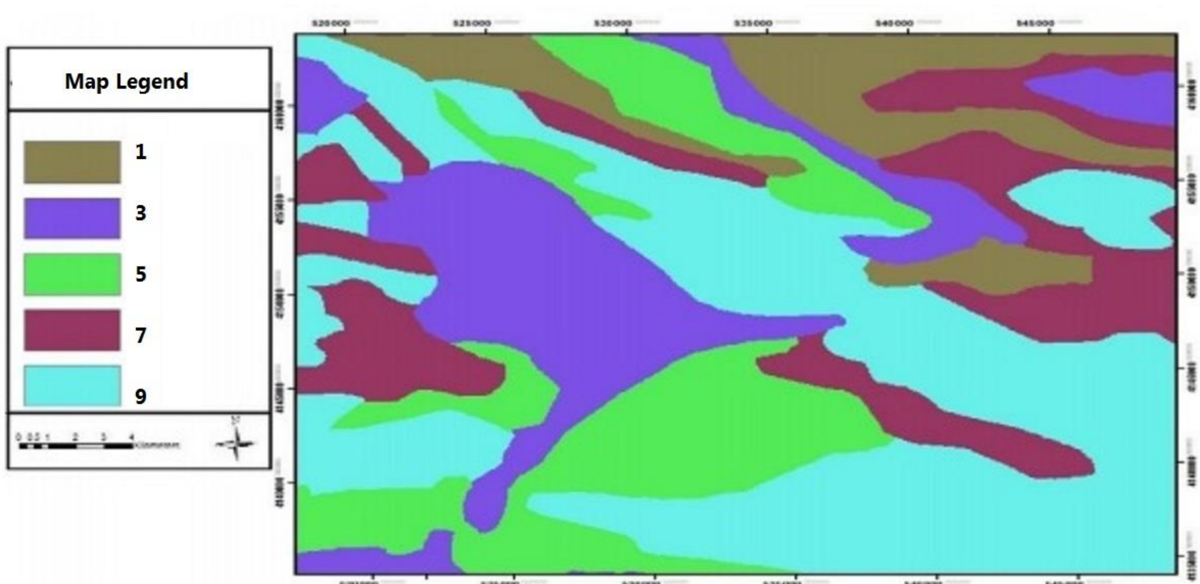

Fig. 11 - Classifying and reassigning scores to the geology layer - Reference: Research Findings, 2016

J: Zoning the study region based on urban surfaces

The indicator of the current city limits was also used in determining suitable sites for physical development. For this purpose, prioritization was performed in the form of built-up surfaces (score of 1) and unbuilt surfaces (score of 9) and the land areas were classified (Fig 12).

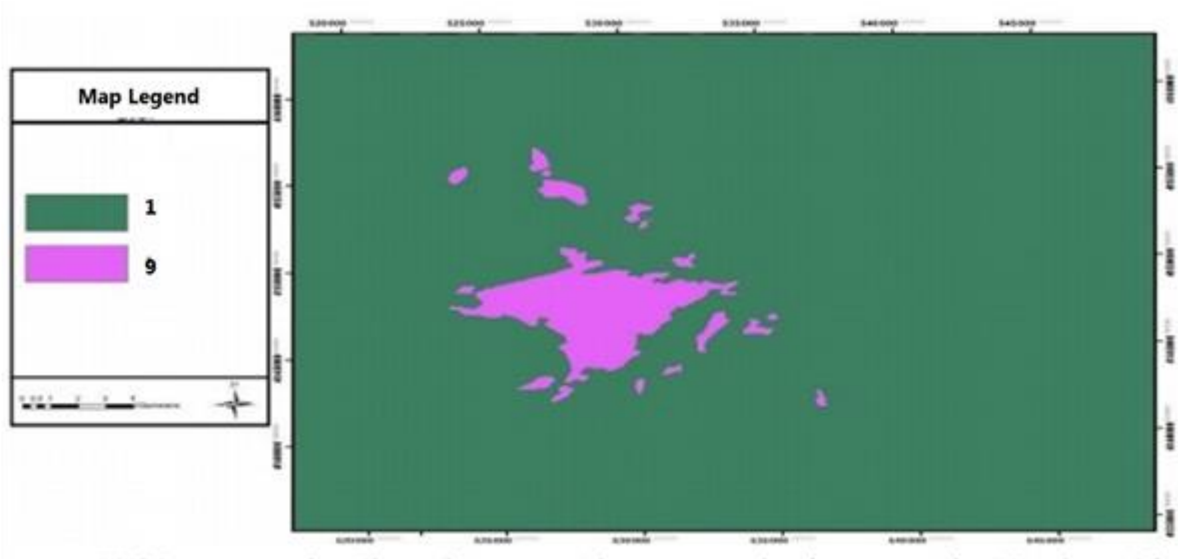

Fig. 12 - Classifying and reassigning scores to the geology layer

K: Determining the Weights of Indices

Since each of the indicators used had a different level of importance, it was necessary to determine the weight or degree of importance for each one. To achieve this, the AHP technique was applied, and the following stages were followed:

1: The Pairwise Comparison Matrix of the Criteria

A nine-point scale was used for pairwise comparison to prioritize the criteria. Based on the input from experts and researchers, as well as available references, executed projects, and previous research, weights were assigned to the criteria (Table 6).

