Identification of optimum afforestation areas considering sustainable management of natural resources, using geo-environmental criteria

Fereshteh Kordrostami[a,c,*], Pedram Attarod[a], Karim C. Abbaspour[b], Ralf Ludwig[c], Vahid Etemad[a], Hossein Alilou[d], Omid Bozorg-Haddad[e]

[a] Department of Forestry and Forest Economics, Faculty of Natural Resources, College of Agriculture and Natural Resources, University of Tehran, Karaj, Iran

[b] Eawag, Swiss Federal Institute of Aquatic Science and Technology, Duebendorf, Switzerland

[c] Department of Geography and Remote Sensing, Ludwig Maximilian University, Munich, Germany

[d] Aquatic Ecodynamics, UWA School of Agriculture and Environment, The University of Western Australia, Crawley, WA 6009, Australia

[e] Department of Irrigation & Reclamation Engineering, Faculty of Agricultural Engineering & Technology, College of Agriculture & Natural Resources, University of Tehran, Karaj, Iran

Abstract

Conservation of natural resources is vital for sustainable management, especially in fragile semi-arid ecosystems. Forest plantations can provide a wide range of ecosystem services and deliver a measure of protection for soil and water resources. This study proposes a novel framework (Optimum Land Suitability Score, OLSS) to prioritize the most suitable areas with high priority for restoring degraded lands and protecting erosion-prone areas. We applied OLSS to the Latian watershed located in Tehran, Iran. The Latian watershed was divided into 56 subbasins, where we studied the importance of each sub-basin for afforestation. We used a multicriteria analysis using the Fuzzy Analytical Network Process to bridge the gap between previous studies for determining suitable areas for afforestation in which 21 factors of environmental variables, morphometric characteristics, and topographical indices were considered. Finally, sub-basins were divided into four classes based on the fuzzy theory. The evaluated result indicated that 9 sub-basins showed the highest priority for afforestation. The identified sub-basins were mostly located in areas of depleted plant coverage due to overgrazing and human interventions. We proposed afforestation with proper species adapted to the environmental characteristics of prioritized sub-basins as ecological management. The measure should decrease erosion and flood risk and sustain the Latian reservoir storage capacity. OLSS offers valuable information for watershed managers and decision-makers to invest in soil conservations.

Introduction

During past decades, considerable efforts have been made to quantify the effect of afforestation on runoff management (Farley et al., 2005; Fukuyama et al., 2010), flood mitigation (Beschta et al., 2000), soil erosion (Fukuyama et al., 2008), and water quality (indirectly through soil erosion) (Fukuyama et al., 2010). Forest plantations either with productive or protective aims have the potential of providing a wide range of ecosystem services, including carbon sequestration (Bonan, 2008; Brainard et al., 2009), biodiversity (Barlow et al., 2007), aesthetic values (Ribe, 1989), transformation and transport of nutrients (Lee et al., 2014; Feng et al., 2015) and environmental impact avoidance (Nin et al., 2016). It is also acknowledged that afforestation with proper species and strategies may reduce erosion (Wang et al., 2007), reinforce the soil (Loades et al., 2010), and mitigate the severity of flood events even under extreme climate change scenarios (Wilby and Keenan, 2012; Dittrich et al., 2019).

Several attempts have been made to identify suitable areas for afforestation projects where land-use changes can lead to fewer environmental issues and provide beneficial ecosystem services. Dubovyk et al. (2016) applied a multicriteria evaluation and fuzzy logic method to map land suitability for afforestation using groundwater and river-related parameters, slope, and irrigation water use. Their findings indicate that groundwater table depth and irrigation water supply are essential criteria to identify suitable areas in degraded irrigated land. Also, Vettorazzi and Valente (2016) developed a conceptual framework to determine suitable areas based on suitability of land use, soil erodibility, erosivity, proximity to roads, and distance from water bodies, using the ordered weighted averaging (OWA). Results show that the critical factors to prioritize the suitable areas are soil erodibility and distance from water bodies in the river basin. Similarly, empirical environmental data, e.g., growing season, precipitation, climate moisture index, growing degree days, and land inventory capability for agriculture and elevation, were integrated into a fuzzy logic model to identify suitable areas for afforestation. Also, ecological criteria (Gkaraveli et al., 2004; Mashayekhan and Salman Mahiny, 2011; Zare et al., 2014), the normalized difference vegetation index (NDVI) (Mohamed Elhag, 2010), environmental, economic, and social factors (Jaimes et al., 2012) are also employed to identify land suitability for establishing forests.

Most of the studies mentioned above have utilized high-quality and long-term data to determine land suitability for afforestation. However, the proper selection of criteria and methods for sustainable planning and management of natural resources is of vital importance for developing countries such as Iran, which have data scarcity and limited financial resources (Alilou et al., 2018; Choubin et al., 2018). Given these limitations, the main question was how to consider the environmental factors for afforestation in data-scarce regions. Based on the literature, we found that several studies have used geo-environmental factors such as morphometric characteristics, topographical indices, and environmental factors for land-use planning, watershed health analysis, watershed prioritization, detection of groundwater potential, and soil erosion risk in semi-arid, tropical, and data-scarce regions (Aher et al., 2014; Alilou et al., 2019; Rahmati et al., 2019; Choubin et al., 2019; Hembram et al., 2019). However, to our knowledge, there is no literature on the use of morphometric characteristics combined with topographical and environmental factors to determine optimum areas for forest plantation. Also, none of the studies of afforestation employed a fuzzy analytical network process (FANP) to improve the identification of optimum afforestation areas. The FANP set theory has advantages in the case of the decision-making process, which needs to rank priorities by distinguishing real differences between ranks and complex decision-making processes (Chang and Lin, 2014; Sajedi-Hosseini et al., 2018).

The overall goal of this study was to introduce an integrated, comprehensive framework for the identification of optimum afforestation areas. Toward this end, the present study aims to: 1) Map potential land suitability for establishing forests considering the geoenvironmental factors using the analytical network process (ANP). 2) Quantify morphometric and topographic parameters for each sub-basin to produce a risk management map. 3) Rank sub-basins for restoration and protection actions using FANP, and 4) determine suitable species for afforestation regarding environmental and ecological requirements. Thus, the principal justification for the present study is the need to be able to characterize the optimum areas for establishing forests intending to restore degraded lands and conserve the soil and water resources in data-scarce regions where empirical environmental data are often lacking. This strategy can provide reliable information for watershed managers and decision-makers and allow them to efficiently invest the resources in critical sub-basins.

2. Materials and methods

2.1. Study area

The watershed is located in the middle part of the Alborz mountains, with a drainage area of approximately 700 km2. It was selected as a representative river basin in a mountainous, cold, semi-arid climate. The watershed is bounded by longitudes of 3,950,000–3,990,000 E and latitudes of 530,000–580,000 N in the zone of 39 N (Fig. 1). The elevation ranges from 1532 m at the outlet to 4298 m a.s.l. The mean annual precipitation of the study area is about 600 mm. Precipitation starts from fall to late spring, with the maximum occurring in March and the minimum at the end of July to mid-August. The dominant soil texture in the watershed is clay loam. The Latian is a strategic area in Tehran because of the multipurpose dam in the outlet of the watershed supplying 25% of the drinking water for the city of Tehran and providing a source of hydropower and irrigation water for the agricultural lands. The area has recently experienced a conversion of forests to residential areas and rangelands. The changing precipitation regime has resulted in erosion and increasing flood risk. Identifying suitable zones for reforestation to protect erosion-prone areas through cost-effective measures that follow the Sustainable Development Goal 15 aims to “protect, restore and promote sustainable use of terrestrial ecosystems, sustainably manage forests, combat desertification, and halt and reverse land degradation and halt biodiversity loss” (UN DESA, 2018). As far as forests are concerned, target 15.2 of the 2030 agenda promotes the implementation of sustainable management of all types of forests, halt deforestation, restore degraded forests and substantially increase afforestation and reforestation globally.

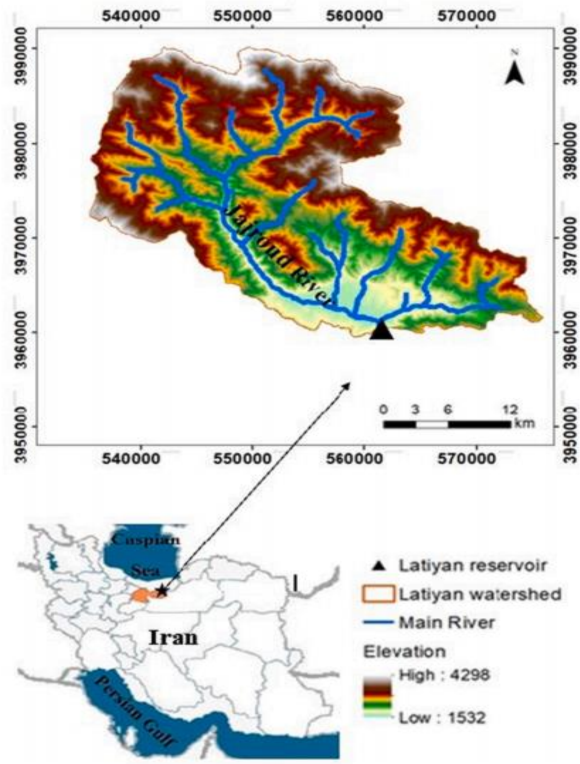

Fig. 1. The Latiyan watershed, Tehran, Iran.

2.2. Methodology

In this study, we used a framework entitled Optimum Land Suitability Score (OLSS) to rank sub-basins according to the potential of land suitability for afforestation and risk of erosion. The framework includes two main steps: multicriteria analysis and fuzzy analysis (Fig. 2). Furthermore, we suggest the most suitable species for afforestation based on the environmental and ecological characteristics of the critical sub-basins.

