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A comparative analysis of three multi-criteria decision-making methods for land suitability assessment

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Abstract Natural resource management relies on identifying the ecological constraints, assessing land suitability, and considering the socio-economic demands in the region. However, in many developing countries, natural resources are extensively overused in favor of economic growth. This is due to the fact that conservation and natural constraints are not always taken into consideration during the planning phase, especially when the decision-making process is mainly influenced by political or economical views. To avoid these subjective plannings, environmental planners are encouraged to consider quantitative planning approaches that can integrate environmental, social, economic, and political matters through a non-bias procedure. The present study, therefore, examines the application of three multi-criteria decision-making methods (MCDM), namely, analytic hierarchical process (AHP), fuzzy analytic hierarchical process (fuzzy AHP), and technique for order of preference by similarity to ideal solution (TOPSIS), for the assessment of land suitability afforestation. Siahpoosh Watershed, in Iran, is used as a case study to compare three MCDM methods. To achieve this, a set of land suitability criteria (i.e., slope, elevation, aspect, soil texture, soil depth, drainage, erosion, temperature, rainfall, and vegetation type and cover) was defined and weighted using the AHP and fuzzy AHP methods. TOPSIS was then used to prioritize and rank the suitability of different sections of the study area for afforestation. The study demonstrates that the fuzzy AHP method combined with TOPSIS generates more reliable outcomes than the AHP method. The results could be useful for making more informed decisions about afforestation in the region.

Keywords Afforestation · AHP · Fuzzy AHP · Buckley method · Multi-criteria decision-making · Siahpoosh Watershed · TOPSIS

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Introduction

Land suitability analysis not only optimizes the use of land but also preserves natural resources for future generations. In recent decades, appropriate and comprehensive environmental planning has been designed based on identifying potentials and assessing land suitability. Comprehensive consideration of ecological capability can reduce the risk of conflicting natural and socio-economic interests and lead to sustainable development (Majnoniyan, 2000). Forest ecosystems, which have been significantly impacted by human activities, play an important and effective role in balancing land use (He et al., 2021). In many developing countries, extensive use of forests due to grazing, preparing firewood, and converting forest lands to agriculture has led to vast deforestation (Doggart et al., 2020; Paul & Banerjee, 2021).

This has led to afforestation planning by government and non-governmental organizations in response to the increasing demand for wood and wood fibers as well as to prevent further deforestation (Mohammadi et al., 2015; Zhao et al., 2021). Afforestation will also improve the hydrological performance of degraded forests and their surrounding areas. On the other hand, the employment of rural people in afforestation activities can improve the living standards of local communities and lead to sustainable development. Therefore, afforestation planning requires considerable attention to all the ecological and socio-economic characteristics of the region and inappropriate decision-making and planning can cause ecosystem instability and social conflicts (Mohammadi et al., 2015; Gholizadeh et al., 2020; Chen et al., 2021). In other words, afforestation planning without an in-depth consideration of ecological capabilities not only does not improve the environmental situation in the region, but also leads to more environmental degradation. Ignorance of ecological conditions and habitat characteristics in the past has led to failure and the unsustainability of afforestation. For instance, the quantitative and qualitative examinations of the afforestation with Cypress (*Cupressus sempervirens* var. horizontalis) in the eastern part of Mazandaran province, Iran, concluded that this afforestation has not been successful due to the lack of attention to habitat characteristics and planting in wet slopes and severe cold weather condition (Kiasari et al., 2010). Afforestation in Chah Afzal, Ardakan County, Yazd province, Iran, is another unsuccessful example due to the high salinity of soil and cold climate of the region (Amiraslani & Dragovich, 2011). To avoid similar scenarios, planners are encouraged to use new approaches such as multi-criteria decision-making techniques that can incorporate heterogeneous data and variables to make more informed and less subjective decisions (Greene et al., 2010).

Multi-criteria decision-making (MCDM) techniques can integrate diverse opinions and handle large amounts of complex information in the decision-making process (Liu et al., 2022a, b). Therefore, the practical application of MCDM techniques has become more common in land suitability studies in Iran such as afforestation planning (e.g., Hajjarian et al., 2016; Mohammadi & Limaei, 2018; Szulecka & Zalazar, 2017). The AHP (analytic hierarchical process) is one of the most common MCDM methods. This method, in combination with geographic information systems (GIS), is widely used to determine the relative weight of decision criteria and to assess ecological capabilities in land suitability and natural resource management (Malczewski, 2004; Ownegh et al., 2006). For example, Alemi et al. (2014) used AHP to identify the suitable area for afforestation of endangered species of yew (*Taxus baccata*) in Pooneh Aram reserve, Golestan province, Iran. Hashemi et al. (2014) used AHP to assess afforestation in Darab Kola, Miandorud County, Mazandaran province, Iran. Gholizadeh et al. (2020) also examined the AHP method to assess two afforestation plans with *Quercus robur* and *Pinus sylvestris* in northeastern Iran.

The fuzzy analytic hierarchical process (FAHP) and technique for order of preference by similarity to ideal solution (TOPSIS) are the other two common MCDM methods. FAHP method was derived from the AHP method and uses fuzzy numbers instead of absolute values. This method aims to overcome ambiguity and reduce uncertainty in the decision-making process. The TOPSIS method is based on the distance measure and was developed by Hwang and Yoon (1981). This method has less sensitivity to weighting the criteria (Malczewski, 1999) and chooses the option with the shortest geometric distance from the positive ideal solution and the longest geometric distance from the negative ideal solution (Mafi-Gholami et al., 2019, 2020).

Few studies in Iran have implemented the use of fuzzy AHP and TOPSIS in afforestation and foresty planning (e.g., Fazlollahi Mohammadi et al., 2014; Rahdari et al., 2019; Vatani et al., 2019). However, comparative analysis of the use of different MCDM methods in the field of afforestation in Iran is rare. The present study, therefore, uses a case study to compare the outcomes of AHP, fuzzy AHP, and TOPSIS in afforestation planning for the Siahpoosh Watershed, located in Ardabil province, Iran.

Materials and methods

Study area

Siahpoosh Watershed is located in the southern part of the city of Koraim, one of the southern cities of

Nir city, Ardabil province, Iran (Fig. 1). The main access route to the watershed is through the Ardabil to Koraim main road, which leads to the watershed by passing through the city of Kuraim through the Khademloo side road. This region is located between 46° 06′ 35"–48°16′ 46" E longitude and 37° 46′ 37"–37° 54′ 37" N latitude with the total area of 10,103.4 ha.

This region is a semi-arid and cold area with the average annual temperature of 7.05 °C and 339.1 mm average of precipitation. The slope of terrain in this area varies between 0 and above 60%. The main soil textures observed in the region are sandy-loamy, loamy, clay, clay-sandy, clay-silty, and sandy-loamy-clay textures, and soil depth varies from very shallow to semi-deep.

