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Integrating AHP (Analytic Hierarchy Process) and GIS (Geographic Information System) for precision land use planning and ecological capacity assessment in Alborz Province, Iran

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Abstract
The study assesses the ecological capacity and land use planning in Alborz Province, Iran for different purposes namely irrigated agriculture, dryland farming, orchards and forestry, rangelands, residential and industrial areas, as well as conservation efforts. Key factors considered include topographic criteria (slope, slope direct, elevation), soil and land criteria (land resources, land use suitability classification, and current land use), as well as vegetation cover, erosion, climatic parameters, and water resources. The analytic hierarchy process (AHP) and pairwise comparisons using geographic information system (GIS) inform the ecological capacity map after weighting and combining the criterion maps. This map is then overlaid with land use maps for specific purposes, such as irrigated agriculture, dryland farming, orchards, forestry, and rangelands. From the results, slope and land resources significantly influence the desired land uses in the study area. Analysis of the land use planning map revealed that within the study area, 63,621 ha (11%) were suitable for irrigated agriculture, 66,730 ha (13%) for orchards and forestry, 79,435 ha (16%) for rangelands, 224,812 ha (44%) for conservation purposes, and 71,471 ha (14%) for residential and industrial development.

Keywords
Land Use Planning, Analytical Hierarchy Process, Ecological Potential, Geographic Information System.

Introduction

In recent years, the imperative of conserving land for agricultural purposes has intensified due to the ever-growing global population. Ensuring an adequate food supply to meet escalating demand remains crucial (Daniel et al., 2022). Paradoxically, the global landscape faces a significant dilemma: the juxtaposition of agricultural and non-agricultural land threatens both food security and sustainable production (Aznar-Sánchez et al., 2019). Simultaneously, the conversion of agricultural lands into urban and industrial zones has become a prevailing trend (Dadashpoor et al., 2019; Huang et al., 2023), posing environmental risks such as soil erosion and habitat destruction (D'Odorico and Ravi, 2023; Powers and Jetz, 2019). Given that agriculture is

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a cornerstone of food production and a major contributor to the global economy, striking a balance between ecological restoration and agricultural practices becomes imperative (Yang et al., 2018). Consequently, judicious utilization of agricultural land is essential for both food security and mitigating adverse environmental consequences associated with land use changes (Akpoti et al., 2019). Land use planning (LUP) involves systematically assessing physical, social, and economic factors to optimize land utilization for productivity and sustainability (Jahantigh et al., 2019). However, conflicts often arise during the LUP process due to the limited and precious nature of land. The increasing demand for diverse land uses frequently leads to conflicts and shifts in land use patterns, particularly the conversion of agricultural land without adequate consideration of suitability and long-term sustainability (Morales and De Vries, 2021). This underscores the critical importance of continuous land preparation, where evolving environmental conditions and development practices are consistently reevaluated to address existing needs and demands. Three primary factors-social, economic, and environmental-shape farmers' decisions regarding land use (Truong et al., 2022). Social factors, influenced by neighbors and agricultural practices, significantly impact land use choices (Liu et al., 2021). Additionally, the environment, characterized by land units (including regional climate, landform, geology, soil, hydrology, and vegetation), plays a pivotal role in land use determination (Shahpari et al., 2021). Experts emphasize that effective land use planning necessitates regional context; without it, practical implementation remains elusive. In the northwest of Turkey, a research study investigated land suitability for agricultural activities, considering soil properties, elevation, slope, and slope direction (Everest et al., 2022). The findings revealed four degrees of land suitability. Similarly, in the Anatolian region of Turkey, Özkan et al. (2020) identified suitable and unsuitable areas for agriculture. Notably, 30.3% of the entire area was highly suitable, 42.7% unsuitable, and 27% unfit for agricultural activities. These studies underscore the critical role of informed land preparation and regional planning in achieving sustainable land use practices. The land use planning process entails evaluating multiple criteria that encompass both qualitative and quantitative information. This evaluation falls under the umbrella of "multi-criteria decision making (MCDM)," which aims to systematically assess obiectives in a rational manner (Kılıc et al., 2022; Li et al., 2024). MCDM involves methodically evaluating criteria, selecting them, and analyzing the interrelationships among parameters (Abdelrahman et al., 2016).

Over the past few decades, Geographical Information System (GIS) and Remote Sensing (RS) technology have played pivotal roles in analyzing land suitability and planning various land uses. These technologies address spatial studies related to land, driven by the need to manage and analyze large volumes of spatial data (López et al., 2020; Memarbashi et al., 2017). In conjunction with GIS, Analytical Hierarchy Process (AHP), a well-established method introduced by Saaty in 1980 (Saaty, 1980) is employed for spatial planning, management, and ecological data interpretation at different planning stages. AHP facilitates comparing the importance of selected criteria by assigning degrees of importance through pairwise comparisons (Roy and Saha, 2018; Salari et al., 2019). Researchers have effectively combined GIS and AHP to evaluate land and assess its ecological potential (Vladimirov, 2018). For example, Ustaoglu and Aydınoglu (2020) conducted a study analyzing land suitability for urban development in the Pendik region using AHP, fuzzy AHP, and GIS. Their findings demonstrated that integrating multi-criteria decision-making with fuzzy methods and GIS enhances the evaluation of urban construction suitability beyond traditional GIS-multi-criteria techniques. Similarly, Hassan et al. (2020) assessed land suitability for agriculture in Alborz province using the AHP method alongside GIS. The study revealed that 13.21% of the area was highly suitable, 11.61% relatively suitable, 13.14% had low suitability, and 62.05% was unsuitable for agriculture. This underscores the effectiveness of integrating GIS and AHP, providing valuable insights for policymakers to enhance land resource management.

Alborz province, situated on the southern slope of the Alborz mountain range, exhibits diverse geographical features. Its northern parts reach elevations of up to 4,000 m, while the central region comprises lowlands and plains at approximately 1,500 m a.s.l (Jaras et al., 2018). These variations have shaped distinct landforms and climatic conditions within the province. Therefore, given the unique blend of climatic and geographical factors conducive to agriculture, Alborz province plays a pivotal role in ensuring food security and influencing its economic landscape. Consequently, assessing the ecological capacity of its lands through effective land use plan-

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ning becomes imperative. This research emphasizes the need to evaluate Alborz province's ecological potential for various agricultural purposes, including irrigation, rainfed farming, horticulture, and arboriculture. Additionally, land suitability for pasture, residential areas, industrial zones, and protective purposes must be considered. By adhering to sustainable land use principles, this assessment aims to create an ecological capacity map for the province. Responsible land management practices will prevent degradation and erosion, safeguarding the region's natural resources. Given the intricate relationships inherent in land use planning, this study adopts the Multi-Criteria Decision Making (MCDM) approach, specifically employing the AHP.

Materials and methods

Study area

The study area for this research encompasses Alborz province, spanning an extensive 514,187 ha. Positioned between 50° to 30/51° E and 30/35° to 36/30° N, Alborz province lies in the southern part of the Alborz mountain range. Currently, the province comprises six cities: Karaj, Eshthard, Saujblag, Taleghan, Nazarabad, and Fardis (see Figure 1). Its total land area approximates 517,371.5 ha, constituting a mere 0.3% of Iran's total landmass. The topography of Alborz province is diverse. Its nor-thern regions ascend to elevations of up to 4,104 m, forming a mountainous expanse that extends east-west. In contrast, central areas consist of low-lying plains. The province exhibits varying slopes-some regions with gradients below 8% (approximately 40% of the province) and others with slopes exceeding 15% (approximately 52% of the province). Pastures cover a substantial 61.7% of the land area. Two major rivers, the Karaj River and the Dorvan River, traverse the province. Precipitation patterns reveal a distinct rainy season during cold months and a dry season with minimal rainfall in the hot months. Spatially, cities predominantly cluster in the southern and central regions, characterized by flat plains and annual rainfall below 300 mm—typical of a dry and semi-arid climate. However, small pockets around the high peaks in the east and north experience more humid conditions, with rainfall ranging from 500 to 600 mm. This province witnesses extreme temperature fluctuations. Recorded absolute minimum and maximum temperatures are -18 and 42 degrees Celsius, respectively, with an average annual temperature of 15.1 degrees Celsius. The region is marked by fundamental Quaternary faults. Landslide risk zoning identifies moderate to high-risk areas primarily in the northern and northeastern sections, aligning with the elevated Alborz mountain ranges. Conversely, central and southwestern areas exhibit very low risk levels. In terms of soil classification, the study area encompasses three major groups: Aridisol, Inceptisols, and Entisols, as per the USDA Soil Taxonomy (Johnson et al., 2023).