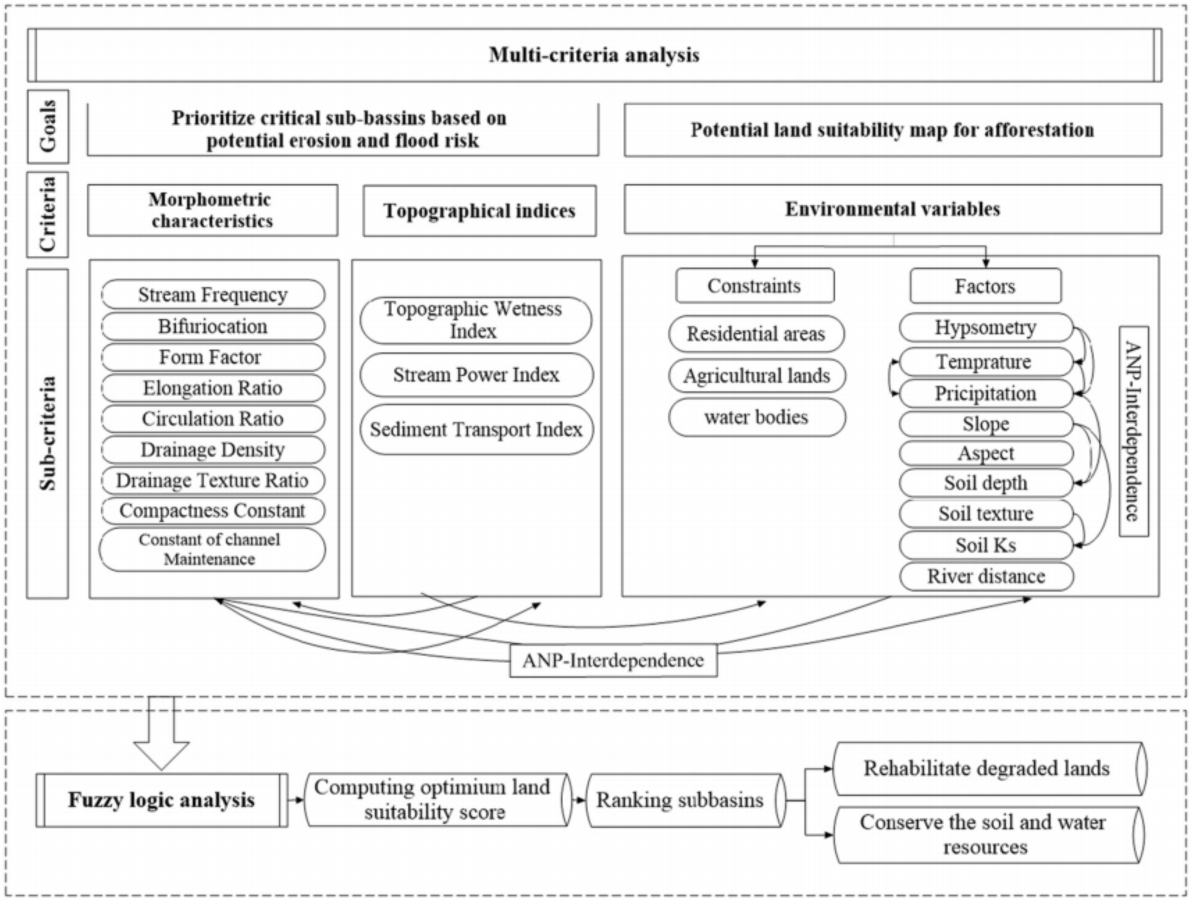

Fig. 2. Schematic illustration of the study framework.

2.2.1. Multicriteria analysis (MCA)

Identification of the most effective criteria is critical when it comes to characterizing suitable areas for afforestation with the aim of restoration and protection. Environmental variables (EV) as criteria were selected to produce a potential land suitability map for afforestation. We chose morphometric characteristics (MC) and topographical indices (TI) to characterize potential areas based on erosion and flood risk. The selected criteria were determined according to the opinions of local and academic experts, data availability, and characteristics of the study area (Makhdoum, 1999; Joss et al., 2008; Jaimes et al., 2012; Elhag, 2010; Aher et al., 2014; Zare et al., 2014; Alilou et al., 2019). We subsequently standardized the sub-criteria, evaluated the inter-relationship between sub-criteria and criteria, and measured their relative weights. More details about the MCA steps are as follows:

2.2.1.1. Environmental variables. A set of environmental sub-criteria

including hypsometry, precipitation, temperature, slope, aspect, soil data (texture, hydraulic conductivity, and depth) were chosen to identify the potentially suitable areas for establishing forests (Elhag, 2010; Jaimes et al., 2012; Zare et al., 2014). To do this, we used a multicriteria evaluation (MCE module) in TerrSet (geospatial monitoring and modeling software) through a weighted linear combination (WLC) method. MCE is based on a weighted average concept in which each factor is standardized using a fuzzy membership function (Table 1). A standardized map was produced for each sub-criterion, where a fuzzy set was defined to a continuous scale of suitability from zero (the least suitable) to one (the most suitable) (Eastman, 1999; Ceballos-Silva and Lopez-Blanco, 2003) (The standardized maps are presented in Fig. S1). The analytic network process was applied to evaluate the interdependence between sub-criteria and calculate their weights, which account for each sub-criterion's relative importance (Eastman, 2001) (Table 2). Each standardized map was then multiplied by its corresponding weight. The last step was to specify constraints, including agricultural lands, residential areas, and water bodies. Constraints were converted into a Boolean map with two values; zero corresponds to areas with no possibility to establish a forest, and one to the rest of the areas. The final output is the result of a combination of all factors and constraints together.

Table 1
Standardization method for environmental factors and optimal ranges for establishing the environmentally adapted species in Latiyan watershed.

Factors	Method of standardization	Optimal ranges
Hypsometry	Symmetric sigmoidal fuzzy function	1500–2200 m
Mean annual precipitation	Symmetric sigmoidal fuzzy function	> 400 mm
Mean annual temperature	Symmetric sigmoidal fuzzy function	12–14 ^{0}c
Slope	Symmetric sigmoidal fuzzy function	20–40%
Terrain aspect	Linear fuzzy function with monotonically decreasing	North
Soil texture	Linear fuzzy function with monotonically decreasing	Loamy-sandy-clay
Soil depth	Symmetric sigmoidal fuzzy function	50–100 cm
Soil Ks	Symmetric sigmoidal fuzzy function	3–4
River distance	Symmetric sigmoidal fuzzy function	20–100 m

Table 2
Weights of factors calculated by ANP.

Factors	Hypsometry	Mean annual precipitation	Mean annual temperature	Slope	Terrain aspect	Soil texture	Soil depth	Soil Ks	River distance
Weights	0.298	0.225	0.143	0.026	0.046	0.077	0.126	0.037	0.019

2.2.1.2. Topographic indices.

Surface water and sediment transport processes were assessed by composite topographical indices, including the topographic wetness index (TWI), stream power index (SPI), and sediment transport index (STI). They were calculated either empirically or by simple equations (Moore et al., 1991) (Eqs. 1–3). Compound indices help specify the spatial distribution of surface saturated zones and soil water content in the watershed. They can also describe the spatial variability of specific processes in the watershed (Moore et al., 1993; Florinsky et al., 2002; Alilou et al., 2019). As SPI, STI, and TWI are related to processes such as surface runoff and infiltration; they are affected by the slope (Lanni et al., 2012). SPI is directly related to stream power and estimates the amount of slope erosion caused by overland flow (Moore et al., 1991). STI quantifies the amount of soil loss influenced by both slope length and steepness and reflects the capacity of flowing water to transport the sediment (Moore et al., 1993; Florinsky et al., 2002). The idea of a wetness index is that the topography controls water flow in rugged and steep terrain. Therefore, the TWI shows the spatial distribution of soil moisture that resulted in surface runoff generation (Beven and Kirkby, 1979; Schmidt and Persson, 2003) (Eqs. 1–3)

$$TWI = ln\left(\frac{A_s}{tan\beta}\right) \quad (1)$$

$$SPI = A_S \times tan\,\beta \quad (2)$$

$$STI = \left(\frac{A_s}{22.13}\right)^{0.06} \times \left(\frac{sin\beta}{0.0896}\right)^{1.3} \quad (3)$$

β corresponds to the slope in degrees, and As is the area of the watershed. The normalized maps of topographical indices are shown in Fig. S2.

2.2.1.3. Morphometric characteristics.

The morphometric analysis is a method for characterizing the risk of erosion (Singh, 1994) and prioritizing micro-watersheds, even without considering the soil map (Biswas et al., 1999). The drainage system may be affected by soils, slopes, and geologic characteristics of a watershed. Morphometric analysis was used to assess the watershed's natural drainage system and prioritize sub-basins using the parameters known as erosion risk assessment factors (Aher et al., 2014). These include form factor (Rf), drainage density (D), stream frequency (Fs), drainage texture ratio (Rt), circularity ratio (Rc), elongation ratio (Re), constant of channel maintenance (C), compactness coefficient (Cc), and bifurcation ratio (Rb) (Table 3). Since morphometric parameters have different ranges and values, they should be standardized for evaluation (Hebert and Keenleyside, 1995). According to past research, standardization was applied using other equations based on the correlation between parameters and soil erosion. It means that if a parameter shows a positive correlation with soil erodibility, the highest rank is given to the highest value of that parameter. On the contrary, the lower value of parameters that reflect the inverse relation with soil erosion is taken at a higher rank. The values of standardized parameters were then expressed in a range of zero to one (Hebert and Keenleyside, 1995; Ratnam et al., 2005; Chang and Lin, 2014). The normalized maps of morphometric characteristics are presented in Fig. S3.