Methods

The land suitability criteria used in this study were selected based on a comprehensive literature review of previous studies and an analysis of the regional characteristics (Szulecka & Zalazar, 2017; Zhang

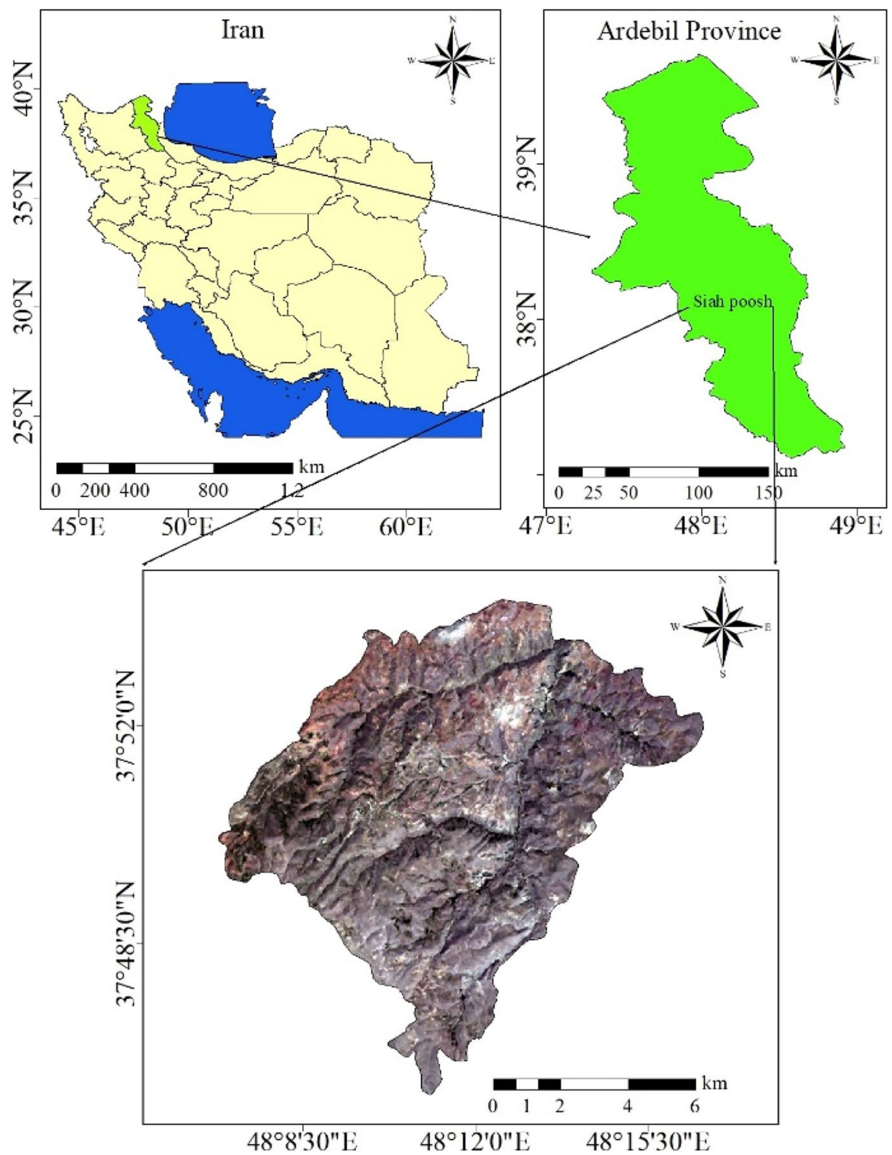

Fig. 1 Geographical location of Siahpoosh Watershed, Ardabil province, Iran

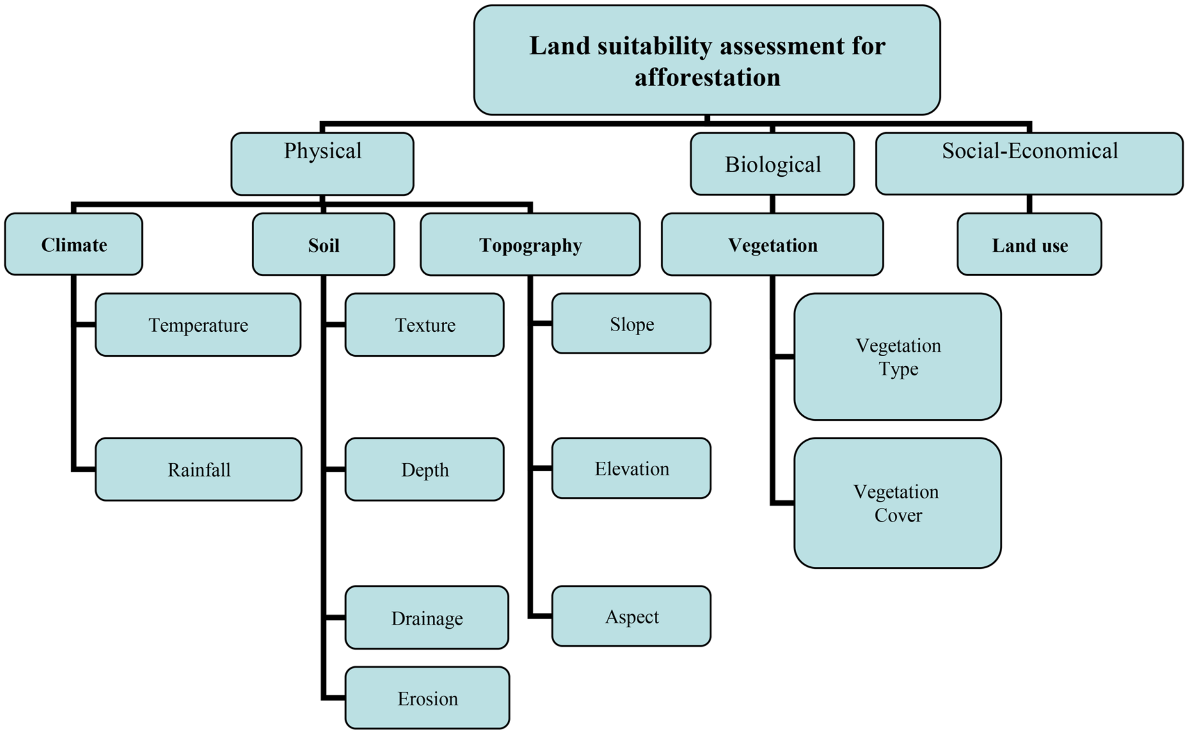

Fig. 2 The flowchart of study

et al., 2019a, b; Rahdari et al., 2019; Liu et al., 2020; Xie et al., 2021; Quan et al., 2022). The suitability criteria were identified at three levels (i.e., main criteria and two sets of sub-criteria). The first level of this structure indicates the aim, which is the ecological capability assessment for afforestation in the study area. At the second level, the effective criteria for afforestation are presented, and the 2nd and 3rd sub-criteria (Fig. 2). These include physical and environmental factors such as the slope, aspect direction, elevation height, temperature, rainfall, soil texture, drainage, depth, erosion and vegetation cover, vegetation type, and vegetation density.

In the next step, the suitability criteria were ranked by a panel of experts and the relative importance of each criterion was calculated using the AHP, FAHP, and TOPSIS methods. Finally, the suitable areas for afforestation were identified using the WLC equation ($LS = \sum_{i=1}^{n} \mathrm{Wi}$). In this formula, *LS* is the suitability for particular land-use, *n* is the number of evaluated criteria, and *Wi* is the weight of each criterion.

AHP method

In the AHP method, the panel of experts is asked to rank the criteria and sub-criteria by referring to the numerical scale of 1–9, with a score of 1 representing indifference between the two criteria and 9 representing absolute importance (Saaty, 1980).

In this study, the data for pairwise comparisons were then analyzed using the EXPERT CHOICE software based on AHP algorithms to obtain the final ranking for each criterion as per the following steps:

1. Preference judgment (pairwise comparisons)

The respondent measures the relative importance or priority of each criterion by making two-way comparisons between the decision elements and by assigning numerical scores indicating the priority or importance between the two decision elements (Ülengin et al., 2001).