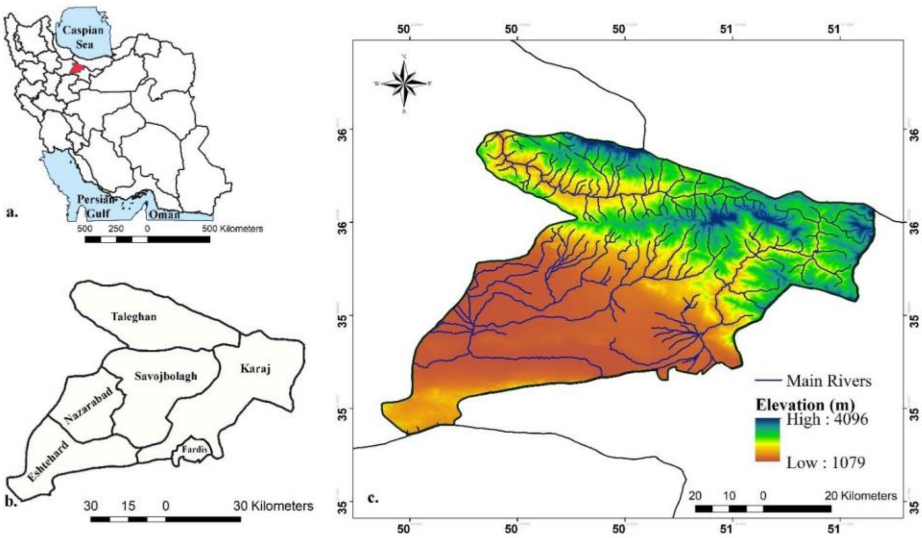

Figure 1
Geographical location of the studied area in
a: Iran
b: Alborz province and its divisions
c: Spatial distribution of height and main rivers

Assessment of ecological power

The assessment of Alborz province's ecological capacity employed the ecological model proposed by Makhdoom (2001). This model utilizes a parametric approach to determine ecological parameters, integrating biological, physical, and chemical factors.

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Initially, key variables—such as elevation, slope, soil composition, precipitation, and temperature—are identified. These factors are then mathematically transformed into indicators of ecological capacity. The parametric analysis of one or more factors is scientifically robust, particularly in land preparation activeities, including land use determination (Juita and Lopulisa, 2020; Marbun et al., 2019). Our research explored various land uses within Alborz province, including irrigated agriculture, rainfed agriculture, horticulture, arboriculture, pasture, urban areas, and protected zones. To assess the potential of each land use, we identified the ecological resources influencing it, as detailed in Table 1 for specific regions. Subsequently, collected data were analyzed to evaluate the ecological capacity associated with each land use.

Land use	Criteria
Irrigated agriculture	Slope, LCC, Land Capability, Hydrology, Land use
Dry farming	Slope, Land Capability, Land use, Precipitation
Garden and tree planning	Slope, Aspect, Land Capability, Land use, Hydrology
Rangeland	Slope, Land Capability, Land use, Precipitation, Vegetation
Urban	Slope, Elevation, Land Capability, Land use, Hydrology, Climate
Protected area	Slope, Land Capability, Vegetation, Erosion, Protected area

Table 1
Criteria and Sub-criteria for each Land Use.

Methodology

The research methodology employed in this study is depicted in Figure 2. To assess ecological power, we followed a systematic approach. Initially, we identified the ecological resources within the region that impact ecological power. These resources play a crucial role in land use planning. Collected data underwent rigorous analysis. We combined GIS and the AHP, a multi criteria decision making method (MCDM). GIS categorized desired criteria into sub-criteria. Expert opinions determined the importance of each sub-criterion, and criteria weights were calculated accordingly. Our scoring system assigned 10 points to the most favorable situation and 0 points to the least favorable situation. Ecological power was ultimately determined using a parametric approach. We utilized maps representing the main criteria for each land use category. The importance coefficient of each criterion, obtained through the AHP method, guided our assessment. Pairwise comparisons of criteria were conducted using Expert Choice software (version 11). Environmental layers were weighted and overlaid. Individual maps for each criterion were generated using Arc-GIS software (version 10.7.1). Finally, we created an integrated land use map for the study area by combining ecological power maps for each land use category.

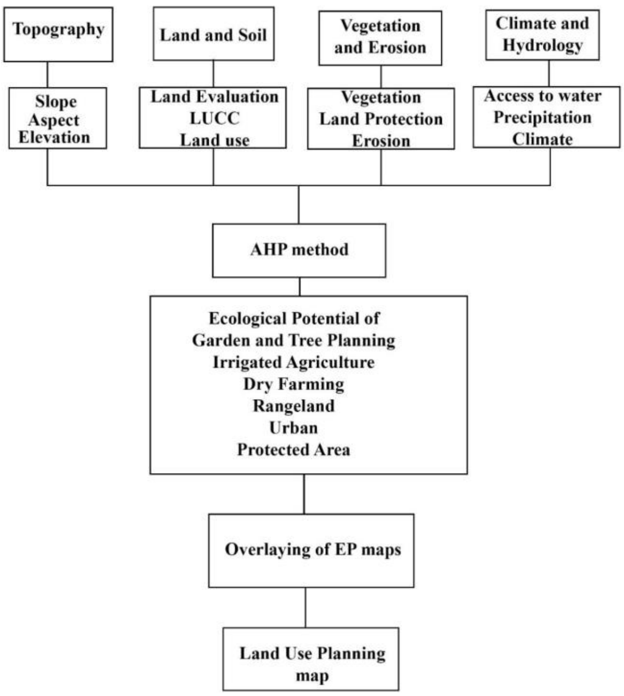

Figure 2. *Research steps*

AHP

The AHP serves as a robust decision-making method, facilitating systematic and logical evaluations in group decision contexts. It establishes a structured framework for comprehending relationships among objectives, criteria, sub-criteria, and alternatives within complex problems. By organizing these elements hierarchically, AHP enables decision makers to arrive at accurate and well-founded conclusions. In the realm of GIS-based land suitability assessment, researchers frequently employ the AHP approach to assign weights.

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to various criteria. The weighting process involves several steps. First, Decision makers compare criteria pairwise, assessing their relative importance. This matrix captures the preferences and priorities. Second, each component of the matrix is normalized by dividing it by the column sum. This step ensures consistency and relative scaling. And, finally the weighted matrix is derived by averaging the values of the normalized matrix across criteria. These weights guide subsequent analyses.

$$Cij = \frac{Cij}{\sum_{i}^{n} = Cij} \quad [1]$$

$$Wij = \frac{\sum_{i}^{n} = 1xij}{n} \quad [2]$$

In the second phase, we perform consistency analysis by calculating the compatibility vector. This involves multiplying the pairwise comparison matrix with the vector of weights.

$$\begin{bmatrix} a11 & a12 & a13 \\ a21 & a22 & a23 \\ aij & aij & aij \end{bmatrix} * \begin{bmatrix} w13 \\ w23 \\ w33 \end{bmatrix} = \begin{bmatrix} cv13 \\ cv23 \\ cv33 \end{bmatrix} \quad [3]$$

The estimation of $\lambda_{\max}$ is derived by calculating the average value of the compatibility vector.

$$\lambda max = \sum_{i-1}^{n} CVij \quad [4]$$

The maximum eigenvalue, denoted as λ (max), is affected by the matrix size, represented by the value of (n). To address this relationship, an inconsistency index (CI) scale has been introduced to aid in its resolution.

$$CI = \frac{\lambda - 1}{n - 1} \quad [5]$$

The inconsistency rate (CR) can be calculated using the following formula, which incorporates the randomness index (R.I). The R.I. is determined by referencing a table corresponding to the number of selected criteria.