2.2.1.4 Weights of criteria

According to multicriteria analyses, it is necessary to consider the relative importance of criteria to include them in the final combination. To prioritize sub-basins, the characterization of inter-relationships among criteria is essential. The analytic network process (ANP) was the method followed to this end. The ANP is the generalization of the analytic hierarchy process (AHP). The AHP assumes various criteria to be independent, which rarely happens, especially among environmental variables (Triantaphyllou and Mann, 1995; Saaty, 2005). However, the ANP considers the interdependence among different criteria (Saaty, 2005). Interdependence considering interaction and feedback within clusters of elements and external dependence, considering those among clusters, were reflected in the network constructed (Liu and Jiang, 2011).

The ANP was applied using Super Decisions 2.2 software (www. superdecisions.com), which is widely used in multicriteria decision making using AHP and ANP (Gardasevic-Filipovic and Saletic, 2010; Liu and Jiang, 2011; Azizi and Maleki, 2014). The weighting step was as follows: (a) characterizing external dependence between criteria; (b) designing the questionnaire (Fig. S4); (c) utilizing the experts' opinions to define the priority of each criterion by scoring it between 1 and 9 by making a pair-wise comparison matrix; (d) testing the consistency of the pair-wise comparison matrix by calculating the consistency ratio, which shows that weights are randomly selected (≤ 0.1 is acceptable); (e) calculating the weights and rank of criteria (Saaty, 2005). The weighted method was used to calculate the land suitability score (LSS) as a solution to the multiple-criteria analysis (Chang and Lin, 2014) (Eq., 4).

$$LSS = \sum_{i=1}^{3} W_i \times N_i \qquad (4)$$

In this equation, the weights of the criteria are given by a symbol as Wi, i = 1~–3. Weights of criteria demonstrate the relative importance of the criteria affecting the final results of multiple criteria analysis. Wi indicates the relative weight of each criterion (ENVIRONMENTAL VARIABLES (EV), MORPHOMETRIC CHARACTERISTICS (MC), TI), and Ni is the standardized value of each criterion. This method's output has been considered a natural break approach (Chang and Lin, 2014). This is a conventional approach that classifies data by minimizing variation within a specific class and maximizing class variation.

Table 3
Morphometric parameters and analysis.

Morphometric parameter	Formula/definition	Reference
Bifurication ratio (R_b)	$R_b = N_u/N_{u+1}$ N_u = Total number of stream segment of order 'u'; N_{u+1} = Number of segments of the next higher order	Schumm (1954)
Stream frequency (F_s)	$F_s = N_u/A$ A: Basin area (km^2)	Horton (1932)
Drainage densty (D)	$D = L/A$ L = is the total length of all channels of all order in the drainage basin	Horton (1932)
Drainage texture ratio (R_t)	$R_t = N_t/P$ N_t = Total number of first order streams; P = Basin Perimeter (km)	Horton (1945)
Form factor (R_f)	$R_F = A/L_b{}^2$ L_b = basin length (km)	Horton (1932)
Elongation ratio (R_e)	$R_e = (2/L_b) * \sqrt{(A/P_i)}$	Schumm (1954)
Circulatory ratio (R_c)	$R_c = 4P_iA/P^2$	Horton (1945)
Compactness constant (C_c)	$C_c = 0.2821\ P/A^{0.5}$	Miller (1953)
Constant of channel maintenance (C)	$C = 1/D$	Schumm (1954)

2.2.2. Fuzzy analysis

Sub-basins' priority was determined using a natural break approach, which is a standard method, and it can minimize variability inside a particular class and maximize the variability among classes (Jenks, 1967). However, specifying the differences between scores through the natural break method is controversial (Chang and Lin, 2014). In this regard, we applied the fuzzy theory to prioritize sub-basins through a new algorithm developed by Chang and Lin (2014), which classified sub-basins based on the fuzzy theory method, including three steps: 1) normalizing the LSS value for each sub-basin with the interval ranging from 0 to 1. The LSSn corresponds to the normalized value of LSS; 2) applying fuzzy membership functions, which account for weights of each sub-basin as low, medium, and high ratings (Fig. S5). These ratings were calculated as l (LSSn), m (LSSn), and h (LSSn), respectively, for each sub-basin (Eqs. 5, 6, and 7), and the combined fuzzy scores for 56 subbasins were calculated using Eq. 8, and symbolized as Optimum Land Suitability Score.OLSSi (i = 56); 3) finally, sub-basins were classified into four classes based on the value of OLSSi.

$$l(LSS_n) = \begin{cases} -2LSS_n + 1 \; LSS_n < 0.5 \\ 0 \; LSS_n > 0.5 \end{cases} \quad (5)$$

$$m(LSS_n) = \begin{cases} 2LSS_n \; LSS_n < 0.5 \\ -2LSS_n + 2 \; LSS_n > 0.5 \end{cases} \quad (6)$$

$$h(LSS_n) = \begin{cases} 0 \; LSS_n < 0.5 \\ 2LSS_n + 1 \; LSS_n > 0.5 \end{cases} \quad (7)$$

$$\mathrm{OLSS_i} = 0 \times \mathrm{l(LSS_{ni})} + 5 \times \mathrm{m(LSS_{ni})} + 10 \times \mathrm{h(LSS_{ni})} \quad (8)$$

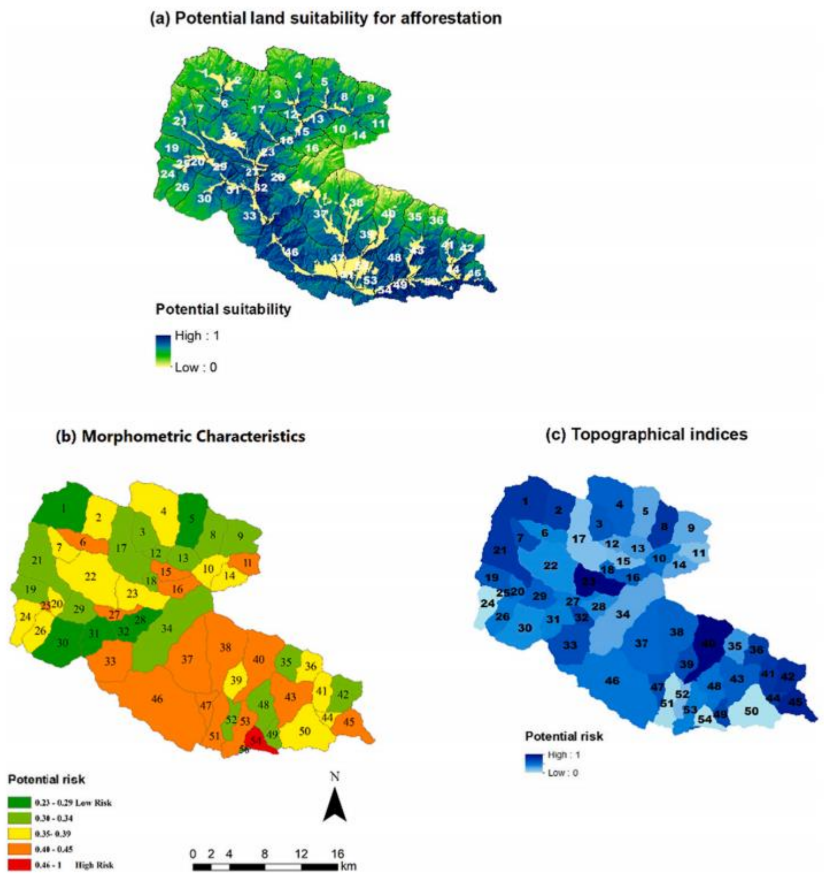

Fig. 3. Final maps of criteria: (a) environmental variables which is resulted in potential land suitability map for afforestation, (b) potential risk areas based on morphometric characteristics, (c) potential risk areas based on topographical indices.

2.2.3. Identifying the appropriate species

After ranking the sub-basins and characterizing critical management areas, appropriate afforestation species were determined based on environmental conditions, ecological requirements of the species (Sabeti, 1976; Mozafarian, 2004; Jafari et al., 2018), and previous afforestation in the areas with the same environmental characteristics (Zare et al., 2014; Ravanbakhsh and Moshki, 2016).

3. Results

3.1. Geo-environmental criteria

3.1.1. Environmental factors

Applying a multicriteria evaluation (MCE) to environmental variables and their relative weights resulted in identifying a potential suitability map for establishing forest in the Latian watershed. The value of suitability between zero to one for planting forests decreases from south to north and from west to east (Fig. 3a). This reduction is affected by changes in the altitude and climatic variables. Based on the study area's characteristics, hypsometry is considered the most critical factor in determining forest expansion as it can affect temperature and precipitation (Sevruk, 1997; Ravanbakhsh and Moshki, 2016). The experts' opinions' used to calculate the weights in the ANP also confirmed this finding as the highest weight was allocated to hypsometry (0.298) followed by precipitation (0.225), temperature, and soil depth, which were found to be the most influential factors. The least weight was allocated to the river distance (0.019) (Table 2). Sub-basins located in the watershed's northern and eastern parts have a higher elevation, resulting in lower temperatures and lower soil depth, and limited root distribution. The suitability of land for afforestation in these areas consequently declined.

3.1.2. Morphometric characteristics

To prioritize sub-basins based on their potential risk of erosion and water availability, we combined the measured values of morphometric parameters, including bifurcation ratio, form factor, drainage density, stream frequency, drainage texture ratio, circularity ratio, elongation ratio, the constant of channel maintenance, and the compactness coefficient based on previous studies (Thakkar and Dhiman, 2007; Aher et al., 2014; Alilou et al., 2019). The bifurcation ratio, drainage density, stream frequency, drainage texture ratio have a positive relationship with soil erodibility, and the sub-basin with the maximum value was ranked one as the highest priority. Also, zero was given to the sub-basin with the minimum value. The inverse rating process was applied for circularity ratio, elongation ratio, the channel maintenance constant, and the compactness coefficient. These demonstrate the inverse proportion with soil erosion factors. It means that one was assigned to the sub-basins having the minimum value and zero to the sub-basin having a maximum value of the parameter (Ratnam et al., 2005; Chang and Lin, 2014). There were 56 sub-basins in the study area. Sub-basins S22 and S46 (Fig. 3b) received the highest priority in terms of morphometric characteristics. Furthermore, S21, S34, S40, and S4 received a medium degree of susceptibility (Fig. 3b).