2. Weighting the criteria and calculating their relative weight

Relative weights are then calculated by the arithmetic mean method, in which the scores of each column in the paired matrix comparison are summed and then each score of the column is divided by the sum of the scores of that column (Eq. (1)). The resulting matrix is the "normalized comparison matrix."

$$\overline{a}_{jk} = \frac{a_{jk}}{\sum_{l=1}^{m} a_{lk}} \tag{1}$$

where a_{jk}: score of the column, $\sum_{l=1}^{m} a_{lk}$: the sum of the scores of that column, and $\overline{a}_{jk}$: normalized comparison matrix.

3. Average relative weight

The scores of each row in the "normalized comparisons matrix" are averaged (Eq. (2)), and this mean represents the relative weight of the decision elements in the rows of the matrix.

$$w_j = \frac{\sum_{l=1}^{m} \overline{a}_{jl}}{m} \tag{2}$$

where $\frac{\sum_{l=1}^{m} \overline{a}_{jl}}{m}$: mean row, and w_j: relative weight.

4. Calculating the final weight

The final weight is obtained by multiplying the relative weight of each element by the weight of the higher elements (Eq. (3)).

$$v = \mathrm{S.w} \tag{3}$$

where S: the weight of the higher elements, w: the relative weight of each element, and v: the final weight.

5. Calculation of consistency

The consistency ratio (CR) shows the consistency of comparisons and indicates the level of correctness of priorities resulting from group members or their combination. This index is measured using Eqs. (4) and (5).

$$\mathrm{CI} = \frac{\lambda_{max} - n}{n - 1} \tag{4}$$

where CI: consistency index, λ_{max}: the principal eigenvalue of the judgment matrix, and n: matrix measure.

Table 2 Triangular fuzzy number (Lin, 2010)

Fuzzy numbers	Linguistic variables	Triangular fuzzy numbers (l, u, m)
1	Equally important	(1, 1, 1)
2	Intermediate	(1, 2, 3)
3	Weakly more important	(2, 3, 4)
4	Intermediate	(3, 4, 5)
5	Strongly more important	(4, 5, 6)
6	Intermediate	(5, 6, 7)
7	Very strongly more important	(5, 7, 8)
8	Intermediate	(7, 8, 9)
9	Absolutely more important	(9, 9, 9)

$$CR = \frac{CI}{RI} \tag{5}$$

where CR: consistency ratio, CI: consistency index, and RI: the random consistency index (see Table 1).

Finally, the potential areas for afforestation were identified and classified using the WLC method and obtained coefficients from the information layers.

FAHP method

The FAHP is a systematic method that uses fuzzy set theory and hierarchical structure analysis. Its graph and paired matrix comparison in the fuzzy form are similar to the non-fuzzy form. However, comparisons were carried out using the fuzzy method (Table 2) and weights were calculated by the improved fuzzy AHP (Buckley technique) (Buckley, 1985).

To create a fuzzy layer, the raster layers were first standardized in the IDRISI operating environment using membership functions (user-defined, decremental line, incremental line, and decremental S-shape) and were converted to values (0, 1) in the raster format, in which 0 and 1 indicate the most and least priority, respectively (Table 3). Then, the standardized layers were multiplied by each of the relative weights obtained by Buckley's (improved fuzzy) method and turned into fuzzy weighted layers.

The steps of Buckley's fuzzy method are as follows:

Table 1 Random consistency index

N	1	2	3	4	5	6	7	8	9	10
RI	0	0	0.58	0.9	1.12	1.24	1.32	1.41	1.45	1.51

Table 3 The function used for criteria fuzzification

Row	Criteria	Fuzzification function	Value of fuzzification function								
			a			b		c		d	
1	Elevation	Decrease linear						1600–1800 1		> 2400 0	
2	Slope	Decrease linear						0–5 1		> 30 0	
3	Rainfall	Increase linear	> 350 0			375–400 1					
4	Vegetation cover	Increase sigmoidal	0% 0			40–60% 1					
5	Drainage	User defined	Poor 0.5			Medium 1					
6	Erosion	User defined	Erodible 0.25			Loose and sensitive to erosion0.5		Medium 0.75		Resistant 1	
7	Temperature	User defined	8.5–10.5 0.5			10.5–12 1					
8	Land use	User defined	Agriculture 0			Rangeland 1					
9	Depth	User defined	Very shallow to shallow 0.5			Shallow to semi-deep 1					
10	Soil texture	User defined	Loamy clay-Loamy sandy 0.34			Loamy clay-loamy sandy clay 0.34		Loamy clay 0.34	Loamy-loamy sandy 0.67	Loamy clay-Loamy 1	
11	Aspect	User defined	S 0.16	SW 0.3	SE 0.44	W 0.44	E 0.58	NW 0.72	NE 0.86	N 0.86	F 1
12	Vegetation type	User defined	Astragalus 0	Festuca-astragalus 0.2	Festuca-Onabrychis-Agropyron 0.36	Festuca-Onabrychis-Astragalus 0.52	Astragalus-Festuca-Stipa 0.68	Astragalus-Festuca-Bromus 0.68	Astragalus-Hordeum-Bromus 0.84	Astragalus-Artemisia-Stipa 1	

The User Defined fuzzification functions do not belong to the a-d categories

1. Fuzzification (triangular): To evaluate the importance of criteria, real scalar values are converted into a triangular fuzzy value with 3 elements whose membership function is shown in Eq. (6). In this model, the value of the membership function is 1 for (m) (Kaufmann & Gupta, 1991).

$$\text{A triangular fuzzy number } \widetilde{T} = (l, m, u): \quad \text{where: } \mu_{\widetilde{T}}(X) = \begin{cases} \frac{x-l}{m-l}.\ l \le x \le m \\ \frac{u-x}{u-m}.\ m \le x \le u \\ 0.\ otherwise \end{cases} \tag{6}$$

Algebraic operations on fuzzy numbers are similar to those on real numbers. Equation (7) shows these calculations, including the addition and multiplication of two fuzzy numbers.

$$\begin{aligned} \widetilde{T}_1 \oplus \widetilde{T}_2 &= \left(l_1 + l_2.m_1 + m_2.u_1 + u_2\right) \text{ where : } T_1 = \left(l_1.m_1.u_1\right) \text{ : a triangular fuzzy number.} \\ \widetilde{T}_1 \otimes \widetilde{T}_2 &\cong \left(l_1 \times l_{2.}m_1 \times m_{2.}u_1 \times u_2\right) \text{ where : } T_2 = \left(l_2.m_2.u_2\right) \text{ : a triangular fuzzy number.} \end{aligned} \tag{7}$$

2. The geometric mean of rows: it is calculated using Eq. (8). This step is the first step of the improved fuzzy AHP method, in which the geometric mean of the rows should be calculated based on the following equation. The geometric mean of the first, second, and third elements is considered because the numbers in each row are fuzzy.

$$\widetilde{r}_i = \left(\prod_{j=1}^{n} \widetilde{t}_{ij}\right)^{1/n} \tag{8}$$

where $\tilde{t}_{ij}$: fuzzy weight criterion$i$ from expert n, and $\tilde{r}_i$: geometric mean of rows.

3. Multiplying the geometric mean of the rows by the inverse of the sum of the geometric mean: First, the geometric mean calculated in the previous step is summed, and then each geometric mean is multiplied by the inverse of this sum (Eq. (9)).

$$w_i = r_i \otimes \left(r_1 \oplus r_2 \oplus \cdots \oplus r_m\right)^{-1} \tag{9}$$

where $\tilde{r}_i$: geometric mean of the rows, and w_i: multiplying the geometric mean of the rows by the inverse of the sum of the geometric mean.