Table 6: Pairwise comparison matrix of the criteria (research findings, 2016)

	Elevation	Slope	City limits	Erosion	Geology	Fault	Groundwater	Vegetation	River	Soil
Elevation		1.8	1.4	1.8	1.8	1.9	2.0	2.7	3.4	2.0
Slope			1.6	1.8	2.1	1.5	2.0	1.3	1.4	2.1
City limits				2.0	2.0	2.3	1.0	1.2	1.5	1.9
Erosion					1.8	2.0	1.2	3.0	2.1	2.1
Geology						1.0	1.0	1.7	2.6	1.4
Fault							3.0	1.4	2.1	1.0
Groundwater								1.6	1.0	1.4
Vegetation									3.0	2.0
River										1.2
Soil	Incon: 0.09									

M: The Final Weights of the Criteria

The final weight of each criterion was calculated by determining the row average, or in other words, the line average, for each criterion. The sum of the weights assigned to each criterion was divided by the number of criteria, and the resulting value represented the weight and influence of each criterion. As shown in Table 7, the average slope, with a weight of 0.133, received the highest score, followed by the criteria of vegetation, faults, and geology, which are highly influential in determining urban land suitability for physical development based on natural factors. The criteria of elevation, river, groundwater, soil type, and soil erosion, with weights of 0.0894, 0.0891, 0.082, 0.069, and 0.065, respectively, ranked fifth to ninth, having the least influence on determining land suitability for physical urban development.

Table 7: Final weights of th criteria

Criteria	Soil erosion	Soil type	Groundwater	River	Elevation	Geology	Fault	Vegetation	Slope
Final weight	0.065	0.069	0.082	0.0891	0.0894	0.117	0.119	0.121	0.133

Calculation of compatibility rate (CR):
The compatibility rate expresses the degree of correctness and accuracy in the prioritization of pairwise comparisons. If the compatibility rate is equal to or less than 0.1, the prioritizations and comparisons can be considered correct and accurate. Otherwise, they need to be revised or corrected (Karam & Mohammadi, 2009). Compatibility rates are calculated by determining the compatibility indices (CI) using the following formula:

In the above relation ,λ_{max} is the eigenvector and “n” the number of options present in the problem (the number of criteria).

$$CI = \frac{\lambda_{max} - n}{n - 1}$$

Calculation of Compatibility Ratio:
Compatibility ratio is obtained by dividing the compatibility index by the random index:

$$CR = \frac{CI}{CR}$$

After weighing and before using the weights, the compatibility ratio must be compared to be sure of its accuracy, following which the compatibility rate can be calculated. The software automatically performed this stage of the calculations, and the determined compatibility index was 0.09.

Combining the weights of indices and layers:
After obtaining the weights for all the layers, they were applied to the layers using the overlay tools in ArcGIS software (Fig. 13).

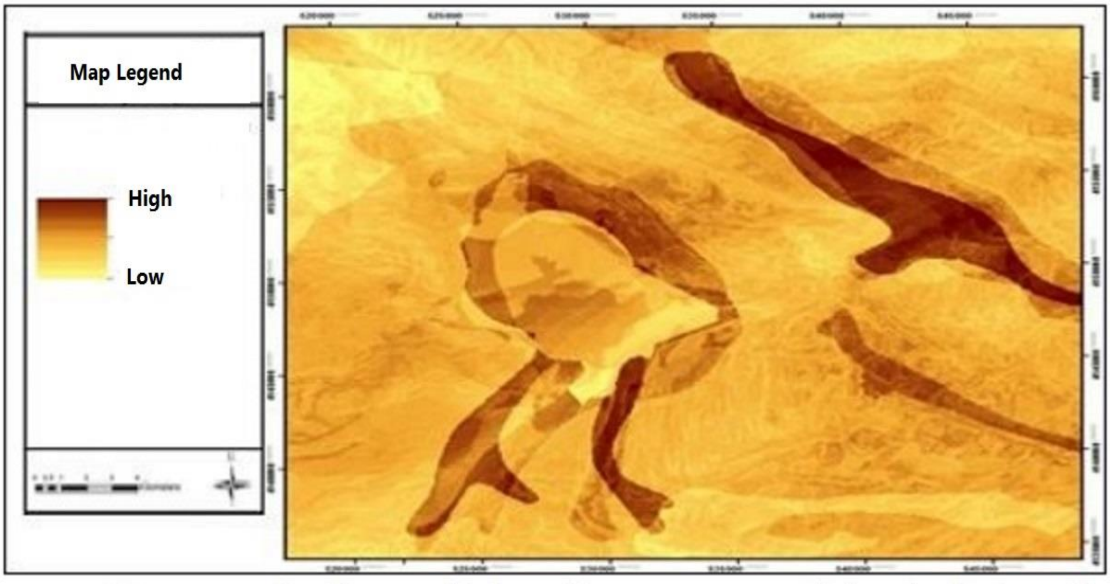

Fig. 13 - prioritization of the study region for development

4. Discussion

The main purpose of this research was to evaluate land suitability for the physical development of Bojnord and its surrounding areas based on natural factors. Natural factors such as slope, vegetation, fault, geology, elevation, groundwater, soil type, and erosion were first entered into the GIS software. The layers were then converted from vector form into raster format. Subsequently, the indicators were reclassified, scores were reassigned, and their weights were determined.