3.1.3. Topographic indices

Topographical properties significantly influence soil erosion and sediment transport by affecting surface flow (Fukuyama et al., 2008). The result of analyzing secondary topographic indices (TWI, SPI, and STI) is presented as a potential risk map (Fig. 3c). S23 and S40 showed the highest ranking of compound topographic attributes, which is specified as the relative susceptibility of these sub-basins to sediment yield and soil erosion compared to other sub-basins. The most important reasons for the susceptibility of S23 and S40 are steep slopes and low vegetation cover (Mirzai et al., 2014; Peyrowan et al., 2017).

3.1.4. Determining the weighs of criteria

Applying the normalized by cluster matrix resulted in calculating the relative weights of criteria based on local and professional experts' opinions (Alilou et al., 2019) and field surveys. Experts stated that environmental factors, especially altitude and climate, were more critical than other factors in the case of planting forests in arid and semi-arid regions. Moreover, field investigations indicated that all of the influential factors on erosion, climate, slope, geological materials, and morphology were the most influential factors in the Latian watershed, which was in agreement with the findings of Feyznia and Zare (2004). In this regard, the pair-wise comparison matrix with a consistency ratio of 0.01 indicated the higher normalized weight for environmental criteria. The morphological criteria represented a relative weight of 0.31, and the lowest weight was allocated to topographical indices (Table 4).

Table 4
Calculated weights of criteria using the ANP.

Criteria	Normalized by cluster
Environmental variables	0.44
Morphometric characteristics	0.38
Topographic indices	0.18

3.1.5. Prioritization based on land suitability score

Merging final maps of all criteria considering their relative weights resulted in producing a land suitability score (LSS) map ranging between 0 and 0.94 (Fig. 4). The higher the value, the higher the priority of implementing management practices. Southern parts of S1, S4, S5, S8, and S34, as well as the main areas of S21, S22, S23, S33, S37, S40, S42, S45, and S46, are considered potential risk areas that are also suitable for planting forests as a sustainable management strategy for natural conservation of soil and water resources in the Latian watershed.

3.1.6. Optimum land suitability score (OLSS) based on fuzzy classification

The sub-basins were classified into four classes based on the OLSS value. The first class (high suitability) (OLSS, 7.5–10) shows the area with a high priority for afforestation (Alilou et al., 2019). The sub-basins with values from 5 to 7.5 are classified as the second priority areas (medium suitability). Other sub-basins with values of 2.5–5 (low suitability) and < 2.5 (no suitability) are classified as the third and fourth priority areas, respectively (Fig. 5). Each class shows the score of sub-basins for establishing forests to conserve soil and water resources. In this regard, S4, S21, S22, S34, S37, S40, S43, S46, and S50 were ranked first with the highest priority for afforestation. This method allows the watershed managers to allocate financial resources to the most critical sub-basins (The necessary information of prioritized sub-basins is presented in (Table 5).

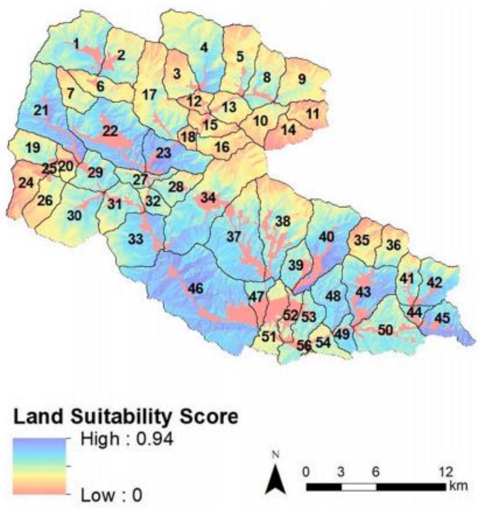

Fig. 4. Land suitability score (LSS) map.

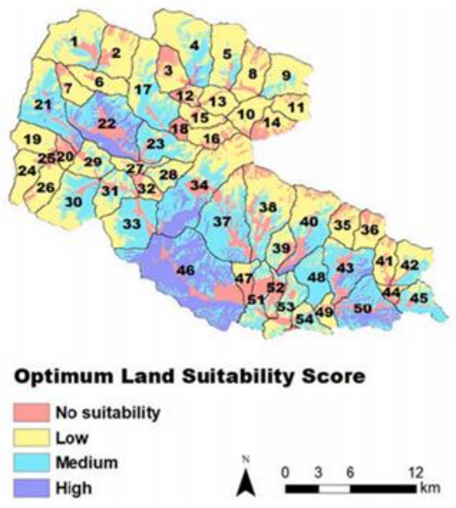

Fig. 5. Optimum land suitability score (OLSS) map.

3.2. Determining species

Afforestation is an appropriate nature-based solution to restore degraded lands. As degradation advances, selecting suitable species that can establish themselves well and provide ecosystem services like soil and water protection becomes of great importance. Choosing appropriate species can accelerate vegetation establishment, restoration, and succession (Wang et al., 2007). A list of species for ecological restoration of prioritized sub-basins includes *Juniperus excelsa*, *Prunus scoparia*, *Berberis vulgaris*, *Celtis caucasica*, *Prunus lycioides*, *Rosa canina*, *Rhus coriaria*, *Pinus eldarica*, and *Pinus nigra* (Table 5).

Table 5
Basic information of prioritized subbasins and suggested species considering environmental and ecological characteristics of them.

Subbasin	Altitude (m)	Temperature (°C)	Precipitation (mm)	Slope %))	Terrain aspect	Soil texture	Recommended species
4	2500–2800	6–8	650–700	20–40	North	Clay-loam	*Juniperus* sp.
21	2300–2500	8–10	550–650	30–50	West	Clay-loam	*Juniperus sp, Berberis integerrima, Amygdalus scoparia, Celtis caucasica, Rhus coriaria*
22	2100–2500	9–11	500–650	20–60	Northeast/ Southwest	Loamy-sandy-clay	*Juneperus* sp., *Berberis integerrima, Amygdalus scoparia, Celtis caucasica, Rhus coriaria*
34	2100–2200	11	500–550	40–60	Northwest	Clay-loam	*Juneperus* sp., *Berberis integerrima, Celtis caucasica, Amygdalus scoparia, Pinus nigra*
37	2300–2400	10	550–600	20–40	Northwest	Clay-loam	*Juniperus sp, Berberis integerrima, Amygdalus scoparia, Celtis caucasica, Rhus coriaria*
40	2000–2200	11–12	500–550	20–40	Northwest	Clay-loam	*Juneperus* sp., *Berberis integerrima, Celtis caucasica, Amygdalus scoparia, Pinus nigra*
43	1900–2100	11–13	450–550	20–60	West/Northwest	Clay-loam	*Celtis caucasica, Amygdalus scoparia, Amygdalus lycioides, Pinus nigra, Rosa canina*
46	1600–2000	12–14	400–500	20–60	East/Northwest	Clay-loam	*Celtis caucasica, Amygdalus scoparia, Amygdalus lycioides, Pinus nigra, Pinus eldarica, Rosa canina*
50	1600–2200	11–14	400–550	20–50	West	Clay-loam	*Celtis caucasica, Amygdalus scoparia, Amygdalus lycioides, Pinus nigra, Pinus eldarica, Rosa canina*

4. Discussion

4.1. How suitable were geo-environmental criteria and the ANP to map potential land suitability In this study, the relationship between geo-environmental criteria was properly revealed using the ANP method, and the relative importance of each sub-criterion was also calculated (Eastman, 2001; Alilo et al., 2019). Environmental factors, hypsometry and precipitation, were found to be the most important variables for establishing forest in the Latian watershed, similar to the findings by Ravanbakhsh and Moshki (2016) for Jajrud watershed, located in the mountainous region of north of Iran. For the Corumbataí river basin, located in the Central-Eastern region of the state of Sao Paulo, Brazil, Vettorazzi, and Valente (2016) found soil erodibility (Soil Ks) and distance from surface water to be the most influential factors for ranking the suitable afforestation areas. Our results agree with those of Zare et al. (2014), who applied land-use planning to position the most appropriate land uses for forest development in the area close to our study site and assigned the same ranking for environmental variables. It means that the highest weight was assigned to hypsometry. Moreover, Joss et al. (2008) indicated that climate factors were more helpful than soil factors to characterize afforestation suitable areas in regional scales. It supports our results and highlights that different factors did not have the same influence in different areas (Zare et al., 2014).

In terms of morphometric characteristics, Feyznia and Zare (2004) evaluated the sensitivity of sub-catchments in the Latian drainage basin to soil erosion by obtaining a land units map of the area using soil, climate, and geological factors. Their findings showed the same susceptibility ratings as our areas, as illustrated in Fig. 3b. Field investigations revealed that morphometric analysis is an effective method to identify sub-basins with critical water and soil degradation conditions, especially in data-scarce regions (Alilou et al., 2019).

When it comes to topographic indices, controlling soil erosion and sediment transport can be calculated either empirically or by simple equations (Moore et al., 1991). These indices specified the spatial distribution of surface saturated zones and soil water content in our study area well (Moore et al., 1993; Florinsky et al., 2002; Alilou et al., 2019). TWI results indicate that the wetness index is highly reliable for foresting because it considers the spatial distribution of soil moisture, which is critical for surface runoff generation (Beven and Kirkby, 1979; Schmidt and Persson, 2003). The SPI, which estimates the amount of slope erosion affected by an overland flow, can also find areas prone to sediment transport and different kinds of soil erosion. Therefore, these areas display suitability to foresting to control soil erosion (Moore et al., 1991).

4.2. Priority assessment based on MCE-FANP

One of the problems associated with afforestation areas is establishing priorities based on sustainable management of natural resources, among limiting financial budgets and watershed development options in environmental fields (Sajedi-Hosseini et al., 2018). The proposed approach enables forest and catchment managers to estimate the suitability of areas and finally select the most critical areas for afforestation. Besides its advantages, “one of the main limitations of MCE-FANP is that the weights have been determined based on experts’ knowledge” (Alilou et al., 2018).