4. Defuzzification of weighted fuzzy mean: Eq. (10) was used for the defuzzification of the weighted fuzzy mean obtained in the previous step.

$$w_{crisp} = \frac{l + 2m + u}{4} \tag{10}$$

where (l, m, u): a triangular fuzzy number, and w_{crisp}: weights defuzzed.

5. Normalizing the weight of the criteria by the linear normalization method: Each weight defuzzed in the previous step is divided by the sum of the weights to obtain the normalized weight (Eq. (11)).

$$\tilde{r}_{ij=\tilde{w}_i=} \frac{z_i}{\sum_{i=1}^{n} \tilde{z}_i} \tag{11}$$

where z_i: weights defuzzed, $\sum_{i=1}^{n} \tilde{z}_i$: sum of the weights, and $\tilde{r}_{ij=\tilde{w}_i}$: normalizing the weight.

6. The final weight of each sub-criterion is determined by Eq. (12).

$$u_{i=} \sum_{j=1}^{n} w_j r_{ij} \tag{12}$$

where w_j: weight of each sub-criterion, r_{ij}: normalizing the weight of the sub-criteria, and u_i: final weight of sub-criterion.

7. Then, the layers were overlapped using the WLC method and acquired coefficients to obtain the final map.

TOPSIS method

TOPSIS is used to prioritize options based on their similarities to the ideal solution. The prioritized option should have the shortest distance from the ideal solution and the farthest distance from the anti ideal solution. This method is a suitable compensatory multi-criteria decision-making technique for prioritizing options based on the similarity to the ideal solution and has very little sensitivity to weighting. The selected option has the shortest distance from the ideal solution and the farthest distance from the anti ideal solution. The fuzzy hierarchical analysis was used to extract pairwise comparisons between criteria, sub-criteria, and relative weights. The final ordering of the options was obtained using the TOPSIS technique in Excel. The final map was obtained after overlapping layers using the WLC method.

The steps are carried out as the following:

1. Creating a data matrix based on n indices and m options (Eq. (13)).

$$X_1\ X_2\ \dots\ X_n$$

$$\mathrm{X} = \begin{matrix} A_1 \\ A_2 \\ \cdot \\ \cdot \\ \cdot \\ A_m \end{matrix} \begin{bmatrix} X_{11} & X_{12} & \dots & X_{1n} \\ X_{21} & X_{22} & \dots & X_{2n} \\ \cdot & \cdot & & \cdot \\ \cdot & \cdot & & \cdot \\ \cdot & \cdot & & \cdot \\ X_{m1} & X_{m2} & & X_{mn} \end{bmatrix} \quad (13)$$

where A_I: m options, and X_{IJ}: the numerical value obtained from options i relative to the indices j.

2. Non-scaling the decision matrix (normalizing the decision matrix) is done through Eq. (14).

$$r_{ij} = \frac{x_{ij}}{\sqrt{\sum_{i=1}^{m} x_{ij}^2}} \quad (14)$$

where x_{ij}: the numerical value obtained from options i relative to the indices j, $\sqrt{\sum_{i=1}^{m} x_{ij}^2}$: the square root of the squares is the numerical value obtained from options i relative to the indices j, and r_{ij}: normalized matrix.

3. Weighting each criterion: the sum of weights (W) obtained in Eq. (15) is multiplied by the normalized matrix (r_{ij}).

$$W = \left(w_1, w_2. \dots .w_j. \dots .w_n\right) \quad (15)$$

where $\sum_{j=1}^{n} w_j = 1$

4. Determining the distance of option (i) from the ideal point (highest performance of each criterion) (Eq. (16)).

$$d_i^+ = \sqrt{\sum_{j=1}^{n} \left(v_{ij} - v_j^+\right)^2} \quad (16)$$

where v_{ij}: numeric value of option, v_j^+: positive idea, d_i^+: distance from the positive idea.

5. Determining the distance of the option (i) from the anti ideal point (lowest performance of each criterion) (Eq. (17)).

$$d_i^- = \sqrt{\sum_{j=1}^{n} \left(v_{ij} - v_j^-\right)^2} \quad (17)$$

where v_{ij}: numeric value of option, v_j^-: negative idea, d_i^-: distance from the negative idea.

6. Developing a distance measure over each criterion to both ideal point (Ai^+) and nadir point (Ai^-) (calculating the similarity index) and prioritizing the options: This index represents the score of each option which is equal to Ai^- divided by the total distance of Ai^- and Ai^+ (denoted by Ci^*) (Eq. (18)).

$$c_{i*} = \frac{d_i^-}{d_i^+ + d_i^-} \quad (18)$$

where d_i^-: distance from the negative idea, d_i^+: distance from the positive ideal, c_{i*}: similarity index.

Results

As discussed previously, Buckley's AHP and FAHP methods were used to weigh the land suitability criteria defined in this research. Fifteen questionnaires were prepared and sent to experts to perform pairwise comparisons. The weight of each sub-criteria was calculated using AHP and FAHP methods for forestry suitability evaluation (Table 4). As shown in Table 4, the highest and lowest weight is assigned to the rainfall and the erosion criteria, respectively. The consistency ratio is less than 0.1, confirming the accuracy of this step. In the FAHP method, the inconsistency rate is also lower than 0.1, indicating the consistency of the fuzzy pairwise comparison matrix. After measuring the final weights of each layer, the spatial database of the study area was formed in the ArcGIS 10.3 software and the layers were overlapped using the WLC method.

The final map of land suitability for afforestation in the region was prepared. The results of the AHP method showed that about 65.7% of the area (about 6639 ha) was medium suitable, and 20.6% (about 2084 ha) was low suitable and very low suitable (Fig. 3 and Table 5).

Table 4 Weight of each sub-criteria using the AHP and FAHP (Buckley) method

Criteria	Slope	Elevation	Aspect	Soil texture	Depth	Drainage	Erosion	Temperature	Rainfall	Vegetation type	Vegetation cover
AHP weight	0.387	0.433	0.169	0.368	0.282	0.2	0.15	0.25	0.75	0.5	0.5
FAHP weight	0.381	0.437	0.181	0.365	0.275	0.202	0.157	0.255	0.744	0.407	0.592

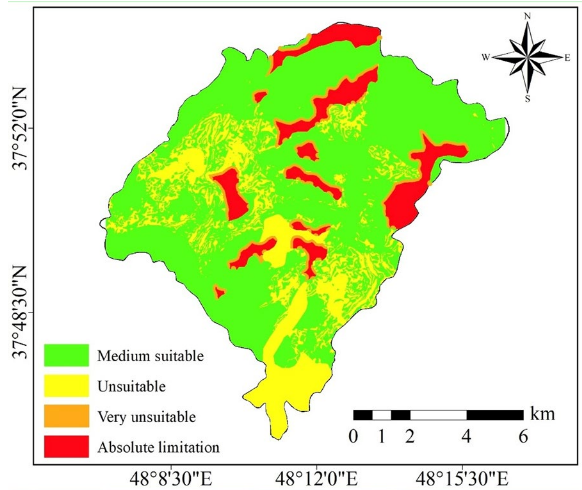

Fig. 3 Final map of afforestation with AHP method

In the results of Buckley's FAHP method (Fig. 4), about 39.2% of the study area (3973.5 ha) was very suitable. Moreover, 0.14% of the area (15 ha) was unsuitable and very unsuitable, 38% (39.2 ha) was suitable, and 8.8% (893.5 ha) was medium suitable (Fig. 4 and Table 6).

