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Evaluating land suitability for *Rhus coriaria* L. (Sumac) by habitat suitability model

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Abstract: The cultivation of *Rhus coriaria* has become necessary to preserve their wild populations. To be competitive in the international market, it is important to develop an efficient production chain to reduce costs and improve the quality of the products. The main objective of this study is to provide a method to determine the suitable areas to develop the *R. coriaria* cultivation with a case study in Gonabad County of Iran. A habitat suitability model (HSM) was applied to survey the distribution of *R. coriaria* and to identify the best areas the growing of its. Three different main criteria including environmental suitability, agronomic suitability, and social-economical suitability selected for the HSM. Then, each of the three main criteria and their multi-specific indicator was defined in Analytic Hierarchy Process (AHP) and the weights of them were calculated by pairwise comparison matrix. In the next stage, the weights are applied to their layers such as hypsometry, slope, slope aspect, mean annual precipitation, mean annual temperature, soil texture, landuse, water resource type, water resource quality and quantity, road network, and land ownership as roaster layers. The results of the HSM showed a weighted map of land suitability for the *R. coriaria* that included the maximum and minimum potential of areas for its planting. Based on these results, the areas with the highest suitability for the *R. coriaria* are strictly associated with precipitation, soil texture, and water resources type.

Key words: AHP; cultivation; HSM; SMCDM; spice; Sumac

Ovrednotenje primernosti zemljišč za uspevanje strojilnega octovca (*Rhus coriaria* L.) z modelom primernega habitata

Izvleček: Gojenje strojilnega octovca (*Rhus coriaria* L.) postaja nuja za ohranjanje njegovih populacij v naravi. Za obstoj konkurenčnosti na mednarodnih trgih je pomembno razviti učinkovito proizvodno verigo za zmanjšanje stroškov in izboljšanje produktov iz te rastline. Namen te raziskave je bil razviti metodo določanja primernih območij za gojenje strojilnega octovca z vzorčno študijo v provinci Gonabad, Iran. Pri popisu razširjenosti strojilnega octovca je bil uporabljen model primernega habitata (A habitat suitability model -HSM) za določitev najboljših območij za njegovo uspevanje. Za model HSM so bili izbrani trije glavni kriteriji, ki so obsegali okoljsko, agronomsko in socio-ekonomsko primernost. Nato so bili vsem trem glavnim kriterijem določeni multispecifični indikatorji v analitičnem hierarhičnem procesu (AHP), kjer so bile njihove uteži izračunane na osnovi relativnih prioritet. V naslednji fazi so bile uteži uporabljene za parametre kot so razgibanost reliefa (hipsometrija), nagib terena, poprečna letna količina padavin, poprečna letna temperatura, tekstura tal, raba tal, vrsta, količina in kakovost vodnih virov, razvitost cestnega omrežja in lastništvo zemljišča kot glavne plasti. Rezultati HSM modela so pokazali uravnoteženo karto primernosti zemljišč, ki je vsebovala maksimalno in minimalno potencialno primerna območja za gojenje te vrste. Na osnovi teh rezulatov so najbolj primerna območja za gojenje strojilnega octovca tesno povezana s padavinami, teksturo tal in vrsto vodnega vira.

Ključne besede: AHP; gojenje; HSM; SMCDM; dišava; strojilni octovec

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1 INTRODUCTION

Rhus coriaria L. which is commonly known as Sumac is widely growing throughout Middle Eastern countries such as Iran. Sumac is a very popular spice in food production. It gives a sour lemon taste to food and is consumed for various foods, spatially meat dishes (Morshedloo et al., 2018).

The cultivation of *R. coriaria* has become necessary to preserve their wild populations. Also, to be competitive in the international market, it is important to develop an efficient production chain to reduce costs and improve the quality of the products. For developing a wild crop in a particular area, such as *R. coriaria*, land suitability analysis is a requisite to achieve optimum exploitation of the available land resources for sustainable agricultural production (Nisar et al., 2000).