$$CR = \frac{CI}{RI} \quad [6]$$

N	2	3	4	5	6	7	8	9	10	11	12	13	14	15
R. I	0	0.58	0.9	1.12	1.24	1.32	1.41	1.45	1.49	1.51	1.58	1.56	1.57	1.59

Table 2. *Random Index.*

Ecological resources

Topography. Ecological resources encompass a range of environmental factors crucial for crop yield, growth, and distribution. Among these factors, soil water content, precipitation, radiation, evaporation, and temperature exhibit variations influenced by topography, including altitude, slope, and slope direction. When assessing ecological power, considering these topographic parameters becomes essential. Slope significantly impacts land suitability for various purposes. Lands with slopes exceeding 15% are unsuitable for both irrigated and rainfed agriculture due to hydraulic gradients that reduce water-holding capacity, leading to inadequate plant water availability and excessive runoff (Everest et al., 2021). Steep slopes (>30%) are impractical for livestock grazing (Jafari and Zaredar, 2010). Conversely, slopes below 15% are suitable for urban areas (Zhan et al., 2018). Notably, 38.5% of Alborz province's total area exhibits slopes exceeding 30% (Table 3). Slope direction influences sunlight exposure, crucial for plant activities (Akpoti et al., 2019). Southern and western directions are generally most suitable for agriculture. Figure 2-b illustrates slope direction in Alborz province, with 18.1% facing the southern slope and 16% facing the western slope (Table 3). Altitude affects environmental elements like radiation, precipitation, and temperature. It significantly influences soil temperature and water content (Ostovari et al., 2019). Alborz province's majority lies within altitudes of 1,500 to 2,000 m (Figure 3.c and Table 3). Urban assessments also consider altitude as an environmental indicator (Parry et al., 2018). The assessment of land resources plays a crucial role in delineating and evaluating distinct land units, considering their specific utilization (Yousif, 2018). These land units are classified based on various physiographic features, such as landforms, which significantly influence land characteristics-such as soil composition, vegetation cover, and current land use. In Alborz province, eight primary land types exist: mountains, hills, plateaus, hilly plains, lowlands, flood plains, gravel-filled landslides, and pebble-alluvium.

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Table 3. *Classification of topographic criteria (slope, aspect and elevation) and score by AHP.*

Criteria	Sub criteria	Area (ha)	Area (%)	Irrigated Agriculture	Dry farming	Garden and Tree Planning	Rangeland	Urban	Protected Area
Slope (%)	0-3	146602.9	28.5	10	10	10	3	7	0
	3-5	24326.1	4.73	10	10	10	3	10	0
	5-7	29716.1	5.77	8	6	8	5	9	4
	7-10	20129.8	3.90	8	6	8	5	8	4
	10-15	24584.7	4.70	6	4	6	8	3	4
	15-20	33269.9	4.50	1	0	4	10	-	4
	20-25	23875.4	4.60	0	0	1	10	-	5
	25-30	23502.7	4.50	0	0	1	10	-	6
	30-35	7256.7	15.37	0	0	1	6	-	7
	35-40	3428.6	7.26	0	0	-	6	-	8
	40-45	3251.4	6.89	0	0	-	6	-	8
	45-50	2977.1	6.30	0	0	-	6	-	9
	>50	1265.7	2.68	0	0	-	-	-	10
Aspect	Flat	201090.5	39.1			10			
	North	64246	12.5			3			
	East	73256.2	14.2			5			
	West	92911.2	18.1			1			
	South	82683.2	16.1			7			
Elevation (m asl)	1000-1250	115177.6	22.4						10
	1250-1500	89982.5	17.5						8
	1500-2000	87271.7	17.0						5
	>2000	221803.4	43.1						1

Each type exhibits unique attributes, including rock composition, peak morphology, soil cover, vegetation, and land use patterns. Additional factors, such as elevation, erosion, salinity, alkalinity, drainage, slope, and road density, contribute to further subdivision into smaller, relatively homogeneous land units. The province identifies a total of 19 such units (Figure 4a), with over 50% of the study area classified as mountainous. The Land Use Capability Classification (LUCC) integrates soil characteristics and other land constraints, considering sub-parameters like climate, topography, and drainage. LUCC assesses and categorizes land suitability for various cultivated crops. The classification comprises two orders and eight classes, primarily tailored for agricultural purposes. Soil slope, erosion, depth, pH, and drainage differentiate these classes (Soil survey staff., 2022). Class I and II soils are highly suitable for cultivation, while Class III lands are less favorable. Class V lands, currently unsuitable, can potentially transform through physical and chemical modifications (Figure 4-b). In Alborz province, 23.63% of lands fall under Class II, and 59.8% are classified as Class I (Table 4).

Land use (LU) critically informs land potential assessment. Firstly, it serves as an indicator of actual capacity, particularly for hydroponics. By considering historical land use practices and corrective measures implemented by farmers and authorities, valuable insights into land potential emerge. Secondly, land use criteria influence and adjust other assessment boundaries. Alborz province identifies specific land-uses such as irrigated agriculture, rainfed agriculture,

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and combined rainfed agriculture with pasture as areas with irrigation potential (Figure 4c). The distribution of land use in Alborz province reveals that pastures occupy the largest share (61.7%), followed by forests and bushes (1.3%), orchards and tree complexes (6.6%), irrigated agriculture (11.2%), rainfed agriculture (1.7%), salty and wet lands (4.10%), population centers (3.5%), and other land uses (1.8%), as shown in Table 4 (Everest, 2017).