Based on the results of the analyses (Fig. 14), it was found that the city limits of Bojnord suitable for physical development were restricted to five areas, ranging from very suitable to very unsuitable. In this classification, only 9 percent (8804 hectares) of the city limits, located in the northwestern and southern parts of the city, were classified as very suitable or suitable. Moreover, about 9.98 percent (9869 hectares) of the urban areas were moderately suitable, while approximately 81 percent (80,203 hectares) were classified as unsuitable or very unsuitable (Table 8).

Table 8: Zones suitable and unsuitable for physical development of Bojnord

Number	Conditions	Area in hectare	Percent of the total
1	Very unsuitable	45,153	45.67
2	Unsuitable	35,050	35.45
3	Moderately suitable	9869	9.98
4	Suitable	5006	5.06
5	Very suitable	3798	3.84
6		98877	100

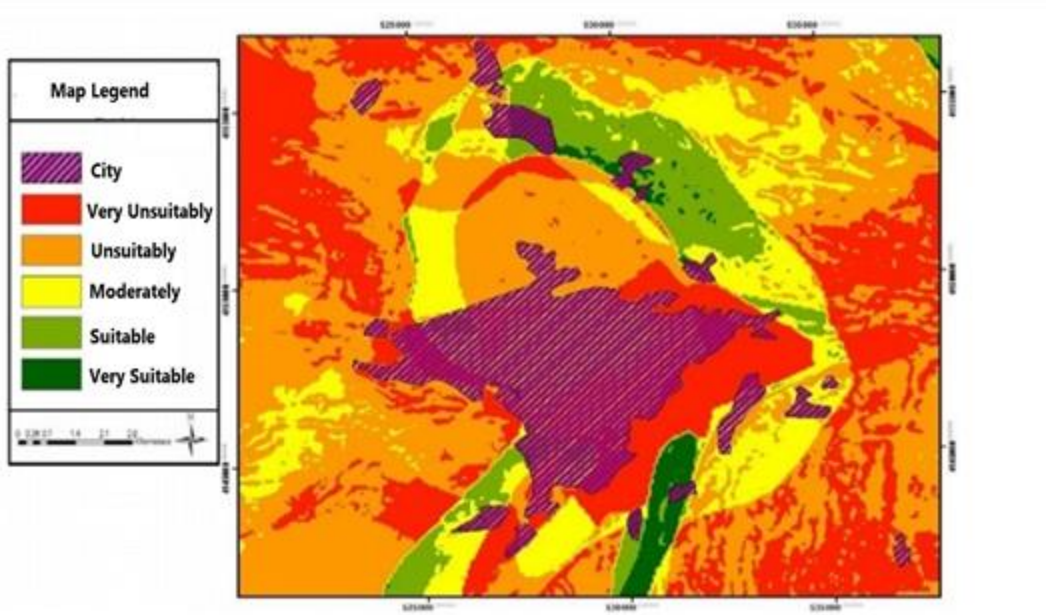

Fig. 14 - Prioritization of the study region with respect to land suitability

In general, the areas suitable and very suitable for future development of Bojnord are those with the best conditions in terms of elevation, a favorable position with respect to slope, and an appropriate distance from rivers. Additionally, the soils in these areas are not suitable for agriculture, have shallow to average depths, experience moderate erosion intensity (with some areas experiencing very slight erosion), and their vegetation consists of low-density and moderately vegetated rangelands. Furthermore, these areas have good access to groundwater resources, and most are situated at a suitable distance (3000-6000 meters) from fault lines.

5. Conclusion

This study evaluated the land suitability for physical development in Bojnord and its surrounding areas by considering key natural factors such as slope, vegetation, fault, geology, elevation, groundwater, soil type, and erosion. The analysis revealed that only 9 percent of the city area, primarily in the northwestern and southern parts, was classified as very suitable or suitable for future development. Approximately 10 percent of the urban area was moderately suitable, while 81 percent was deemed unsuitable or very unsuitable. The most suitable areas for development were characterized by favorable elevation, slope, and proximity to rivers, with soils that are not suited for agriculture, moderate erosion intensity, and limited vegetation. These areas also had good access to groundwater resources and were located at an optimal distance from fault lines. This research provides a comprehensive assessment for guiding sustainable urban development in Bojnord, emphasizing the importance of natural factors in land use planning.

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Declarations

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Conflict of Interest /Competing interests (None)
Availability of Data and Material (Data are available when requested)
Consent to Publish (Author consent to publishing)
Authors Contributions (Author contributed to the manuscript)
Code availability (Not applicable)

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