To evaluate land suitability for a specific species, it is important to know its specific habitat of it (Barbaro et al., 2011). The habitat is an area with a combination of resources (such as food, cover, water) and environmental conditions (temperature, precipitation, presence or absence of predators and competitors) that promotes the occupation of individuals of a certain species (or population) and allows to those individuals to survive and reproduce (Morrison et al., 2006). For plants, the habitat suitability models (HSMs) are tools to analyze the best areas for growing using land knowledge (Hirzel et al., 2001). The HSMs are used both to predict the distribution of a specific plant species and to identify the best areas for its growth (Guisan & Zimmermann, 2000). HSMs allow being evaluated the quality of the habitat for a species within its study area. In GIS, HSMs apply land suitability to layers such as land use, elevation, slope, slope aspect, roads network, water sources, and other important factors as a raster-based layer (Barbaro et al., 2011). One of the common ways to build the LSM is a literature review and expert opinion. The procedure requires expert knowledge to assign a weight to each factor and a land suitability score to each class within a factor. Suitability scores for all factors are then combined to form a single land suitability map with a suitability score for each pixel (Barbaro et al., 2011).

One of these solutions for this purpose is using the spatial multi-criteria decision making (SMCDM) methods. Integrating the geographical information systems (GIS) with multi-criteria decision making (MCDM) methods leads to SMCDM methods (Malczewski, 1999).

The analytic hierarchy process (AHP) is one of the main methods of the MCDM which can be used for allocating weights to indicators. The AHP is a mathematical model which was developed for solving the multi-criteria decision making by Saaty in 1977. The most important abilities of it consider both quantitative and qualitative criteria (Taslicali & Ercan, 2006). In general, the AHP model is composed of a goal, criteria, sub-criteria, and alternatives (Buyukyazc & Sucu, 2003).

A GIS-based model can be applied for conservation planning and regional management and determining the best growing areas (Barbaro et al., 2011). Several GIS models have been developed to evaluate the suitability of cropland. Sicat Rodrigo et al. (2004) introduced a fuzzy modeling method to evaluate farmers' knowledge to create a cropland suitability classification. Liu et al. (2006) showed methods to analyze the land suitability in the Qinling Mountains of China. Another method was developed by Pirbalouti (2009) to select the best patterns of cropping at a regional level. Recently, a methodology was developed to analyze land suitability for forest plantations (Dengiz et al., 2010). Also, Hua et al. (2010) introduced a GIS-based prediction methodology for the conservation planning of medicinal plant distributions.

Many types of research have been done in the field of environmental management based on MCDM methods. Recently, the AHP-Fuzzy method was used to evaluate rangeland suitability for livestock grazing in the Bagheran Birjand watershed of Iran (Rouhi-Moghaddam et al., 2017). Two methods of MCDM (AHP and analytic network process) were used to estimate the potential areas of flooding in Kakhk paired catchment in Iran and were compared with each other (Eshghizadeh, 2017). Also, the AHP method was used to prioritize and determine the most important factors that affected sediment yield in a semi-arid region of Iran (Eshghizadeh et al., 2015). The groundwater artificial recharge suitable area was determined by GIS and AHP methods in the Silakhor, Borujerd of Iran (Mehrabi et al., 2012). All results showed that the AHP method can prioritize the environmental criteria.

R. coriaria, commonly called sumac, is a deciduous shrub to a small tree in the Anacardiaceae family. The *R. coriaria* grows up to 5 meters and has composite leaves of 9 to 15 leaflets that are covered with cracks. It is in flower from March to April and is hermaphrodite. It can grow in all three types of sandy, loamy, and clay soil texture but prefers well-drained soil. Suitable soil reaction is from acid to neutral and basic. It is not shade-tolerant. It can grow in both dry and moist soil. The *R. coriaria* is a native shrub in southern Europe and western Mediterranean and Iran (Shahrokhi, 2015).

Due to the occurrence of perennial droughts in the east of Iran, many tree and shrub species such as figs, almonds, pomegranates, and grapes were destroyed or severely damaged. While the *R. coriaria* showed good resistance to drought. Based on local farmers' experience and knowledge, this species is one of the most suitable species for development in this area. In the northeastern regions of Iran, which are affected by drought, identifying areas that are suitable for cultivation of the *R. coriaria*, especially in the form of biological and biomechanical watershed management plans, or replacing them as a compatible species by watershed stakeholders can be effective in improving socio-economic status and soil and water protection. Therefore, the main objective of this study is to provide a method to determine the suitable areas to develop the *R. coriaria* cultivation with a case study in Gonabad County, which has the highest area of the *R. coriaria* in the east of Iran. For this purpose, the HSM by integrating GIS and AHP has been developed to survey the current distribution of the *R. coriaria* and to determine the land suitability for its cultivation.