Following the results of afforestation studies (Wang et al., 2007; Loades et al., 2010; Wilby and Keenan, 2012; Dittrich et al., 2019), we introduced a reliable and integrated framework using multicriteria decision analysis, fuzzification, and clustering to prioritize watersheds in terms of afforestation for both data-scarce and ungauged and gauged regions.

4.3. The advantage of restoring the critical sub-basins using selected species

In the early stages of land rehabilitation, where there are no secondary forest or nurse species to provide shade, priority should always be given to local and native pioneers and light-demanding species to ensure the success of afforestation in open areas. We propose species according to the successional stages of vegetation in the study area. The literature on local flora and plant communities showed that sparse grass communities existed in the study area (Ravanbakhsh et al., 2016). Therefore, we suggested planting diverse shrubs and trees to increase the density of land coverage as well as biodiversity. Diverse vegetation cover with various rooting systems and depths can contribute to anchorage and stabilization of the soil, especially in erosion-prone areas (Korner, ¨ 2004; Hudek et al., 2017).

In this regard, we proposed *Prunus spp*., *Rhus coriaria*, Berberis spp., and *Rosa canina* as pioneer shrubs (Sabeti, 1976; Mozafarian, 2004). Based on phytosociological studies and field observations, these species were seen sporadically in the study area, especially where trees and shrubs were removed mostly due to human interventions (developing urbanization, heavy grazing, and agriculture) (Ravanbakhsh et al., 2016).

All of the selected species are well-adapted to the mountainous semi-arid regions. They are drought resistant and can establish themselves in different soil types and depths (Sabeti, 1976; Mozafarian, 2004). *Juniperus sp.,* especially the *Juniperus excelsa* grow naturally in most mountainous areas of Iran and have great ecological importance (Mar vie-Mohadjer, 2006). They thrive in different elevations ranging between 1900 and 2800 m a.s.l, tolerate severe weather conditions, and show great adaptability to different light regimes (Ravanbakhsh et al., 2016). They are recommended for ecological restoration in high altitudes without limitations (Zare et al., 2014). They have an essential role in runoff management because of their higher soil water holding capacity than other proposed species (Jafari et al., 2018).

The *Prunus scoparia* tolerates severe water scarcity, temperature fluctuation and thrives in ranges between 600 and 2700 m a.s.l. It grows in different soil depths, gravelly soils, and calcareous-siliceous formations (Sabeti, 1976; Jafari et al., 2018). The *Celtis caucasica* is drought, disease, and pest resistant; it grows in arid and steppe regions of Iran between 800 and 2600 m a.s.l and adapts to any slope, sedimentation, and clay soil. The *Celtis caucasica* and *Amygdalus scoparia* are considered major species of the arid and semi-arid mountains in the Irano-Turanian region (Ravanbakhsh and Moshki, 2016). Therefore, they are well adapted to the Latian watershed located in the Irano-Turanian phytogeographic region.

Berberis integerrima and *Prunus lycioides* occupy large areas in mountainous and cold semi-arid regions of Iran and show high adaptability to different environmental conditions (Sabeti, 1976). *Berberis integerrima* thrives up to 2600 m a.s.l and can establish itself even in thin, dry, and shallow soils. *Juniperus excelsa* and *Berberis integerrima* communities are observed at higher altitudes of the Latian watershed (Ravanbakhsh and Moshki, 2016). This shrub has the ability for high coppice shoots; it also develops extensive roots and rhizomes and a thick mass of fibrous roots that are beneficial for soil reinforcement, slope stability and reduces the risk of soil erosion (Loades et al., 2010).

Prunus lycioides is resistant to abiotic stresses like the severe cold in winter and drought. This shrub grows well in gentle and steep slopes at an altitude of 1300–2100 m asl (Marvie-Mohadjer, 2006). It is a multi-purpose shrub to control soil erosion and is planted in the arid and semi-arid regions of

Iran (Jafari et al., 2018). It is recommended to plant *Berberis integerrima* in higher altitudes and *Prunus lycioides* in lower altitudes as the pioneer species to ensure the success of restoration efforts in critical sub-basins (Ravanbakhsh and Moshki, 2016).

The *Rhus coriaria* is a resistant tree that grows well in soils with high Ca and clay content and on high slopes at an altitude of 1100 to 2650 m a.s.l, with an annual rainfall of about 600 mm (Sabeti, 1976; Ravanbakhsh and Moshki, 2016). According to phytosociological studies in the current study area, it is recommended to plant *Rhus coriaria* with *Celtis caucasica*, *Berberis spp.*, and *Prunus spp.* in prioritized sub-basins (Ravanbakhsh and Moshki, 2016).

Rosa canina is a deciduous shrub that is suitable for light (sandy), medium (loamy), and heavy (clay) soils. It acts as a pioneer species due to its high coppice shoot ability, which is used in afforestation projects in semi-arid mountainous regions of Iran to rapidly cover degraded soils and improve soil properties (Sabeti, 1976; Ravanbakhsh and Moshki, 2016).

Of all of the above-mentioned indigenous species, *Pinus eldarica* and *Pinus nigra* are exotic. Species not indigenous in an area are called exotic species. When generating a negative impact on the local ecosystem, exotic species comply with the definition of IUCN for invasive species (https://www.iucn.org/regions/europe/our-work/biodiversity-conservation/invasive-alien-species). Therefore, investigating the ecological effect of exotic species and their potential negative impact on the local ecosystem and species is of great importance.

A nationwide species trial program was carried out from 1968 to 1973 in different provinces of Iran using several exotic species. The goal of this study was to evaluate and select the appropriate exotic species in unirrigated conditions in humid and semi-arid areas. This included about 300 different species and provenances. Elimination/ adaptation trials in the 1960s indicated that P. eldarica and P. nigra were among the most promising exotic species for planting in afforestation/restoration projects in the semi-arid areas (Webb, 1973). After five decades, *Pinus eldarica* and *Pinus nigra* were not considered invasive species in Iran. They were successfully applied in various afforestation/restoration projects in the arid and semi-arid regions of Iran (Sagheb-Talebi et al., 2009; Zare et al., 2014). They regenerated naturally, which showed their adaptability to this region's environmental conditions (Marvie Mohadjer, 2006). The selection of plantation species can be flexible if environmental and ecological benefits can be achieved in the same system (Prevot-Julliard et al., 2011). Therefore, we proposed *Pinus eldarica* and *Pinus nigra* based on flexibility in management strategies to us their benefits.

Pinus eldarica and *Pinus nigra* are fast-growing evergreen conifers that make them proper for speedy rehabilitation of degraded lands (Sagheb Talebi et al., 2009). As a result of their ecological flexibility, they have been widely used as tree species for worldwide forestation. We proposed Pinus nigra for planting in critical sub-basins with higher altitudes than the *Pinus eldarica*, since it is resistant to snow and ice damage (MarvieMohadjer, 2006). It also has a strong root system that enables it to penetrate rocky areas and establishes itself on steep slopes (Jafari et al.,

2018). *Pinus eldarica* grows well in all parts of Iran except in subtropical regions in the south. It is a drought and wind-tolerant tree, but it can be easily damaged by low winter temperatures (Jafari et al., 2018). In this regard, we proposed establishing this tree in prioritized sub-basins located in lower altitudes. Sadeghi et al. (2016) compared commonly planted tree species in Tehran, Iran, based on their rainfall partitioning differences to guide tree species selections for afforestation in semi-arid regions. According to their result, *Pinus eldarica* might be the best species to plant in semi-arid regions when afforestation aims to reduce erosion and stormwater runoff.

5. Conclusion

The present study used a practical framework to characterize the optimum areas for establishing forests to restore degraded lands and conserve soil and water resources. The proposed framework is based on a combination of 21 different criteria (environmental, morphological, and topo-hydrological criteria) and methods (ArcGIS tool, multicriteria evaluation (MCE) and the fuzzy analytical network process (FANP)), which are considered practical and efficient in both data-scarce and ungauged regions. With this method, local and professional experts' opinions were also taken into account to assign the weights of the criteria based on the study area's characteristics. Findings demonstrated that critical sub-basins are located in areas with land-use change and the areas with a lack of land coverage due to human interventions (developing urbanization, heavy grazing, and agriculture). Therefore, planting forests in the prioritized sub-basins and using appropriate species that are adapted to the region will provide a sustainable development strategy to protect natural resources. The method has the capability to use proper criteria and methods where data scarcity and limited financial resources are the main problems. Besides, there is no high cost to collect the data because most of them are available using remote sensing and universal data (e.g., k-factor). This strategy will provide reliable information for watershed managers and decision-makers, even in data-scarce regions where empirical environmental data are often lacking, and allow them to efficiently invest resources in critical sub-basins.

References

Aher, P.D., Adinarayana, J., Gorantiwar, S.D., 2014. Quantification of morphometric characterization and prioritization for management planning in semi-arid tropics of India: a remote sensing and GIS approach. J. Hydrol. 511, 850–860.

Alilou, H., Nia, A.M., Keshtkar, H., Han, D., Bray, M., 2018. A cost-effective and efficient framework to determine water quality monitoring network locations. Sci. Total Environ. 624, 283–293.

Alilou, H., Rahmati, O., Singh, V.P., Choubin, B., Pradhan, B., Keesstra, S., Ghiasi, S.S., Sadeghi, S.H., 2019. Evaluation of watershed health using Fuzzy-ANP approach considering geo-environmental and topo-hydrological criteria. J. Environ. Manag. 232, 22–36.

Azizi, A., Maleki, R., 2014. Comparative study of AHP and ANP on multi-automotive suppliers with multicriteria. Proc Int Multiconf Eng Comp Sci 2, 12–14.