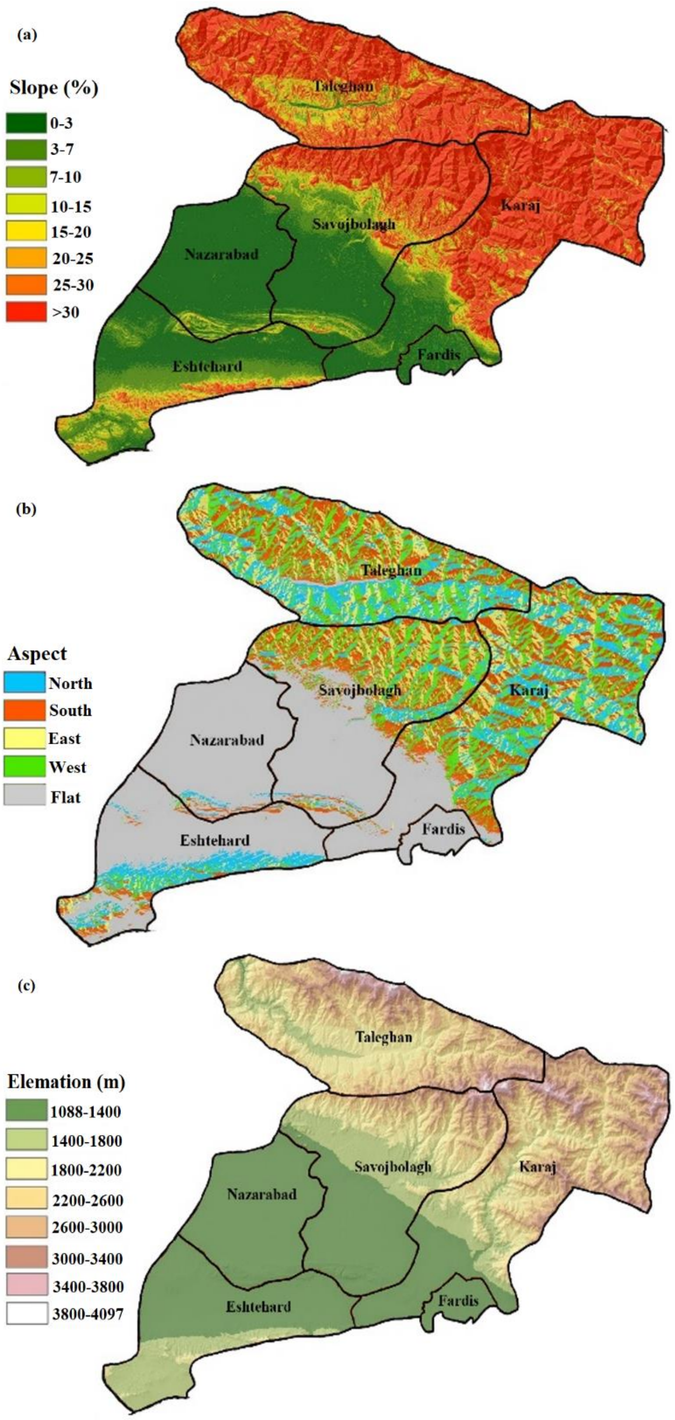

Figure 3. *Map of topographic criteria*
a: slope
b: direction of slope
c: height

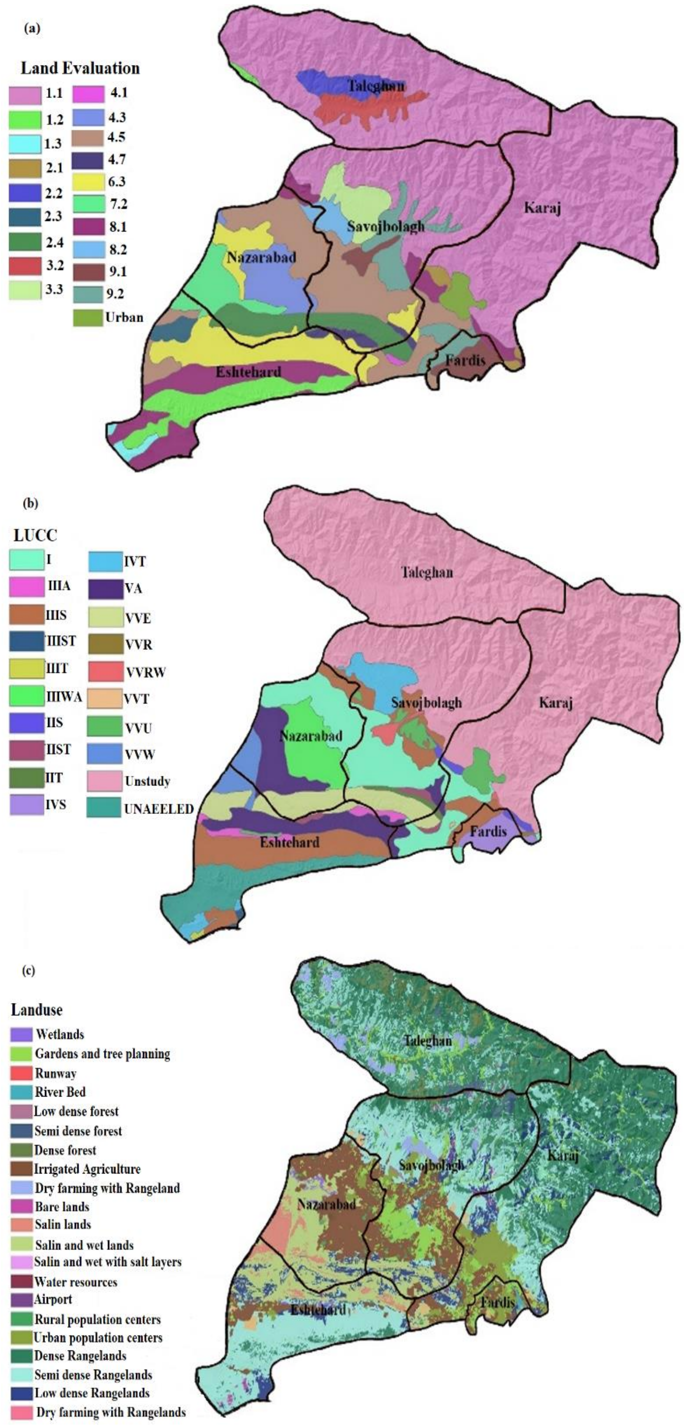

Figure 4. *Map of criteria*
a: land evaluation
b: land use capability classification (LUCC)
c: land use

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Table 4. *Classification of land and soil criteria score by AHP.*

Criteria	Sub criteria	Area (ha)	Area (%)	Irrigation Agriculture	Dry Farming	Garden and tree planning	Rangeland	Urban	Protected area
Land Evaluation	Unit 1.1	260836	50.7	-	0	-	-	-	10
	Unit 1.2	20022	3.9	-	0	-	-	-	10
	Unit 1.3	2281	0.4	-	0	-	-	-	10
	Unit 2.1	2437	0.5	-	2	-	-	-	8
	Unit 2.2	7447	1.4	-	2	-	10	-	8
	Unit 2.3	3176	0.6	-	2	-	10	-	7
	Unit 2.4	16187	3.1	-	2	-	-	-	7
	Unit 3.2	10587	1.2	5	10	4	-	-	-
	Unit 3.3	9510	1.8	5	10	4	-	-	6
	Unit 4.1	13761	2.7	10	-	10	-	-	-
	Unit 4.3	422	0.1	10	-	10	-	7	-
	Unit 4.5	48621	9.5	10	-	10	-	-	-
	Unit 4.7	3532	0.7	10	-	10	-	-	-
	Unit 6.3	35996	7.0	-	-	-	-	3	5
	Unit 7.2	12753	2.5	-	-	.	-	8	4
	Unit 8.1	32463	6.5	3	4	6	5	10	-
	Unit 8.2	4974	1.0	3	4	6	5	10	-
	Unit 9.1	6047	1.2	-	-	-	-	-	-
	Unit 9.2	17818	3.5	2	1	7	3	5	-
	Urban	4318	0.8	-	-	.-	-	-	-
Land Use Capability Classification	I	44207	8.6	10					
	II	121507	23.6	9					
	III	61990	12.0	8					
	IV	87713	17.1	7					
	No study	176852	34.4	0					
	Unrecognized	21918	4.3	0					
Land use	Low dense Rangeland				-	-	6	5	4
	Semi dense Rangeland	317253	61.7		2	-	8	-	4
	Dense Rangeland				-	-	10	-	4
	Low dense Forest					6			7
	Semi dense Forest	159398	3.1			8			8
	Dense Forest					9			10
	Gardens	33936	6.6			10		-	-
	Irrigation farming	57589	11.2			7		-	-
	Dry farming	8741	1.7			-		-	-
	Saline and wet lands	53475	10.4			-		-	5
	Urban	195391	3.8			-		10	-
	River Bed				-		-	-	10
	Dry farming wirh rangel.				10		4	4	-
	Waste Lands	15988	1.8		-		2	-	8
	Reservoir				-		-	-	9
	Bare Lands				-		-	6	6
	Others				-		-	-	-

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Vegetation and erosion. The presence of steep slopes significantly contributes to soil erosion, resulting in the loss of fertile topsoil and overall land degradation (Kılıc et al., 2022). This erosion process leads to a reduction in soil depth, which subsequently impacts agricultural productivity. Within the study area, approximately 48.5% of the lands experience high erosion, while 23.1 ha exhibit moderate erosion, and 28.4 ha face low erosion (Table 5). Monitoring the condition and effective management of pastures, rain-