Table 6 shows the comparison of the area and its percentage in the two methods.

The final maps prepared by these two methods were examined using ecological criteria, Google earth images, and field observations. The results showed that the map prepared by the FAHP method is more realistic and consequently was used as the basis of the TOPSIS method.

TOPSIS method

After determining areas with high suitability for afforestation, it is necessary to determine the priority of options. Although there are various methods and techniques for the MCDM, the TOPSIS method is less sensitive than the weighting method (Malczewski, 1999). Therefore, the TOPSIS method was used to rank the options (117 polygon areas) selected by the FAHP method. It is necessary to use weights obtained from FAHP to make the calculations. After creating the matrix and entering the homogenous data in Excel software, the results of the weights with homogenous units were obtained shown in Fig. 5 and Table 6.

Table 5 Area of different classes in the two AHP and FAHP methods

Method/class		Very suitable	Suitable	Medium suitable	Low	Very low	Absolute limitation
AHP	Area (hectare)	-	-	6639	2075.5	8.5	1347.5
	Area (%)	-	-	65.7	20.5	0.08	13.3
FAHP	Area (hectare)	3973.5	3859	893.5	15	15	1350
	Area (%)	39.2	38	8.8	0.14	0.14	13.3

According to Table 6, polygon areas with No. 267, 268, 269, 270, 249, 244, 245, 246, 247, 248, 300, 301, 296, 219, 294, 295, 297, 220, 263, 264, 265, 262, 266, and 185 (647 ha) are the best area for afforestation (Table 7).

Figure 6 shows the area with high suitability (in 5 priorities) in an implementation plan for afforestation.

Discussion

The land suitability criteria used in this study were defined based on a comprehensive review of previous studies reported in the literature. Ecological criteria including slope, aspect, altitude, soil (depth, texture, and drainage), climate, vegetation (type), and land use were used to assess and classify the study area for afforestation (Babaei, 2006). Hosseinzadeh (2007) used slope, aspect, altitude, soil (depth, texture), geology, climate, and vegetation (type) to assess ecological capability in the Galanderoud 48 (Kodir Sar, Nur County, Mazandaran Province, Iran). Loi and Tuan (2008) used slope, aspect, altitude, soil suitability, climate, and vegetation (type) within a GIS to perform the land suitability assessment in the forest of Tatin, Vietnam. Slope, aspect, altitude, soil (depth, texture, and erosion), and climate were used for the ecological capability assessment of afforestation (Shamseh, 2010). Slope, aspect, altitude, soil (depth, texture, drainage, PH, EC, OM, and $Caco_3$), climate, and vegetation (type) were used in a GIS to assess the land suitability for afforestation (Dengiz et al., 2010). Rahimizadeh et al. (2012) determined suitable species for afforestation in the southern part of the Alborz mountains based on aspect, altitude, soil (texture and drainage), and climate. Zare et al. (2011) used slope, aspect, altitude, soil (depth, texture, and drainage), and climate. Moradzadeh et al. (2011) assessed the ecological capability for afforestation using slope, aspect, altitude, and soil (depth, texture, organic matter, and erosion) in the Dadabad watershed forest, Lorestan province, Iran.

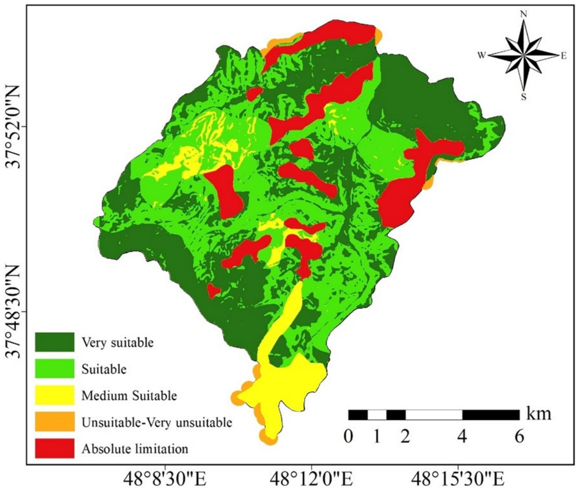

Fig. 4 Final map of afforestation with FAHP method

Figure 2 lists criteria used in this study, which include physical, biological, and socio-economical factors such as the slope, aspect, altitude, soil (depth, texture, drainage, and erosion), climate, vegetation (type and cover), and land use. Based on the literature review, in this study, a comprehensive set of criteria was used to assess the land suitability. The land cover map, which has been used in few studies (Babaei, 2006), was incorporated into the analysis. This criterion is very important because it determines the socio-economic restriction of the region for afforestation.

Previous studies showed that the use of AHP and FAHP is the most straightforward approach for either land suitability or land vulnerability assessments. Amiri et al. (2009) assessed the ecological capability for forestry use in the northern part of Iran. After

Table 6 Rank of the polygon for afforestation

Polygon	267	268	269	270	249	244	245	246	247	248	300
Rank	1	2	2	3	4	5	6	6	7	8	9
Similarity index	0.6132	0.6020	0.6020	0.5991	0.5873	0.5844	0.5743	0.5743	0.5713	0.5676	0.5575
Polygon	301	296	219	294	295	297	220	263	264	265	262
Rank	10	11	12	13	14	15	16	17	18	19	20
Similarity index	0.5485	0.5443	0.5431	0.5409	0.5378	0.5348	0.5344	0.4980	0.4773	0.4728	0.4685
Polygon	266	185	243	238	187	237	242	214	239	241	261
Rank	21	22	23	24	25	26	27	28	29	30	31
Similarity index	0.4643	0.4536	0.4454	0.4394	0.4342	0.4314	0.4270	0.4246	0.4232	0.4198	0.4193
Polygon	299	240	260	215	298	213	218	211	216	256	221
Rank	32	33	34	35	36	37	38	39	40	41	42
Similarity index	0.4190	0.4180	0.4164	0.4147	0.4123	0.4105	0.4066	0.4054	0.4036	0.4004	0.4000
Polygon	217	186	207	208	288	292	289	236	206	290	235
Rank	43	44	45	45	46	47	48	49	50	51	52
Similarity index	0.3987	0.3975	0.3971	0.3971	0.3969	0.3949	0.3919	0.3888	0.3871	0.3863	0.3859
Polygon	287	190	279	258	259	233	293	284	210	273	209
Rank	53	54	55	56	56	57	58	59	60	61	62
Similarity index	0.3813	0.38024	0.38023	0.3798	0.3798	0.3797	0.3769	0.37679	0.37678	0.37676	0.3748
Polygon	196	291	227	212	286	251	252	201	285	283	253
Rank	63	64	65	66	67	68	68	69	70	71	72
Similarity index	0.3711	0.3705	0.3702	0.3656	0.3643	0.3637	0.3637	0.3631	0.3156	0.3594	0.3589
Polygon	188	250	255	257	277	254	230	231	194	232	222
Rank	73	74	75	75	76	77	78	78	79	80	81
Similarity index	0.3586	0.3546	0.3510	0.3510	0.3465	0.3460	0.3437	0.3437	0.3423	0.3337	0.3275
Polygon	224	226	225	223	272	281	274	189	203	280	276
Rank	82	83	84	85	86	87	88	89	90	91	92
Similarity index	0.3216	0.3124	0.3071	0.3026	0.3005	0.3004	0.2940	0.2927	0.2918	0.2854	0.2839
Polygon	278	228	275	204	234	199	198	193	195	205	192
Rank	92	93	94	95	96	97	98	99	99	100	101
Similarity index	0.2839	0.2810	0.27866	0.2786	0.2773	0.2770	0.2769	0.2761	0.2761	0.2753	0.2709
Polygon	229	202	271	197	200	282	191				
Rank	102	103	104	105	106	107	108				
Similarity index	0.2557	0.2524	0.2358	0.2138	0.1994	0.1952	0.1697				