Barlow, J., Gardner, T.A., Araujo, I.S., Avila-Pires, ´ T.C., Bonaldo, A.B., Costa, J.E., Esposito, M.C., Ferreira, L.V., Hawes, J., Hernandez, M.I., Hoogmoed, M.S., 2007. Quantifying the biodiversity value of tropical primary, secondary, and plantation forests. Proc. Natl. Acad. Sci. 104 (47), 18555–18560.

Beschta, R.L., Pyles, M.R., Skaugset, A.E., Surfleet, C.G., 2000. Peakflow responses to forest practices in the western cascades of Oregon. USA J Hydrol 233 (1–4), 102–120.

Beven, K.J., Kirkby, M.J., 1979. A physically based, variable contributing area model of basin hydrology/Un mod`ele a ` base physique de zone d'appel variable de l'hydrologie du bassin versant. Hydrol. Sci. J. 24 (1), 43–69.

Biswas, S., Sudhakar, S., Desai, V.R., 1999. Prioritisation of sub-watersheds based on morphometric analysis of drainage basin: A remote sensing and GIS approach. J. Indian Soc. Remote Sens. 27 (3), 155–166.

Bonan, G.B., 2008. Forests and climate change: forcings, feedbacks, and the climate benefits of forests. Sci. 320 (5882), 1444–1449.

Brainard, J., Bateman, I.J., Lovett, A.A., 2009. The social value of carbon sequestered in Great Britain's woodlands. Ecol. Econ. 68 (4), 1257–1267.

Ceballos-Silva, A., Lopez-Blanco, J., 2003. Delineation of suitable areas for crops using a Multi-Criteria Evaluation approach and land use/cover mapping: a case study in Central Mexico. J Agric Syst 77 (2), 117–136.

Chang, C.L., Lin, Y.T., 2014. A water quality monitoring network design using fuzzy theory and multiple criteria analysis. Environ. Monit. Assess. 186 (10), 6459–6469.

Choubin, B., Darabi, H., Rahmati, O., Sajedi-Hosseini, F., Kløve, B., 2018. River suspended sediment modelling using the CART model: a comparative study of machine learning techniques. Sci. Total Environ. 615, 272–281.

Choubin, B., Rahmati, O., Soleimani, F., Alilou, H., Moradi, E., Alamdari, N., 2019. Regional groundwater potential analysis using classification and regression trees. In:

Gokceoglu, C. (Ed.), Pourghasemi, H. Elsevier, Spatial modeling in GIS and R for earth and environmental sciences, pp. 485–498.

Dittrich, R., Ball, T., Wreford, A., Moran, D., Spray, C.J., 2019. A cost-benefit analysis of afforestation as a climate change adaptation measure to reduce flood risk. J. Flood Risk Manag. 12 (4) https://doi.org/10.1111/jfr3.12482 e12482.

Dubovyk, O., Menz, G., Khamzina, A., 2016. Land suitability assessment for afforestation with Elaeagnus angustifolia L. in degraded agricultural areas of the lower amudarya river basin. Land Degrad. Dev. 27 (8), 1831–1839.

Eastman, J.R., 1999. Multicriteria evaluation and GIS. Geogr Inf Syst 1 (1), 493–502.

Eastman, J.R., 2001. Guide to GIS and Image Processing, Vol. 2. Clark University, USA, p. 144.

Elhag, M., 2010. Land suitability for afforestation and nature conservation practices using remote sensing and GIS techniques. CATRINA 6 (1), 11–17.

Farley, K.A., Jobb´agy, E.G., Jackson, R.B., 2005. Effects of afforestation on water yield: a global synthesis with implications for policy. Glob. Chang. Biol. 11 (10), 1565–1576.

Feng, Y., Friedrichs, M.A.M., Wilkin, J., Tian, H., Yang, Q., Hofmann, E.E., Wiggert, J.D., Hood, R.R., 2015. Chesapeake Bay nitrogen fluxes derived from a land-estuarine ocean biogeochemical modeling system: model description, evaluation, and nitrogen budgets. J. Geophys. Res. Biogeosci. 120, 1666–1695. https://doi.org/10.1002/ 2015JG002931.

Feyznia, S., Zare, K.E.M., 2004. Sensitivity of rocks and formations to erosion and sediment yield in latian drainage basin area. IJNRR 56 (4), 365–381.

Florinsky, I.V., Eilers, R.G., Manning, G.R., Fuller, L.G., 2002. Prediction of soil properties by digital terrain modelling. Environ. Model. Softw. 17 (3), 295–311.

Fukuyama, T., Onda, Y., Takenaka, C., Walling, D.E., 2008. Investigating erosion rates within a Japanese cypress plantation using Cs-137 and Pb-210ex measurements. J. Geophys. Res. Earth Surf. 113 (F2).

Fukuyama, T., Onda, Y., Gomi, T., Yamamoto, K., Kondo, N., Miyata, S., Kosugi, K.I., Mizugaki, S., Tsubonuma, N., 2010. Quantifying the impact of forest management practice on the runoff of the surface-derived suspended sediment using fallout radionuclides. Hydrol. Process. 24 (5), 596–607.

Gardaˇsevi´c-Filipovi´c, M., Saleti´c, D.Z., 2010. Multicriteria optimization in a fuzzy environment: the fuzzy analytic hierarchy process. Yugosl J Oper Res 20 (1), 71–85.

Gkaraveli, A., Good, J.E.G., Williams, J.H., 2004. Determining priority areas for native woodland expansion and restoration in Snowdonia National Park. Wales Biol Conserv 115 (3), 395–402.

Hebert, C.E., Keenleyside, K.A., 1995. To normalize or not to normalize? Fat is the question. Environ. Toxicol. 14 (5), 801–807.

Hembram, T.K., Paul, G.C., Saha, S., 2019. Comparative analysis between morphometry and geo-environmental factor based soil erosion risk assessment using weight of evidence model: a study on Jainti river basin, eastern India. Environ Process 6 (4), 883–913.

Horton, R.E., 1932. Drainage basin characteristics. Trans. Am. Geophys. Union 13, 350–361.

Horton, R.E., 1945. Erosional development of streams and their drainage basins; hydrophysical approach to quantitative morphology. Geol. Soc. Am. Bull. 56 (3), 275–370.

Hudek, C., Stanchi, S., D'Amico, M., Freppaz, M., 2017. Quantifying the contribution of the root system of alpine vegetation in the soil aggregate stability of moraine. Int Soil Water Conserv Res 5 (1), 36–42.

Jafari, M., Tavili, A., Panahi, F., Esfahan, E.Z., Ghorbani, M., 2018. Reclamation of Arid Lands. Springer International Publishing.

Jaimes, N.B.P., Sendra, J.B., Delgado, M.G., Plata, R.F., N´emiga, X.A., Solís, L.R.M., 2012. Determination of optimal zones for forest plantations in the state of Mexico using multicriteria spatial analysis and GIS. J. Geogr. Inf. Syst. 4 (3), 204–218.

Jenks, G.F., 1967. The data model concept in statistical mapping. Int. Yearbook Cartograph. 7, 186–190.

Joss, B.N., Hall, R.J., Sidders, D.M., Keddy, T.J., 2008. Fuzzy-logic modeling of land suitability for hybrid poplar across the Prairie Provinces of Canada. Environ. Monit. Assess. 141 (1–3), 79–96.

Korner, ¨ C., 2004. Mountain biodiversity, its causes and function. Ambio. 33 (13), 11–17.

Lanni, C., Borga, M., Rigon, R., Tarolli, P., 2012. Modelling catchment-scale shallow landslide occurrence by means of a subsurface flow path connectivity index. Hydrol. Earth Syst. Sci. Discuss. 9 (3), 4101–4134.

Lee, M., Malyshev, S., Shevliakova, E., Milly, P.C.D., Jaffe, P.R., 2014. Capturing interactions between nitrogen and hydrological cycles under historical climate and land use: susquehanna watershed analysis with the GFDL land model LM3-TAN. Biogeosciences 11, 5809–5826. https://doi.org/10.5194/bg-11-5809-2014.

Liu, S., Jiang, M., 2011. Providing efficient decision support for green operations management: An integrated perspective. In: Jao, C. (Ed.), Efficient Decision Support Systems: Practice and Challenges in Multidisciplinary Domains. InTech, London, pp. 247–270.

Loades, K.W., Bengough, A.G., Bransby, M.F., Hallett, P.D., 2010. Planting density influence on fibrous root reinforcement of soils. Ecol. Eng. 36 (3), 276–284.

Makhdoum, M., 1999. Fundamental of land use planning. Tehran University Press, Tehran, p. 289.

Marvie-Mohadjer, M., 2006. Silviculture. Tehran University Press, Tehran.

Mashayekhan, A., Salman Mahiny, A., 2011. A Multi-Criteria Evaluation approach to Delineation of Suitable areas for Planting Trees (Case Study: Juglans regia in Gharnaveh Watershed of Golestan Province). Journal of Rangeland Science 1 (3), 225–234.

Miller, V.C., 1953. A Quantitative Geomorphic Study of Drainage Basin Characteristics in the Clinch Mountain Area. In: Technical Report 3. Columbia University, Department of Geology.

Mirzai, M., Sajadi, A., Nazari, A., 2014. Modeling and simulation of watershed erosion: Case study of Latian dam watershed. Int J Phys Sci 9 (9), 224–232.

Moore, I.D., Grayson, R.B., Ladson, A.R., 1991. Digital terrain modelling: a review of hydrological, geomorphological, and biological applications. Hydrol. Process. 5 (1), 3–30.

Moore, I., Turner, A.K., Wilson, J.P., Jenson, S.K., Band, L.E., 1993. GIS and land-surface subsurface process modeling. Environmental modeling with GIS 20, 196–230.

Mozafarian, V., 2004. Trees and Shrubs of Iran. Farhang Moaser Press, Tehran.

Nin, M., Soutullo, A., Rodríguez-Gallego, L., Di Minin, E., 2016. Ecosystem services-based land planning for environmental impact avoidance. Ecosyst Serv 17, 172–184.