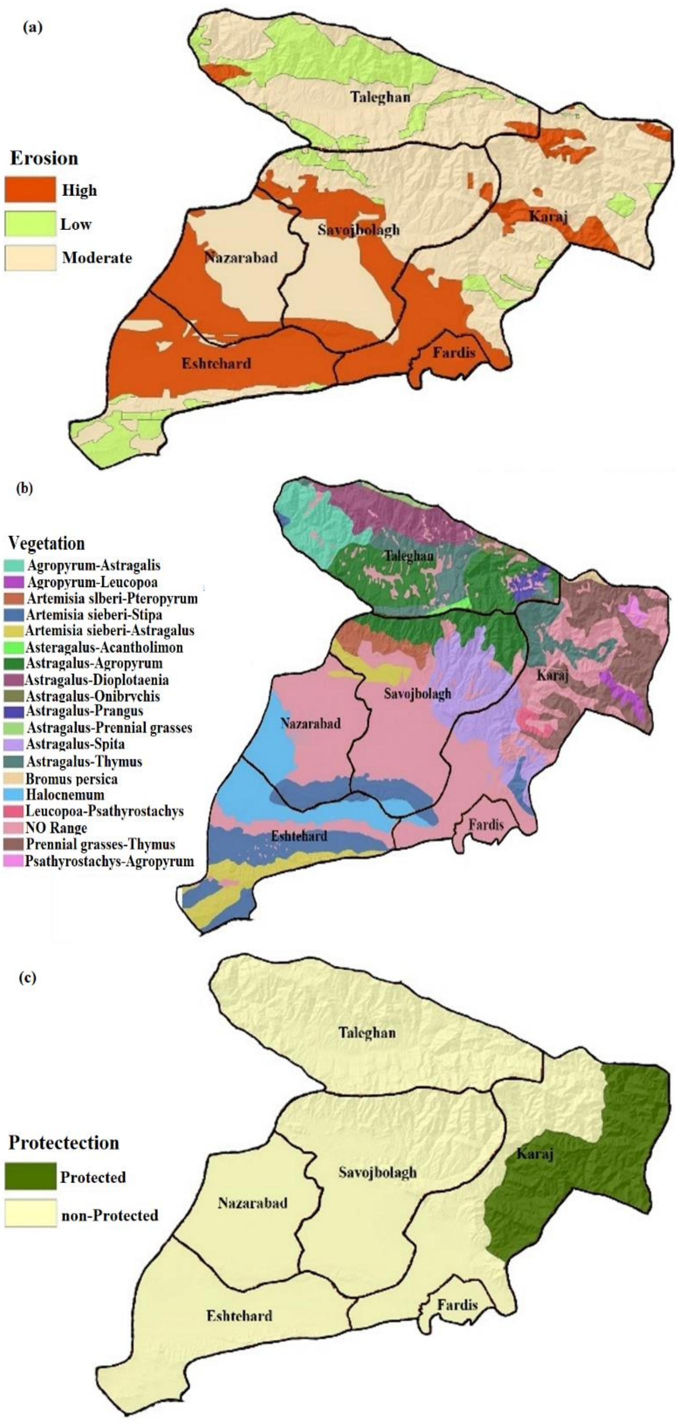

Figure 5. *Map of criteria*
a: vegetation
b: land protection
c: erosion

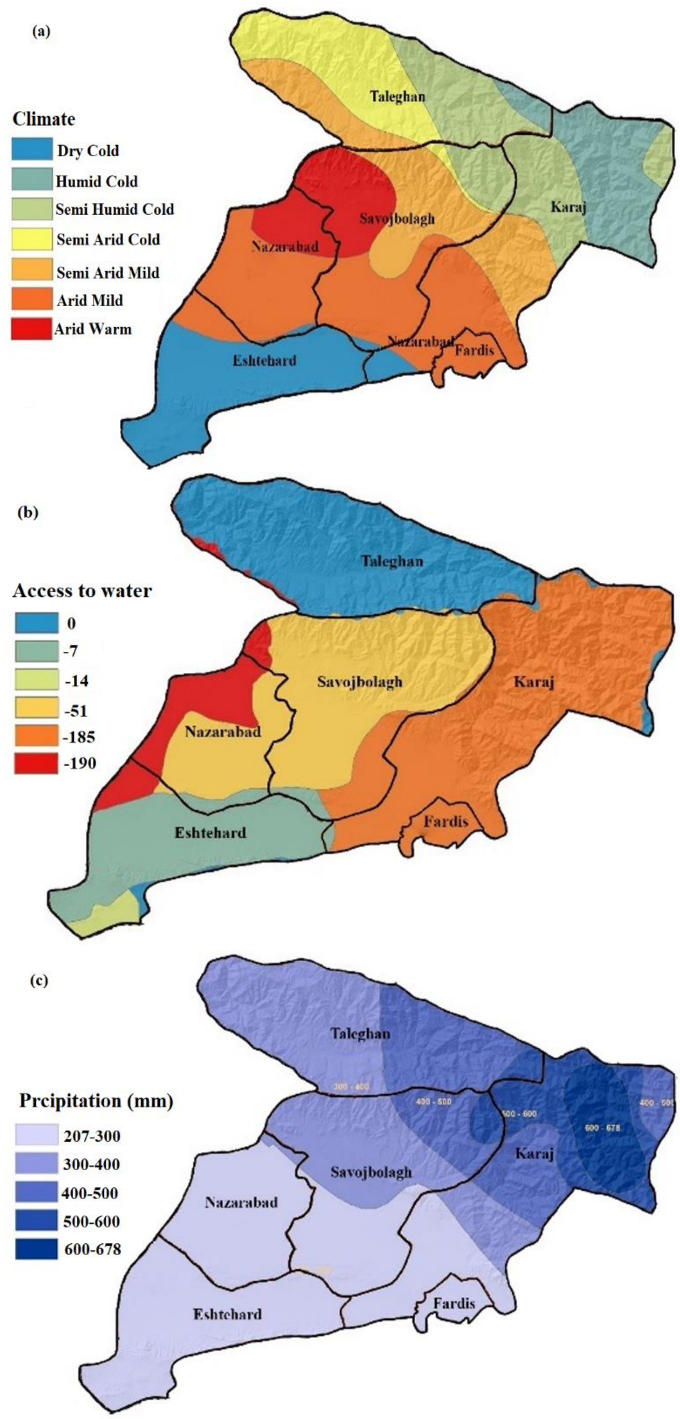

Figure 6. *Map of criteria*
a: climate
b: rainfall
c: hydrology.

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Table 5. *Classification of vegetation and erosion criteria and score by AHP*

		Area (ha)	Area (%)	Rangeland	Protected area
Vegetation	<10%	182022	35.4	0	10
	10-25%			3	5
	25-50%	330622	64.3	3	5
	50-75%			10	2
	>75%	1543	0.3		
Land protection	Protected area	59131	11.5		10
Erosion	Low	146203	28.4		1
	Moderate	118692	23.1		5
	High	249291	48.5		10

fed lands, and protected areas rely on vegetation as a crucial biophysical indicator (Abdolalizadeh et al., 2020). The study findings indicate that areas with high vegetation coverage encompass 1542.5 ha, while those with medium coverage span 330621.5 ha. Additionally, areas with low vegetation cover occupy 182021.8 ha. Notably, the total extent of protected areas in Alborz province amounts to 64149 ha (see Table 5). Figure 5 visually illustrates the distribution of erosion, vegetation, and protected areas.

Climate and hydrology. Water scarcity imposes significant constraints on agricultural activities. To mitigate this challenge, optimizing the utilization of limited agricultural land, enhancing water use efficiency, optimizing crop distribution, and adopting modern cultivation techniques are crucial (Mesgaran et al., 2017). The quantity and spatial distribution of atmospheric preci-pitation play a pivotal role in determining the ecological capacity for rainfed agriculture. An annual rainfall exceeding 800 mm is considered optimal for rainfed cultivation; however, in Alborz province, this thres-hold should not exceed 600 mm (see Figure 6a). The availability of water resources significantly influences the ecological capacity for various functions. Given Alborz province's relatively small size and the limited number of hydrological units within it, water resource assessments reveal negative balances and, in some areas, even restrictions. Consequently, water availability uniformly impacts all major activities and cannot serve as a distinguishing feature among them (refer to Figure 5b). Therefore, ensuring sufficient water provision becomes a prerequisite for all assessments related to these activities. However, the influence of water availability on evaluating ecological potential should not be overlooked. Notably, 112,363 ha of Alborz province exhibit a zero-water balance, while 19,194.7 ha experience a water balance of -190 (see Table 6)

Data used

To assess the ecological potential of the land, a comprehensive investigation was conducted, utilizing various ecological resources including topography, land capability, climate, and hydrology (Makhdoom, 2001).

Table 6. *Classification of Climate and hydrology criteria and score by AHP*

		Area (ha)	Area %	Irrigation Agriculture	Dry Farming	Garden and tree planning	Rangeland	Urban
Access to water (cm)	0	112363	21.8	10		10		10
	7-	79000	15.3	8		8		8
	14-	151303	29.4	7		7		5
	51-	4825	0.9	6		6		4
	185-	147500	28.8	4		4		2
	190-	19195	3.7	3		3		1
Precipitation (mm)	207-300	248352	48.3		0		4	
	300-400	100266	19.5		2		5	
	400-500	78156	15.2		4		6	
	500-600	52961	10.3		7		8	
	>600	381	7.4		10		10	
Climate	Hot	70444	13.7					7
	Moderate	252980	49.2					10
	Cold	190763	37.1					1

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Topographical data . such as slope, slope direction, and elevation - were obtained using the digital elevation model of the ASTER, providing accuracy up to 30 m. Multiple organizations contributed data related to vegetation, soil erosion, land capability (including landform, soil class, and land use), climate (rainfall and climatic comfort), and hydrology for different regions within the province. However, due to differences in data structures, direct utilization was challenging. Consequently, information layers underwent processing and standardization to ensure compatibility with the image system and other structural features. These processed layers were then integrated into the model. To adhere to map preparation standards and ensure coordination, digital official maps at a scale of 1:25000 and guidelines from the country's mapping organization informed the selection of database image specifications. Additionally, all layers were organized within the UTM image system. For efficient processing, all information layers were prepared and processed in a raster structure.