determining the ecological parameters, the fuzzification of effective criteria in forestry use was carried out using linear and nonlinear membership functions. Then, these criteria were weighted by the AHP method and the final map was prepared in GIS. They concluded that the weighting and fuzzification of criteria using the MCDM methods have an important role in the land suitability assessment. In another study, Amir Amadi and Mozaffari (2012) analyzed appropriate zones for ecotourism development using GIS-based techniques that prepared the required information layers and then overlapped them using the AHP weights. Greene et al. (2010) and Phua and Minowa (2005) have also used a combination of MCDM and GIS for forestry. The WLC method enables decision-makers to involve more important factors in the land suitability assessment, and the results are more accurate and reliable compared to its other spectra, confirmed by other studies (Malik & Bhat, 2015). The WLC method has been used to produce a land capability map for forestry in the Behbahan suburb) Rahimi et al., 2015) and a suitable place for establishing a forest park in the Badreh county of the Ilam province (Piran et al., 2013).

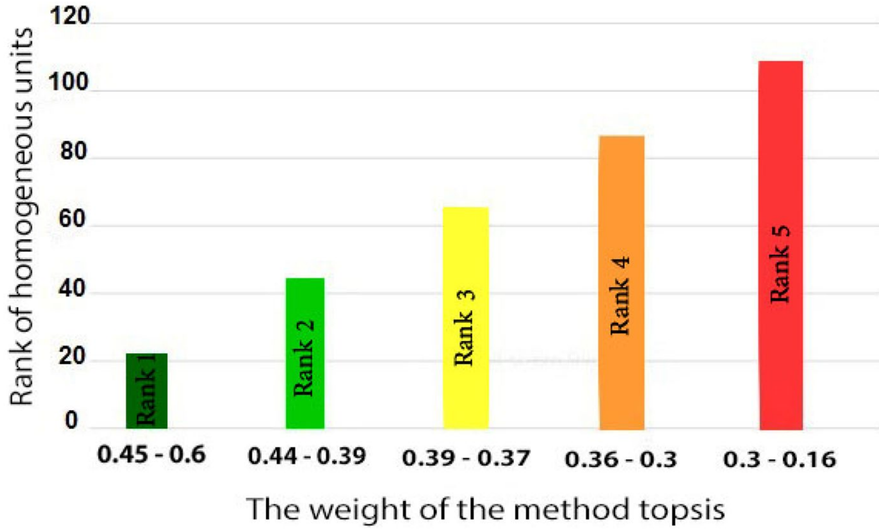

Fig. 5 Results of the TOPSIS method rank the options for afforestation

Table 7 The suitable areas for afforestation

Priority	1	2	3	4	5
Area	647	627.16	945	922	850.8
(%)	6.3	6.1	9.3	9.1	8.4

This study demonstrated that the results of the FAHP were closer to the reality and the ecological condition of the region, which support the findings in some of the previous studies. For example, Chan and Kumar (2007), Hamzeh et al. (2014), and Rezaei and Jamshidi Zanjani (2017) also reported that the FAHP method produced more accurate and reliable results in land suitability analysis.

This study went one step further in using a triangular improved fuzzy method (Buckley) to perform FAHP. Buckley's method is known to overcome some of the limitations in commonly used Chang's fuzzy model. The TOPSIS method was then used to rank the priority of the suitable areas determined by the FAHP method, as suggested in previous studies (e.g., Chu, 2002; Alavi & Alinejad-Rokny, 2011; Fazlollahi Mohammadi et al., 2014; Patawaran et al., 2019; Sabir et al., 2020). According to the results, the western portions of the study area

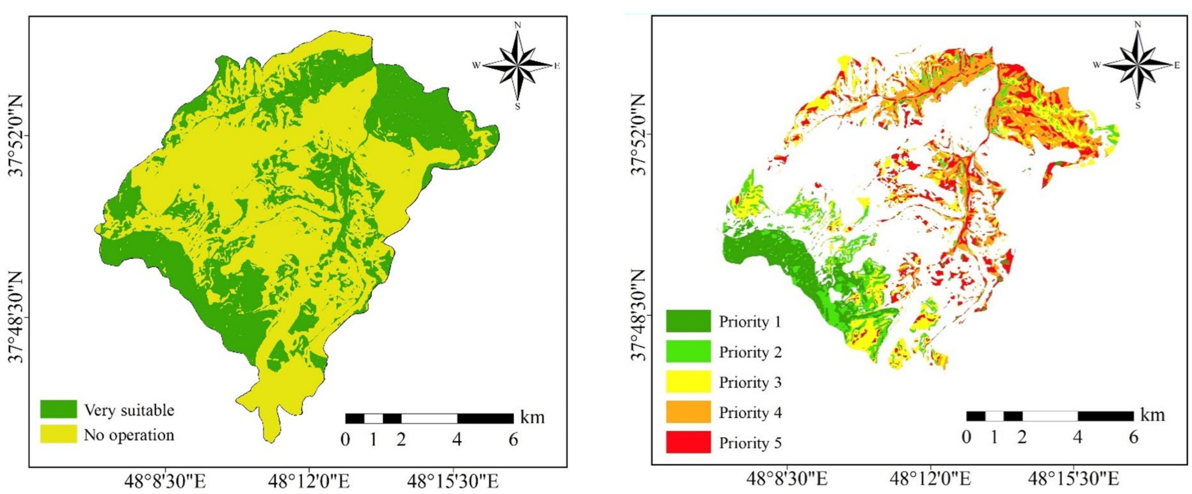

Fig. 6 Priority map of the most suitable polygons for afforestation

were identified as the most suitable for afforestation, whereas the eastern, northern, and eastern north portions ranked as the least priority.

Conclusions

The natural environment has a specific potential for human use. Thus, the ecological capability assessment should be carried out with principled planning before land use planning. In this study, three MCDM methods, namely, AHP, FAHP, and TOPSIS, were used to identify the most suitable areas for afforestation. This study combined the results of FAHP and TOPSIS within a GIS environment to locate suitable locations for afforestation and demonstrated that the MCDM techniques can be a great help in ranking the best available solutions. Therefore, afforestation projects informed by MCDM will make afforestation more efficient. In future research, the utility of other MCDM methods (e.g., ANP, SAW, PROMETHEE, and ELECTRE) can be compared to provide better insights for method selection.

Author contribution All authors of the paper have actively contributed to the scientific study reported in the paper and to the preparation of the manuscript.

Data availability The authors confirm that the data supporting the findings of this study are available within the article.

Declarations

Conflict of interest The authors declare no competing interests.

References

Alavi, I., & Alinejad-Rokny, H. (2011). Comparison of Fuzzy AHP and Fuzzy TOPSIS methods for plant species selection (case study: Reclamation plan of sungun Copper Mine; Iran). *Australian Journal of Basic and Applied Sciences, 5*(12), 1104–1113.