Peyrowan, H.R., Shariat Jafari, M., Lotfollah Zadeh, D., 2017. Impact of landslides on sediment load of Jajrood River. Iranian J. Watershed Manag. Sci. Eng. 9 (2), 179–189.

Pr´evot-Julliard, A.C., Clavel, J., Teillac-Deschamps, P., Julliard, R., 2011. The need for flexibility in conservation practices: exotic species as an example. J. Environ. Manag. 47 (3), 315–321.

Rahmati, O., Samadi, M., Shahabi, H., Azareh, A., Rafiei-Sardooi, E., Alilou, H., Melesse, A.M., Pradhan, B., Chapi, K., Shirzadi, A., 2019. SWPT: an automated GIS-based tool for prioritization of sub-watersheds based on morphometric and topo hydrological factors. Geosci. Front. 10 (6), 2167–2175.

Ratnam, K.N., Srivastava, Y.K., Rao, V.V., Amminedu, E., Murthy, K.S.R., 2005. Check dam positioning by prioritization of micro-watersheds using SYI model and morphometric analysis—remote sensing and GIS perspective. J. Indian Soc. Remote. Sens. 33 (1), 25.

Ravanbakhsh, H., Moshki, A., 2016. The influence of environmental variables on distribution patterns of Irano-Turanian forests in Alborz Mountains, Iran. J. Mt. Sci. 13 (8), 1375–1386.

Ravanbakhsh, H., HamzeH'Ee, B., Etemad, V., Marvie Mohadjer, M.R., Assadi, M., 2016. Phytosociology of *Juniperus excelsa* M. Bieb forests in Alborz mountain range in the north of Iran Plant Biosyst 150 (5), 987–1000.

Ribe, R.G., 1989. The aesthetics of forestry: what has empirical preference research taught us? Environ. Manage. 13 (1), 55–74.

Saaty, T.L., 2005. Theory and Applications of the Analytic Network Process: Decision Making with Benefits, Opportunities, Costs, and Risks. RWS publications.

Sabeti, H.A., 1976. Forests, Trees and Shrubs of Iran. Ministry of Agriculture and Natural Resources press, Tehran.

Sadeghi, S.M.M., Attarod, P., Van Stan, J.T., Pypker, T.G., 2016. The importance of considering rainfall partitioning in afforestation initiatives in semi-arid climates: a comparison of common planted tree species in Tehran. Iran Sci Total Environ 568, 845–855.

Sagheb-Talebi, K., Yousefi, P., Kananian, M., 2009. Forest rehabilitation in Iran. Keep Asia green 4.

Sajedi-Hosseini, F., Choubin, B., Solaimani, K., Cerda, ` A., Kavian, A., 2018. Spatial prediction of soil erosion susceptibility using FANP: application of the Fuzzy DEMATEL approach. Land Degrad. Dev. 29 (9), 3092–3103. https://doi.org/ 10.1002/ldr.3058.

Schmidt, F., Persson, A., 2003. Comparison of DEM data capture and topographic wetness indices. Precis. Agric. 4 (2), 179–192.

Schumm, S.A., 1954. The relation of drainage basin relief to sediment loss. Int Assoc Sci Hydrol 36, 216–219.

Sevruk, B., 1997. Regional dependency of precipitation-altitude relationship in the Swiss Alps. Climatic Change at High Elevation Sites Springer Netherlands 123–137. https://doi.org/10.1007/978-94-015-8905-5_7.

Singh, S., 1994. Remote-Sensing in the evacuation of morpho-hydrological characteristics of the drainage basins of the jojri catchment. Ann. Arid Zone 33 (4), 273–278.

Thakkar, A.K., Dhiman, S.D., 2007. Morphometric analysis and prioritization of mini watersheds in Mohr watershed, Gujarat using remote sensing and GIS techniques. J Indian Soc Remote Sens 35 (4), 313–321.

Triantaphyllou, E., Mann, S.H., 1995. Using the analytic hierarchy process for decision making in engineering applications: some challenges. IJIETAP 2 (1), 35–44.

Vettorazzi, C.A., Valente, R.A., 2016. Priority areas for forest restoration aiming at the conservation of water resources. Ecol. Eng. 94, 255–267.

Wang, F., Wang, Z., Leeb, J.H.W., 2007. Acceleration of vegetation succession on eroded land by reforestation in a subtropical zone. Ecol. Eng. 31, 232–241.

Webb, D.B., 1973. The Introduction and Trial of Exotic Tree Species in the Semi-Arid Zone of Iran. Internal report, Research Institute of Forests and Rangelands, Tehran.

Wilby, R.L., Keenan, R., 2012. Adapting to flood risk under climate change. Prog. Phys. Geogr. 36 (3), 348–378.

Zare, R., Fathi, M., Pour, M.J., Babaei, S., 2014. Positioning of appropriate land uses for forest management by multi criteria decision methods and GIS (Dareh Vesyeh Watershed in Tehran). J Biodivers Environ Sci 4 (2), 225–236.

Suplementary information

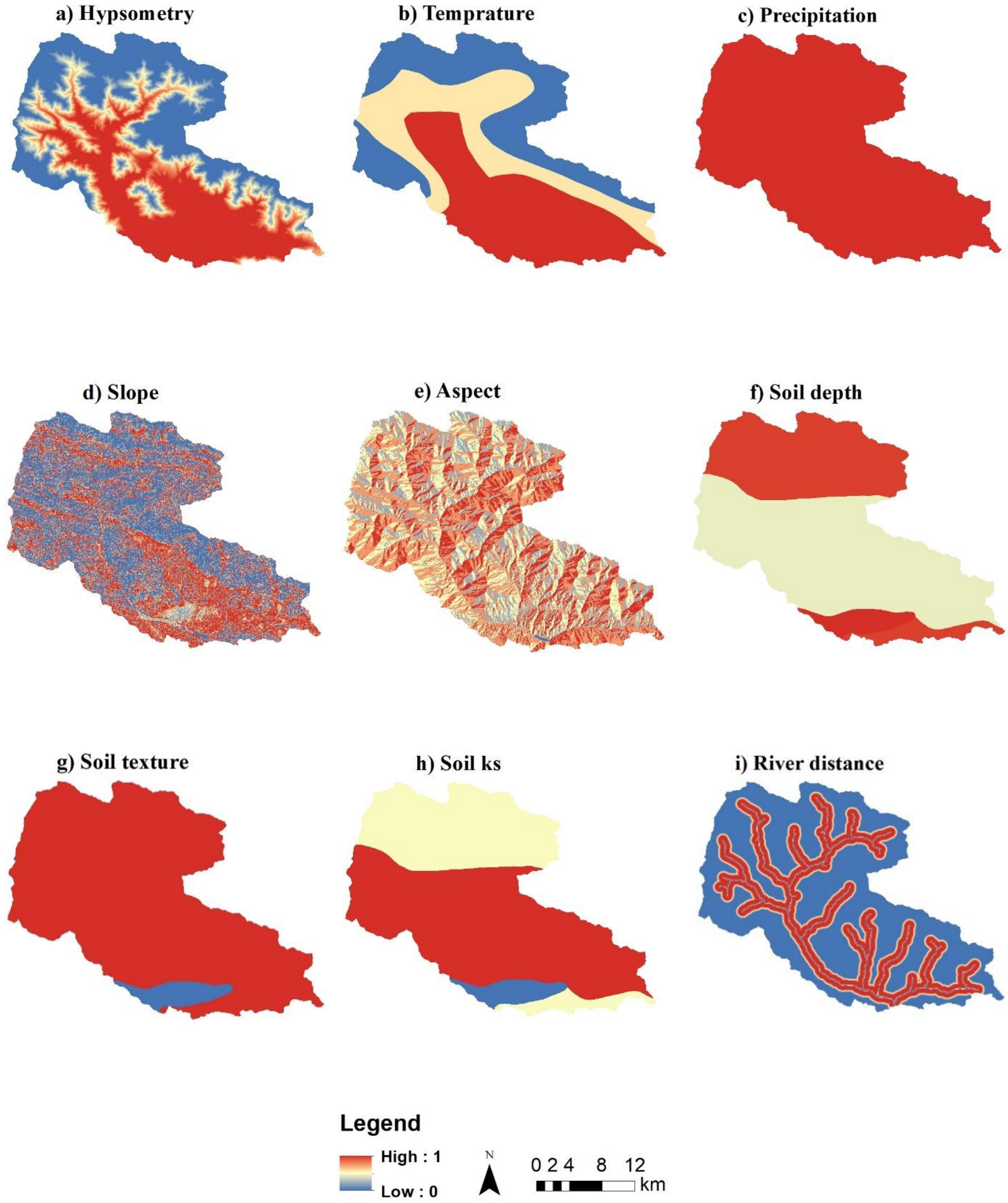

Fig. S1. Standardized maps of environmental variables: (a) hypsometry, (b) temprature, (c) precipitation, (d) slope, (e) aspect, (f) soil depth, (g) soil texture, (h) soil ks, (i) river distance.