Ecological potential and land preparation. To create ecological power maps for each land use, we employed maps generated and classified using criteria and weights established through the Analytic Hierarchy Process (AHP) method. After scoring and determining the criteria weights, an ecological power analysis was conducted. To achieve this, the criteria maps specific to each land use were integrated following equation [7] (Kılıc et al., 2022).

$$S = \sum_{i=1}^{n} Wi.Vi \quad [7]$$

where, S is ecological power (suitability for the intended function), V sub-criterion score, and W criterion weight. The ecological power of the studied area is evaluated for various land uses, including irrigated agriculture, rainfed agriculture, garden and arboriculture, pasture, city, and protected areas. These assessments result in five distinct classes; class 1: high suitability, class 2: medium power, class 3: low power, class 4: very low power, and class 0: no power. Finally, by integrating the obtained ecological power maps, a comprehensive land use map is prepared.

Results and Discussion

An examination of the topography and land characteristics in Alborz province indicates that more than 50% of the area consists of mountainous terrain. Additionally, approximately 184,078.5 ha (38.5%) exhibit slopes exceeding 30 degrees, rendering them unsuitable for irrigated agriculture, rainfed agriculture, gardens, and tree planting.

Ecological power of hydroponics

Figure 7a depicts the ecological potential of the study area for hydroponics. Among the total land, 320,120 ha (62.26%) fall into the 'no power' category (class 0), while 78,117 ha exhibit low power (class 3). Additionally, 59,065 ha demonstrate medium power (class 2), and 56,875 ha (11.06%) are deemed suitable (class 1) for irrigated agriculture. Considering the weight assigned to different land resource criteria (weight = 0.1), it becomes evident that land resources constitute the most limiting factor for irrigated agriculture in the study area (refer to Table 7). Furthermore, slope, access to water resources, and land use also contribute to these limitations.

Table 7. *Calculated final weight for each criterion in each Land Use*

Criteria	Irrigation Agriculture	Dry farming	Garden and Tree Planning	Rangelands	Urban	Protected area
Slope	0.2	0.23	0.15	0.2	0.2	0.2
Aspect	-	-	0.15	-	-	-
Elevation	-	-	-	-	0.15	-
Land evaluation	0.1	0.3	0.25	0.2	0.2	0.1
Land Classification	0.3	-	-	-	-	-
Land use	0.2	0.27	0.2	0.2	0.1	0.25
Vegetation	-	-	-	0.2	-	0.15
Protected area	-	-	-	-	--	0.2
Erosion	-	-	-	-	-	0.2
Hydrology	0.2	-	0.25	-	0.2	-
Precipitation	-	0.2	-	0.2	-	-
Climate	-	-	-	-	0.15	-

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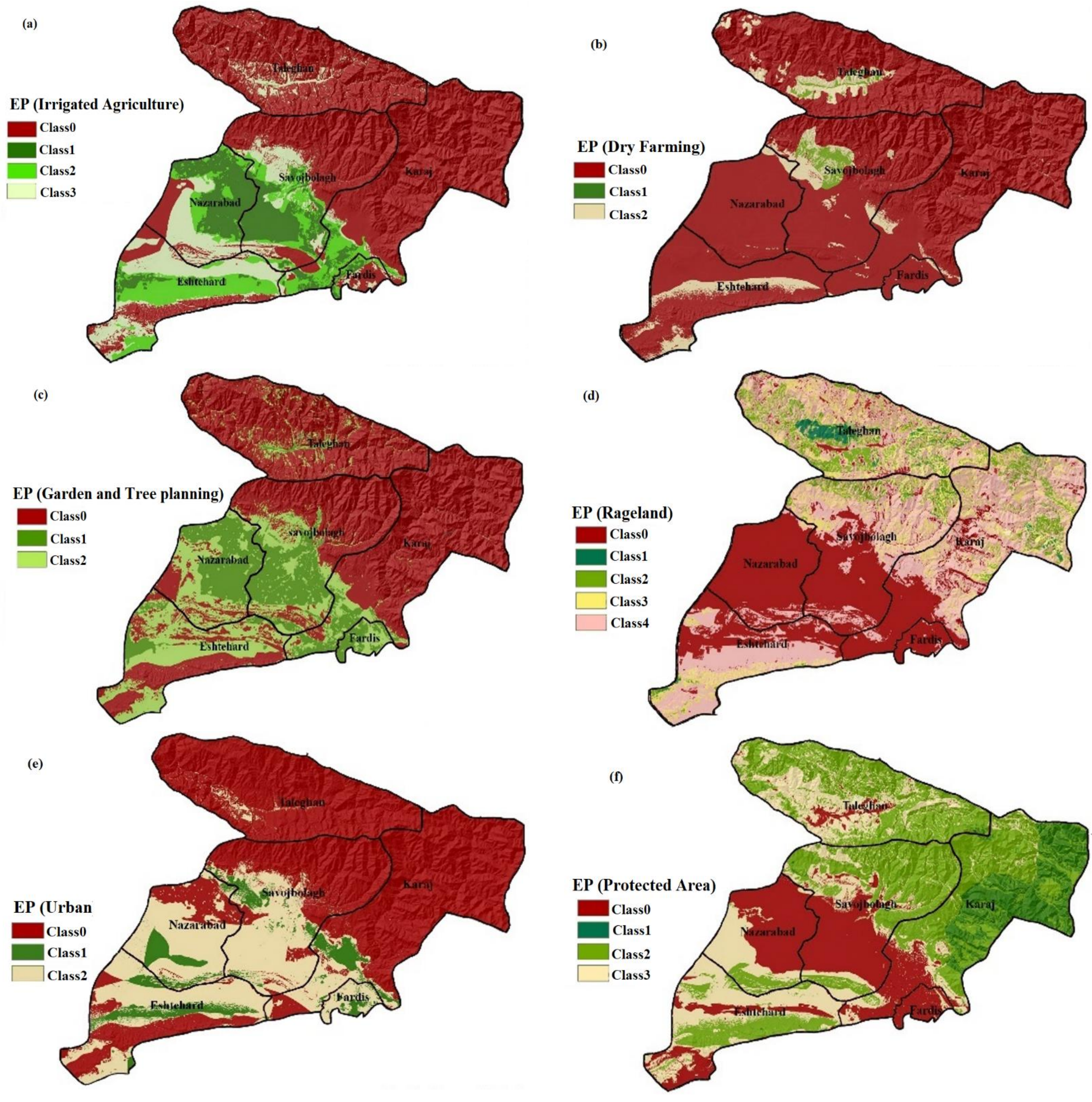

Figure 7. *Ecological power map*
a: irrigated agriculture *c: garden and arboriculture* *e: residence and industry*
b: rainfed agriculture *d: pasture* *f: protection*

Rainfed agriculture

For rainfed agriculture, the ecological potential of the study area is illustrated in Figure 7b. The map reveals that 82.89% of the land (equivalent to 461,813 ha) falls into the 'no capacity' category (class 0). Additionally, 8.42% of the area exhibits medium capacity (class 2), while 1.76% is deemed suitable (class 1) for rainfed agriculture. Analyzing the criteria weight table (refer to Table 7), we find that rainfall, slope, and land use play pivotal roles as limiting factors for rainfed agriculture. Specifically, their respective weights are 0.20, 0.23, and 0.27.

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Garden and arboriculture

When considering gardens and tree planting, the most influential limiting factors in the study area are slope and slope direction, both assigned a weight of 0.15 (as indicated in Table 7). Figure 7c illustrates that 70.86% of the land falls into the 'no power' category (class 0), while 15.39% exhibits good power (class 1), and 13.75% demonstrates medium power (class 2) for gardens and tree plantations (refer to Table 8).

Pasture

Expert opinions and rigorous criteria highlight that slopes with gradients exceeding 50% and areas with less than 10% vegetation cover significantly limit pasture utilization in Alborz province. A mapped representation of the ecological capacity for pasture (Figure 7d) reveals the following: suitable capacity (class 1): approximately 3,185 ha (0.62% of the land) exhibit favorable conditions for pasture, average capacity (class 2): cround 31,953 ha (6.21%) fall into this category, very low capacity (class 4): A. fall into this category, very low capacity (class 4): A substantial portion - 76.33% - of the land faces severe limitations, and no capacity (class 0): The central part of the province, comprising 31.06% of the land, lacks suitability for pasture.