Alemi, A., Eslami, A., & Shataee Joibari, S. (2014). Investigation on development potential of endangered species of Taxus baccata at Golestan province, based on GIS technology (case study: Pooneh Aram reserve). *Iranian Journal of Forest and Poplar Research, 21*(4), 678–689. https://doi.org/10.22092/IJFPR.2014.5141

Amir Amadi, A., & Mozaffari, H. (2012). Analysis of appropriate zones for ecotourism development in Zanjan province using GIS. *Geographical Researches Quarterly Journal, 27*(3), 135–150.

Amiraslani, F., & Dragovich, D. (2011). Combating desertification in Iran over the last 50 years: An overview of changing approaches. *Journal of Environmental Management, 92*(1), 1–13. https://doi.org/10.1016/j.jenvman.2010.08.012

Amiri, M. J., Jalali, S. G., Salman Mahini, A., Hossaini, S. M., & Azari Dehkordi, F. (2009). Ecological potential evaluation of Dohezar and Sehezar watersheds in north of Iran using GIS. *Environmetal Studies, 50*(35), 33–44. https://doi.net/20.1001.1.10258620.1388.35.51.7.9. Accessed 3 June 2022.

Babaei, S. (2006). Environmental evaluation for forest land classification by using of GIS (case study in Kazemrood watershed north of Iran). *Journal of Agricultural Sciences, 12*(1), 67–80.

Buckley, J. J. (1985). Fuzzy hierarchical analysis. *Fuzzy Sets and Systems, 17*(3), 233–247. https://doi.org/10.1016/0165-0114(85)90090-9

Chan, F. T., & Kumar, N. (2007). Global supplier development considering risk factors using fuzzy extended AHP-based approach. *Omega, 35*(4), 417–431. https://doi.org/10.1016/j.omega.2005.08.004

Chen, X., Quan, Q., Zhang, K., & Wei, J. (2021). Spatiotemporal characteristics and attribution of dry/wet conditions in the Weihe River Basin within a typical monsoon transition zone of East Asia over the recent 547 years. *Environmental Modelling & Software, 143*, 105116.

Chu, T. C. (2002). Selecting plant location via a fuzzy TOPSIS approach. *The International Journal of Advanced Manufacturing Technology, 20*(11), 859–864. https://doi.org/10.1007/s001700200227

Dengiz, O., Gol, C., Sariolu, F. E., & Edi, S. (2010). Parametric approach to land evaluation for forest plantation: A methodological study using GIS model. *African Journal of Agricultural Research, 5*(12), 1482–1496. https://doi.org/10.5072/ZENODO.36366

Doggart, N., Morgan-Brown, T., Lyimo, E., Mbilinyi, B., Meshack, C. K., Sallu, S. M., & Spracklen, D. V. (2020). Agriculture is the main driver of deforestation in Tanzania. *Environmental Research Letters, 15*(3), 034028. https://doi.org/10.1088/1748-9326/ab6b35

Fazlollahi Mohammadi, M., Soleimani, A., Ezati, S., & Sepahvand, A. (2014). Selection of the most suitable species in order to forestation in southern Zagros forests using AHP & TOPSIS techniques. *Ecology of Iranian Forest, 2*(4), 45–55.

Gholizadeh, A., Bagherzadeh, A., & Keshavarzi, A. (2020). Model application in evaluating land suitability for OAK and PINE forest plantations in northeast of Iran. *Geology, Ecology, and Landscapes, 4*(3), 236–250. https://doi.org/10.1080/24749508.2019.1633217

Greene, R., Luther, J. E., Devillers, R., & Eddy, B. (2010). An approach to GIS-based multiple criteria decision analysis that integrates exploration and evaluation phases: Case study in a forest-dominated landscape. *Forest Ecology and Management, 260*(12), 2102–2114. https://doi.org/10.1016/j.foreco.2010.08.052

Hajjarian, M., Hosseinzadeh, O., & Khalledi, F. (2016). Using combined MADM approach for Hyrcanian forests management. *Environmental Sciences, 14*(3), 1–12.

Hamzeh, S., Mokarram, M., & Alavipanah, S. K. (2014). Combination of fuzzy and AHP methods to assess land suitability for barley: Case study of semi arid lands in the southwest of Iran. *Desert, 19*(2), 173–181. https://doi.org/10.22059/jdesert.2014.52346

Hashemi, S. F., Hojjati, S. M., Jalilvand, H., & Hosseini Nasr, S. M. (2014). Assessment of successfulness of tree plantations based on multiple criteria in north of Iran. *ECOPERSIA, 2*(1), 485–497. http://dorl.net/dor/20.1001.1.23222700.2014.2.1.7.4. Accessed 3 June 2022.

He, G., Liu, X., & Cui, Z. (2021). Achieving global food security by focusing on nitrogen efficiency potentials and local production. *Global Food Security, 29*, 100536.

Hosseinzadeh, J. (2007). *Evaluation of ecological potential of 48 Glendrood basin (Pimood series - Kadir Sar) using GIS* (p. 50). Master Thesis in Forestry, Islamic Azad University, Chalous Branch, Faculty of Agriculture and Natural Resource.

Hwang, C. L., & Yoon, K. (1981). *Multiple attribute decision making. Methods and applications: A state-of-the-art survey* (p. 186259). Springer-Verlag: Berlin, Germany. https://doi.org/10.1007/978-3-642-48318-9

Kaufmann, A., & Gupta, M. M. (1991). *Introduction to fuzzy arithmetic: Theory and application*. Van Nostrand Reinhold. https://doi.org/10.2307/2008199

Kiasari, S. M., Sagheb-Talebi, K., Rahmani, R., Adeli, E., Jafari, B., & Jafarzadeh, H. (2010). Quantitative and qualitative evaluation of plantations and natural forest at Darabkola, east of Mazandaran. *Iranian Journal of Forest and Poplar Research, 18*(3), 337–351.

Lin, H. F. (2010). An application of fuzzy AHP for evaluating course website quality. *Computers & Education, 54*(4), 877–888. https://doi.org/10.1016/j.compedu.2009.09.017

Liu, S., He, X., Chan, F. T., & Wang, Z. (2022a). An extended multi-criteria group decision-making method with psychological factors and bidirectional influence relation for emergency medical supplier selection. *Expert Systems with Applications, 202*, 117414.

Liu, S., Zhang, J., Niu, B., Liu, L., & He, X. (2022b). A novel hybrid multi-criteria group decision-making approach with intuitionistic fuzzy sets to design reverse supply chains for COVID-19 medical waste recycling channels. *Computers & Industrial Engineering*, 108228.

Liu, Y., Zhang, K., Li, Z., Liu, Z., Wang, J., & Huang, P. (2020). A hybrid runoff generation modelling framework based on spatial combination of three runoff generation schemes for semi-humid and semi-arid watersheds. *Journal of Hydrology, 590*, 125440.

Loi, N. K., & Tuan, V. M. (2008). *Integration of GIS and AHP techniques for land use suitability analysis in Di Linch district – Upstream Dong Nai watershed – Vietnam Fortrop II Internatioanl Conference Tropical Forestry Change in a Changing World* (pp. 17–20). Kasetsart University.

Mafi-Gholami, D., Jaafari, A., Zenner, E. K., Kamari, A. N., & Bui, D. T. (2020). Vulnerability of coastal communities to climate change: Thirty-year trend analysis and prospective prediction for the coastal regions of the Persian Gulf and Gulf of Oman. *Science of the Total Environment, 741*, 140305.

Mafi-Gholami, D., Zenner, E. K., Jaafari, A., Bakhtyari, H. R. R., & Bui, D. T. (2019). Multi-hazards vulnerability assessment of southern coasts of Iran. *Journal of Environmental Management, 252*, 109628.