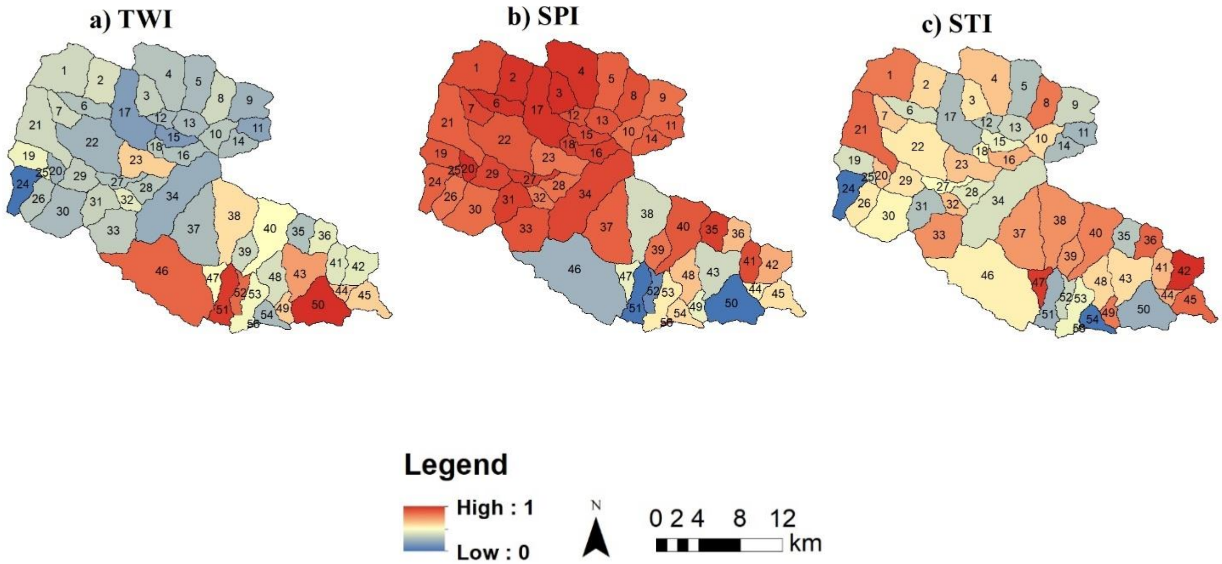

Fig. S2. Normalized topographical indices: (a) topographic wetness index (TWI), (b) stream power index (SPI), and (c) sediment transport index (STI).

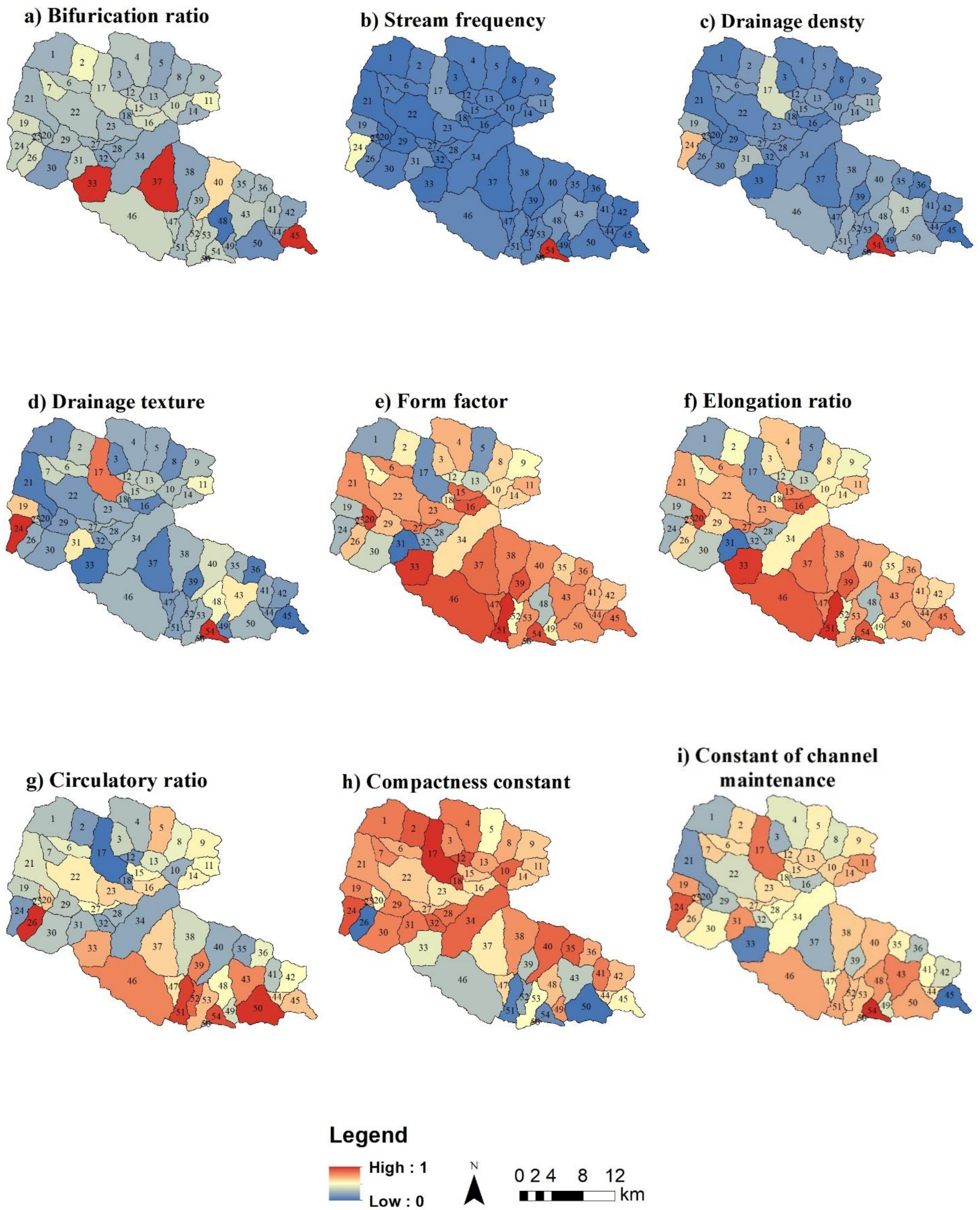

Fig. S3. Normalized morphometric characteristics: (a) bifurcation ratio, (b) stream frequency, (c) drainage density, (d) drainage texture, (e) form factor, (f) elongation ratio, (g) circularity ratio, (h) compactness coefficient, (i) constant of channel maintenance.

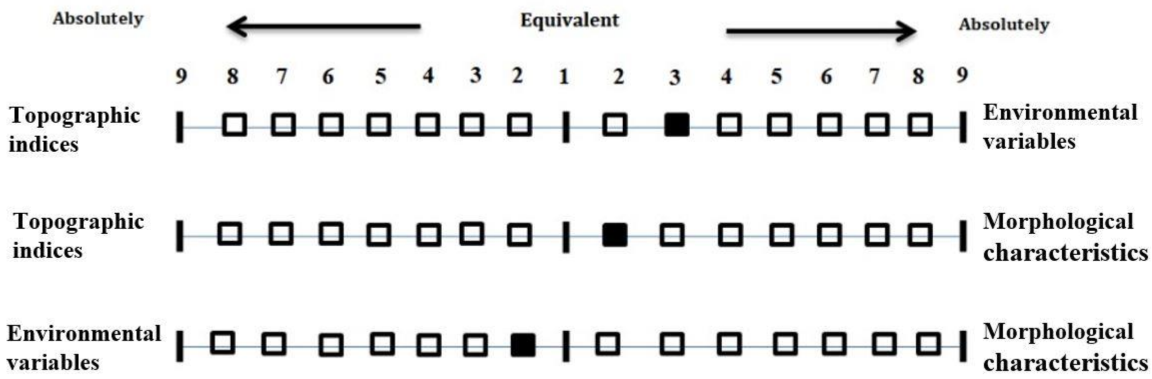

Fig. S4 An example of pairwise comparison questionnaire

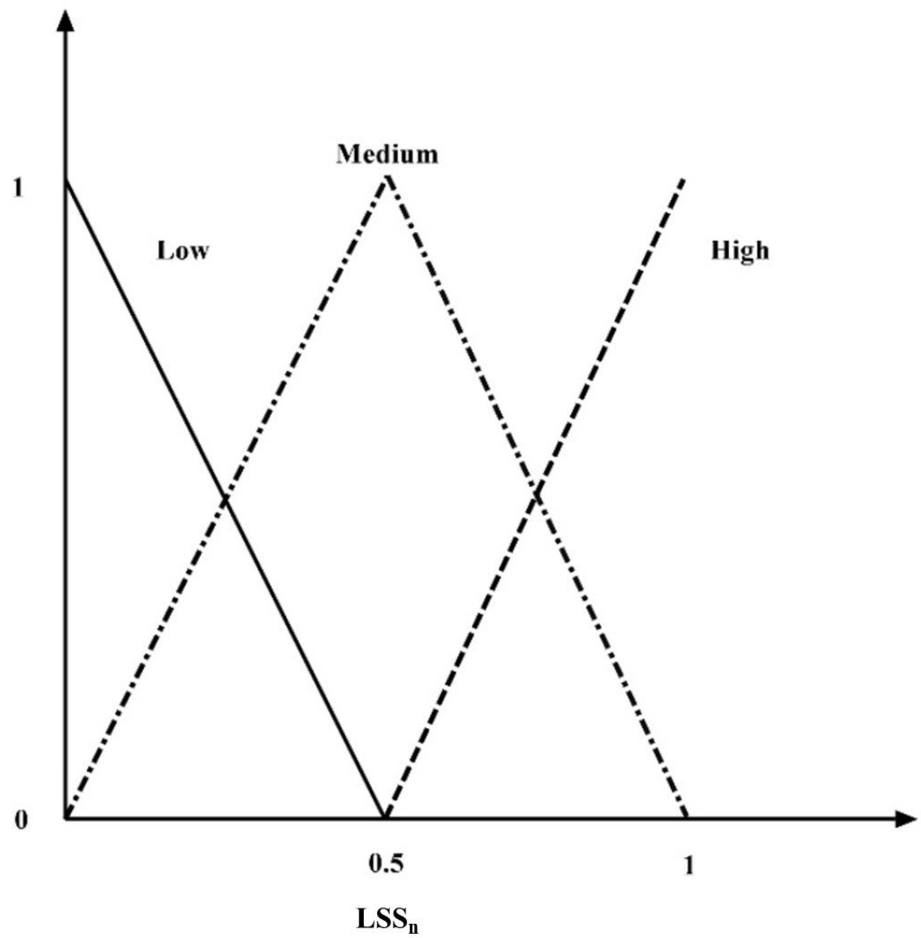

Fig. S5 Fuzzy membership function