Residence and industry

In the context of residential and industrial development, several critical factors influence the ecological capacity within the study area. These factors include altitude, land use patterns, and climatic comfort (as outlined in Table 7). The ecological capacity map for residential and industrial purposes (Figure 7e) reveals the following distribution: no capacity (class 0): approximately 63.71% of the land lacks the necessary ecological capacity, suitable capacity (class 1): about 54.6% of the area exhibits favorable conditions, and moderate capacity (class 2): approximately 29.75% falls into this category.

Table 8. *Ecological Potential Classification*

	C1		C2		C3		C4		C5	
	ha	%	ha	%	ha	%	ha	%	ha	%
Irrigation	56875	11.1	59065	11.5	78117	15.19	-	-	320120	62.3
Dry Farming	-	-	9064	1.8	43305	8.42	-		461813	89.8
Garden and Tree Planning	79142	15.4	70699	13.6	-	-	-	-	364338	70.9
Rangelands	3185	0.6	31953	6.2	145716	28.34	173598	33.8	159728	31.1
Urban	33638	6.5	152982	29.8	-	-	-	-	327562	63.7
Protected area	54946	10.7	137959	26.8	208588	40.57	-	-	112683	21.9

Protection

In the context of protection, the ecological capacity map for conservation (Figure 7f) reveals significant insights about Alborz province: highly suitable capacity (class 1): approximately 54,946 ha (10.69%) of the land are well-suited for protection, suitable capacity (class 2): an additional 137,959 ha (269.83%) fall into this category, low capacity (class 3): about 208,588 ha (40.57%) exhibit limited suitability, and no capacity (class 0): a substantial portion—equivalent to 112,683 ha (21.92%)—lacks the necessary capacity for protection (refer to Table 8). Vegetation cover and land use capability emerge as critical factors limiting the ecological potential for protection (as indicated in Table 7). The northern region of Alborz province presents challenges for various agricultural practices, including irrigated, rainfed, and garden and arboriculture. These limitations arise primarily due to the rugged mountainous terrain, high altitudes, steep slopes, and the prevalence of rocky outcrops with shallow soils (as depicted in Figure 7a, b, and c). Notably, previous studies by Kazemi and Akinci (2018) and Kılıc et al. (2022) also highlighted the impact of high slopes and shallow soils as constraints for rainfed and irrigated wheat cultivation. Analyzing the spatial distribution of Land Capability Classification (LCC), we find that the most favorable land for cultivation lies in the Nazarabad and Saujbalag regions. Here, conditions align favorably: deep soil with good drainage, lower altitudes, and gentle slopes

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(Class I). These areas exhibit minimal restrictions for cultivation and consist of gravelly alluviums and hilly plains, aligning with class 1 hydroponics (as shown in Figure 7a). However, approximately 68.35% of the study area falls into class II and III, indicating limited agricultural potential due to factors such as shallow soil depth, salinity, and drainage issues (Figure 7a). In a related study, Yohannes and Soromessa (2019) explored the impact of land capability on agricultural suitability. They identified critical limiting factors, including soil depth, texture, drainage, and slope. Similarly, in M. et al. (2021), the presence of high slopes and rocky outcrops was identified as a constraint for hydroponics. Rainfed agricultural production relies on natural rainfall as the primary water source. However, crop production decline can be attributed to several factors. Limited water resources, uneven spatial and temporal distribution of rainfall, and changes in the timing of rainfall and crop water demand periods all contribute to this decline. Notably, in rainfed areas with lower precipitation, a significant portion of the rainfall is lost due to surface runoff and ineffective evaporation (Liu et al., 2020). Interestingly, regions with steep slopes (over 50%) receive the highest rainfall (over 600 mm), which paradoxically makes rainfed agriculture unpopular in the studied area. The ecological potential map for rainfed agriculture (Figure 7b) further corroborates this observation, revealing that the northwest portion of the studied area, along with a smaller section in the west, exhibits low potential for rainfed agriculture due to its proximity to the Taleghan dam. Conversely, hydroponic agriculture, gardens, and arboriculture heavily depend on soil moisture and water availability (Aldababseh et al., 2018). Within the study area, there exists a favorable ecological potential for gardens and tree planting (class 1), and a medium potential (class 2) particularly in Eshtehard city. This suitability arises primarily from accessible water sources in the middle belt of the province, including Nazar Abad, South Saujblag, and South Karaj. Notably, Bortolini and Zanin (2019) emphasized the importance of managing runoff and drainage to support the growth of diverse tree species. However, certain limitations persist. Lands with slopes exceeding 50% and those with less than 10% vegetation cover pose significant challenges for pasture use within the province. These areas are predominantly rocky outcrops in the mountainous regions, rendering plant growth unfeasible. Despite these constraints, lowlands - characterized by stony terrain, river bottoms, rocky outcrops, and irreparable salinity - can be irrigated under current and future conditions, as they are unsuitable for traditional agricultural purposes. Notably, the ecological potential map for pasture (Figure 7d) highlights the northern half of the province, particularly Taleghan city, and select areas in Eshtehard city as having the highest potential for pasture. Moreover, land erosion in specific central and western areas of the province has led to reduced vegetation growth and density, resulting in the establishment of weak pastures. Farazmand et al. (2019) identified high slopes and classified abilities as limiting factors for pasture in Firouzkoh city, Iran. Similarly, Rajabi et al. (2020) conducted a study to assess land suitability for pasture use. Their findings emphasized that climate and slope play pivotal roles in determining suitable locations for pasture improvement and development projects. Additionally, Piri Sahragard et al. (2018) highlighted the impact of soil salinity on the distribution of pasture species. The ecological potential map of the province reveals that the northern half of Taleghan city and select areas in the southern half of Eshtehard city are primarily suitable for pasture (class 1 and class 2). In terms of settlement and industry, lands in the western and southwestern parts of the province—particularly in Nazarabad and Eshtehard cities—exhibit favorable conditions. These lands feature low slopes, moderate altitudes, and a temperate climate. Notably, they are predominantly located in the central plains of the province, characterized by alluvial sediments with varying grain sizes. Remarkably, these plains harbor abundant underground water tables due to their high permeability. Moving toward the north, northeast, and west of the province, population density decreases due to challenging topographical conditions and limited accessibility. Taleghan city, in particular, exhibits limited suitability and ecological capacity for industrial and residential development. Parry et al. (2018) conducted a study examining the viability of settlements and found that as altitude increased, the ecological suitability of these settlements decreased due to steep slopes and inadequate facilities. Similarly, Rahman and Szabó (2022) identified environmental conditions as a critical factor influencing the suitability of residential and industrial areas. In Alborz province, the distribution of protected areas managed by the Environmental Protection Organization is uneven. Notably, Figure 7f on the map highlights a portion of the northern region of Karaj city falling within the central Alborz protected area. Additionally, other areas warrant special attention for conservation, inclu-

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ding the highlands in the northern part of the province, Taleghan highlands, and ecologically fragile lands in the southern half of the province. Luan et al. (2021) also found that mountainous areas with steep slopes exhibit moderate suitability for protection. To evaluate the ecological potential of Alborz province for diverse land uses - such as agriculture, gardening, pasture, residential and industrial development, and conservation - researchers employed a combination of AHP and GIS methods. Previous studies have also leveraged AHP to determine the weightage of influential factors across various fields, including land use suitability assessments. The systematic approach, logical underpinnings, and mathematical properties of AHP make it a favorable choice for evaluating land suitability. Assigning weights to each criterion is pivotal in determining suitability levels, as these weights signify the relative importance of criteria compared to others (Han et al., 2021; Pilevar et al., 2020; Ramamurthy et al., 2020; Seyedmohammadi et al., 2019; Tashayo et al., 2020). Notably, the citation by Morales and De Vries (2021) underscores that the significance of a measure in overall utility increases as its assigned weight grows. While the knowledge-based approach may exhibit some subjectivity compared to automatic or data-driven methods, it remains a common choice in land use planning studies. Additionally, recent research by Jamil et al. (2018), Roy and Saha (2018), and Tadesse and Negese (2020) has also utilized soil and topography climatic parameters to assess land suitability.