Majnoniyan, H. (2000). *Iran's protected areas. Foundations and measures to protect the park and regions* (p. 216). Environmental Protection Agency, Tehran.

Malczewski, J. (1999). *GIS and multicriteria decision analysis*. John Wiley and Sons Press.

Malczewski, J. (2004). GIS-based land-use suitability analysis: A critical overview. *Progress in Planning, 62,* 3–65.

Malik, M. I., & Bhat, M. S. (2015). Sustainability of tourism development in Kashmir—Is paradise lost? *Tourism Management Perspectives, 16*, 11–21. https://doi.org/10.1016/j.tmp.2015.05.006

Mohammadi, M. F., Najafi, A., & Ahmadlo, F. (2015). Using the analytical network process (ANP) based on BOCR model to select the most suitable region for forestation with almond species. *Nusantara Bioscience, 7*(2), 118–127. https://doi.org/10.13057/nusbiosci/n070210

Mohammadi, Z., & Limaei, S. M. (2018). Multiple criteria decision-making approaches for forest sustainability (case study: Iranian Caspian Forests). *Forest Research*, *Forestry Research and Engineering International Journal,* 2(2): 114–120. https://doi.org/10.15406/freij.2018.02.00035

Moradzadeh, F., & Babaei kafaki, S., & Mataji. A. (2011). Assessing the ecological potential of afforestation using geographic information system (GIS) (case study: Dadabad region in Lorestan province). *Journal Renewable Natural Resources Research, 2*(4), 11–22.

Ownegh, M., Ghanghermeh, A., & Abedi, G. (2006). Land use management plan for southeastern coasts of the Caspian Sea: (Introduction a numerical model for ecological potential assessment and land use planning). *Agricultural Natural Resource Sciences, 13*(15), 139–152.

Patawaran, N., Darsono, T.A., Wayangkau, I., & Mangngenre, S. (2019). Determining the location of rubber plantation locations in Merauke district based on AHP Topsis. IOP Conference Series: Earth and Environmental Science, Volume 343, The 1st International Conference of Interdisciplinary Research on Green Environmental Approach for Sustainable Development (ICROEST) 2019 3–4 August 2019, Universitas Muhammadiyah Buton, Indonesia.

Paul, R., & Banerjee, K. (2021). Deforestation and forest fragmentation in the highlands of Eastern Ghats, India. *Journal of Forestry Research, 32*(3), 1127–1138.

Phua, M. H., & Minowa, M. (2005). A GIS-based multi-criteria decision making approach to forest conservation planning at a landscape scale: A case study in the Kinabalu Area, Sabah. *Malaysia. Landscape and Urban Planning, 71*(2–4), 207–222. https://doi.org/10.1016/j.landurbplan.2004.03.004

Piran, H., Maleknia, R., Akbari, H., Soosani, J., & Karami, O. (2013). Site selection for local forest park using analytic hierarchy process and geographic information system (case study: Badreh County). *International Research Journal of Applied and Basic Sciences, 6*(7), 930–935.

Quan, Q., Liang, W., Yan, D., & Lei, J. (2022). Influences of joint action of natural and social factors on atmospheric process of hydrological cycle in Inner Mongolia. *China. Urban Climate, 41*, 101043.

Rahdari, V., Sofyanian, A. R., Pourmanafi, S., & Maleki, S. (2019). Assessment of land forestry capability using multi criteria evaluation and fuzzy analytical hierarchy process

method. *Iranian Journal of Forest and Range Protection Research, 17*(1), 26–39.
Rahimi, V., Porkhabaz, H. R., Aghdar, H., & Mohammad, & Yari, F. (2015). Comparison of fuzzy AHP Buckley model and ANP in forestry capacity assessment (case study: Behbahan suburb). *Iranian of Journal Applield Ecology, 4*(13), 15–30. https://doi.org/10.18869/acadpub.ijae.4.13.15
Rahimizadeh, N., Babai Kafaki, S., & Mataji, A. (2012). Determine the appropriate species for afforesting according to ecological capability of southern rage Alborz using GIS (Darakeh-Velenjak Shemiran Watershed). *Journal of Science and Technology of Natural Resources, 7*(1), 43–56.
Rezaei, M., & Jamshidi Zanjani, A. (2017). Landfill site selection using combination of fuzzy logic and multi criteria decision making method (Case Study: Arak Iran). *Modares Civil Engineering Journal, 17*(2), 120–130.
Saaty, T. (1980). *The analytical hierarchy process. Planning Priority Setting Resource Allocation* (pp. 287). New York, McGraw-Hill, Suffolk.
Sabir, M., Ali, Y., Khan, I., & Salman, A. (2020). Plants species selection for afforestation: A case study of the billion tree tsunami project of Pakistan. *Journal of Sustainable Forestry*, 1–13. https://doi.org/10.1080/10549811.2020
Shamseh, M. (2010). *Evaluation of ecological potential for afforestation using GIS geographical information system in Qaleh Gol watershed and Khorramabad city* (pp. 78). Master Thesis in Forestry Faculty of Natural Resources University of Guilan.
Szulecka, J., & Zalazar, E. M. (2017). Forest plantations in Paraguay: Historical developments and a critical diagnosis in a SWOT-AHP framework. *Land Use Policy, 60*(1), 384–394. https://doi.org/10.1016/j.landusepol.2016.11.001
Ülengin, B., Ülengin, F., & Güvenç, Ü. (2001). A multidimensional approach to urban quality of life: The case of Istanbul. *European Journal of Operational Research, 130*(2), 361–374. https://doi.org/10.1016/S0377-2217(00)00047-3
Vatani, L., Hosseini, S. M., Raeini Sarjaz, M., Alavi, S. J., Shamsi, S. S., & Zohd Ghodsi, M. J. (2019). Effect of tree species on albedo in Iranian temperate forests: Comparing conifers and broadleaf trees in two seasons. *Journal of Solar Energy Research*, *4*(3), 188–199. https://doi.org/10.22059/jser.2019.289156.1128
Xie, W., Nie, W., Saffari, P., Robledo, L. F., Descote, P. Y., & Jian, W. (2021). Landslide hazard assessment based on Bayesian optimization–Support vector machine in Nanping City. *China. Natural Hazards, 109*(1), 931–948.
Zare, R., Babaei, K. S., & Mataji, A. R. (2011). Suggestion the appropriate species for afforestation in south hillside of Alborz mountain by using GIS (case study: Dareh Vesieh Watershed). *Renewable Natural Resources Research, 2*(1), 55–67.
Zhang, K., Ali, A., Antonarakis, A., Moghaddam, M., Saatchi, S., Tabatabaeenejad, A., ... & Moorcroft, P. (2019a). The sensitivity of North American terrestrial carbon fluxes to spatial and temporal variation in soil moisture: An analysis using radar-derived estimates of root-zone soil moisture. *Journal of Geophysical Research: Biogeosciences, 124*(11), 3208 3231.
Zhang, K., Wang, S., Bao, H., & Zhao, X. (2019b). Characteristics and influencing factors of rainfall-induced landslide and debris flow hazards in Shaanxi province, China. *Natural Hazards and Earth System Sciences, 19*(1), 93–105.
Zhao, X., Xia, H., Pan, L., Song, H., Niu, W., Wang, R., ... & Qin, Y. (2021). Drought monitoring over Yellow River basin from 2003–2019 using reconstructed MODIS land surface temperature in Google Earth Engine. *Remote Sensing, 13*(18), 3748.

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