Land use planning

Land use planning entails assessing the ecological potential of various land functions and determining the optimal use for each area. Notably, some areas may exhibit potential for multiple uses, yet practical constraints often prevent simultaneous utilization for all purposes. In such scenarios, a judicious selection process becomes necessary to prioritize the most suitable land use. This process involves evaluating the ecological capacity of the land and planning accordingly. When creating an environmental assessment map, several factors come into play. For land units with significant capacity for irrigated agriculture, gardens, arboriculture, pasture, or conservation, priority is assigned based on the existing common use. For instance, if a parcel of land is currently utilized as pasture and exhibits a high ecological suitability score for pasture, regardless of its potential for other purposes, the priority remains maintaining it as pasture. However, when the current land use diverges from its assessed potential, priority shifts to the use that demonstrates the highest ecological potential. By adhering to these guidelines and tailoring them to the unique conditions of Alborz province, priorities among various land uses were established. Essential adjustments - such as level corrections, conflict resolution, and the removal of small polygons - were implemented to create the definitive environmental map for the province. This comprehensive approach ensures that land use planning is conducted efficiently and sustainably (see Figure 8).

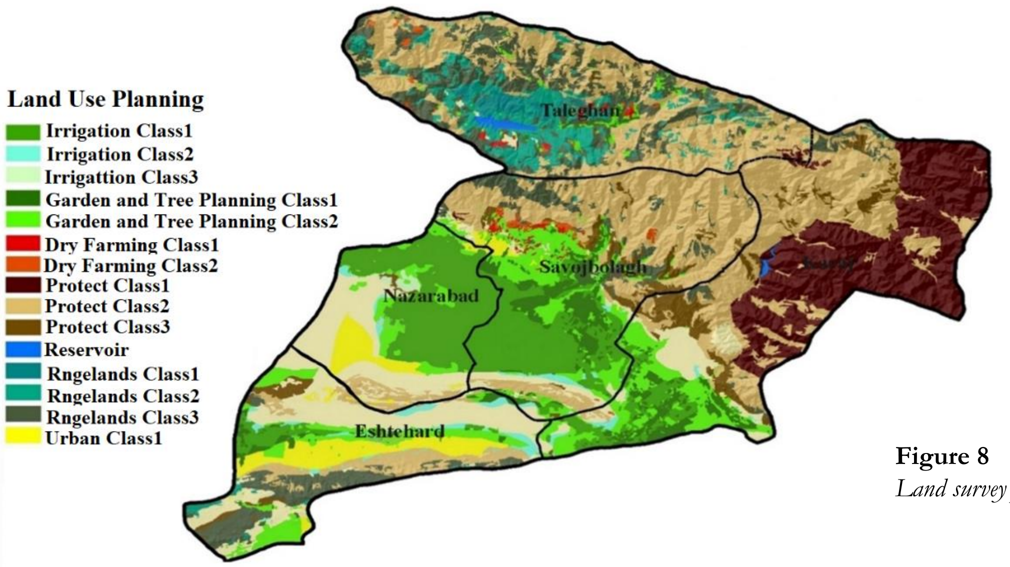

Figure 8
Land survey planning map of the studied area

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The distribution of land uses within Alborz province reveals notable patterns. Areas designated for protection, particularly those falling into class 1 to class 3 categories, occupy the largest share compared to other uses. This prevalence can be attributed to the rugged mountainous terrain and steep lands in the northern parts of the province, as well as the presence of ecologically sensitive areas with fragile ecological conditions in the south. Allocating approximately 44% of the province's area to conservation may initially seem excessive, but it is essential to consider the broader ecosystem perspective. Protecting these lands ensures the regulation of critical conditions that impact the optimal utilization of other areas. For instance, safeguarding these lands contributes to water flow regulation and provides essential water resources for drinking, industry, agriculture, and other needs in residential and industrial zones. Moreover, conservation efforts mitigate the pressures of drought, control floods and erosive flows, and prevent sediment transport to reservoirs behind dams. Beyond ecological benefits, conservation also enhances tourism potential and attractions, as recognized by the International Union for Conservation of Nature (IUCN) in 2018 (IUCN, 2018). Currently, approximately 12.5% of the study area's lands at altitudes exceeding 3,200 m are under protection due to their unique topography, climatic conditions, and the presence of plant species with special genetic diversity. Regarding wildlife, the southern Alborz region provides favorable habitats for various animal species due to its climatic diversity and distinctive ecological and topographical characterristics. Protecting these habitats is crucial for maintaining biodiversity and ecological balance. Notably, nearly half of Karaj city's area lies within the central Alborz protected zone, which holds exceptional environmental value and is unlikely to face encroachment. However, the northern parts of the city, along with a significant portion of these lands, require careful attention for protection. Conversely, the southern half of Karaj city faces environmental threats due to residential expansion amidst agricultural and garden lands. Taleghan city lacks capacity for irrigated agriculture but compensates with suitability for rainfed agriculture, gardens, arboriculture, and pastures. Among the province's cities, Saujblag stands out for its diverse ecological potential, particularly for irrigated agriculture. Nazar Abad city balances agricultural capacity with residential and industrial development, while Eshtehard city leans more toward housing and industrial growth, lacking agricultural potential. A distinctive feature of Alborz province is its substantial allocation of land for pasture and conservation purposes. In Alborz province, certain areas are well-suited for diverse agricultural activities, including irrigated and rainfed agriculture, gardens, and tree plantations. These areas collectively cover approximately 25% of the province's total land area, equivalent to 134,739 ha. This substantial coverage underscores the province's significant potential for

	Land use capability		Current land use	
Land Use	Area (ha)	Area (%)	Area (ha)	Area (%)
Irrigation Class1	56680	11		
Irrigation Class2	5987	1	57588.8	11.2
Irrigation Class3	954	0		
Garden and Tree Planning Class1	20330	4	33936.2	6.6
Garden and Tree Planning Class2	46400	9		
Dry Farming Class1	2024	0	8741.1	1.7
Dry Farming Class2	2363	0		
Rangelands Class1	3429	1		
Rangelands Class2	22017	4	317252.7	61.7
Rangelands Class3	53989	11		
Urban Class1	17486	3	17996.5	3.5
Urban Class2	53985	11		
Protect Class1	57416	11		
Protect Class2	151636	30	64149	12.47
Protect Class3	15760	3		
Reservoir	1348	0	1466	0.2
Others			14522	2.8

Table 9
Calculated Area for each land use in land use planning map and current land use.

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agricultural purposes stands at only 19.5%. In contrast, there exist sizable tracts—approximately 71,471 ha—that hold promise for residential and industrial development. Remarkably, this accounts for about 14% of the province's land area. Notably, this proportion exceeds the immediate requirements to meet the population's needs. Consequently, this situation presents a favorable opportunity for synergistic growth across both the industry and agriculture sectors within the province. By strategically harnessing these available lands, Alborz can achieve a balanced and sustainable development trajectory. For further details, refer to Table 9.

Conclusions

In this study, we aimed to assess the ecological potential of lands in Alborz province for various agricultural purposes, including irrigation, rainfed farming, gardening, arboriculture, as well as for pasture, residential, industrial, and protective uses. Our evaluation considered several critical criteria, such as topography (slope, slope direction, height), soil and land characteristics (land resources, land use capability classification), vegetation cover, erosion, climate, rainfall, and water availability. To determine the significance of each criterion, we employed the Analytical Hierarchy Process (AHP) method, which allowed us to assign appropriate weights. Notably, slope and land resources emerged as the most influential factors affecting the ecological capacity of the region across different land uses, including agriculture, residential zones, and industrial areas. Our land survey map revealed that a significant portion of the study area is suitable for protection purposes. Additionally, approximately 25% of the region exhibits agricultural potential, specifically for irrigated agriculture, gardens, and tree planting. However, we observed a discrepancy between the current land use and the land's potential. To address this, modifying the land use pattern based on the land use map becomes crucial to prevent further degradation and promote sustainable resource utilization.
Understanding the fundamental constraints is essential for enhancing productivity and building resilience against climate change and extreme weather events. Moreover, recognizing spatial variations in these constraints enables optimal resource allocation and targeted interventions. When resources are limited, focusing on high-risk areas with cost-effective measures can yield maximum benefits. Multi-Criteria Decision-Making (MCDM) methods, such as AHP, allow us to integrate expert opinions with factual information. By evaluating diverse criteria and considering conflicting outcomes, AHP ensures robust decision-making. Through pairwise comparisons of available options, this method minimizes the risk of overlooking the most suitable alternative, ultimately leading to optimal outcomes.

Conflict of interests

Authors disclose that there are no conflicts of interest to declare.

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