2 MATERIALS AND METHODS

A habitat suitability model of *R. coriaria* was developed by a procedure including three steps: i) the definition of an analytical hierarchical model; ii) the preparation of data; iii) the implementation of the procedure on the raster layers in the GIS.

2.1 DEFINITION OF THE ANALYTICAL HIERARCHICAL MODEL

An analytical hierarchical model is defined in an analytic hierarchy process (AHP). In general, an AHP model is composed of a goal, criteria, sub-criteria, and alternatives (Buyukyazc and Sucu, 2003). Because of the success a supply chain of *R. coriaria* relies on the satisfaction of different criteria, three different main criteria have been evaluated from different aspects:

- environmental suitability criteria
- agronomic suitability criteria
- socio-economic suitability criteria.

For each of the three main criteria, multi-specific indicators (sub-criteria) were defined in the AHP model as shown in Figure 1. This classify was done based on the main factors that control the growth of *R. coriaria* in the study area (Shahrokhi, 2015; Saghari et al., 2017).

Table 1: Saaty's fundamental scale (Saaty, 1980)

Intensity of importance	Definition
1	Equal importance
3	Moderate importance
5	Strong importance
7	Very strong importance
9	Extreme importance
2, 4, 6, 8	Intermediate values

In the AHP model, the weight of each main criteria and their sub-criteria were calculated by a pairwise comparison matrix. In a pairwise comparison matrix, the elements of one level of the hierarchy model are compared as a pairwise judgment based on Table 1. For each level of the hierarchy, a matrix of relative weights is generated based on the results of the pairwise comparisons. Since pairwise comparisons are based on personal judgments, consistency among pairwise comparisons has to be verified. This verification is done by determining consistency ratios computed for each pairwise comparison (Saaty, 1980).

The matrices of the pairwise comparisons were entered into the Expert choice (EC) program. The EC program presents a graph of the weights and shows their inconsistency. In general, if the inconsistency rate is less than 0.1, the inconsistency is acceptable. If more than 0.1 should be revised in the judgments (Saaty and Vargas, 2006).

2.2 PREPARATION AND ANALYSIS OF DATA

Data for three main criteria and their multi-specific indicator (sub-criteria) were prepared in a GIS environment (ILWIS 3). The hypsometry, slope, and aspect maps were created by a digital elevation model (DEM). The source of DEM was topographic maps that were prepared from the database of the natural resources and watershed management department of Gonabad County. The original spatial resolution of the map was 30 x 30 m that due to the large volume of data and area of the study area became 100 x 100 meters to run the calculations in GIS layers.

The main source of climatic data was the national meteorological station located in the northeast of Iran. For this purpose, stations located up to a radius of 100 km in the study area, including 15 synoptic, climatological, and evaporative stations were used. After examining the correlation relationships between stations, the mean annual precipitation and temperature maps were created by calculating the correlations between temperature and precipitation with the altitude of each station and applying their gradient equation on the DEM map of the study area.

The soil, landuse, water resources, road network, and land ownership maps were obtained from the database of the department of natural resources and watershed management in Gonabad County. All the layers were classified based on the optimal conditions for *R. co-*

riaria (Figure 1) in the ILWIS 3. The final weight of each class for criteria and sub-criteria was calculated via multiplying the relative importance of criteria by the relative importance of their sub-criteria and classes. Then, the final calculated weights in the AHP model were imported to the classes of each layer in the ILWIS 3. In the next stage, the weight map of each criterion was prepared by applying the sum operator on their sub-criteria layers in ILWIS 3. In the final, a value map of land suitability was calculated by summing of the weight maps of environmental, agronomic, and social-economical layers.

2.3 STUDY AREA

The study area was Gonabad County, in Razavi Khorasan province, northeast of Iran. The study area is part of the Dasht-e Kavir of Iran and is located in the east of it (Figure 2). The elevation range is between 839 and 2830 meters above sea level. The general slope of the area is from south to north in the mountain. The average annual precipitation is 148 mm in the Gonabad synoptic station. Also, the average annual evaporation is 1800 mm and the temperature is 17.5 °C. The current climate in the study area is arid in the north to semi-arid in the south.

3 RESULTS AND DISCUSSION

The evaluation procedure aimed to create an HSM by MCDM method at a regional scale, following the principle of the best available data. The implementation of the land evaluation procedure allowed the most suitable areas for cropping *R. coriaria* on the considered territory to be identified.

In HSM must be considered the ecologic, agronom-

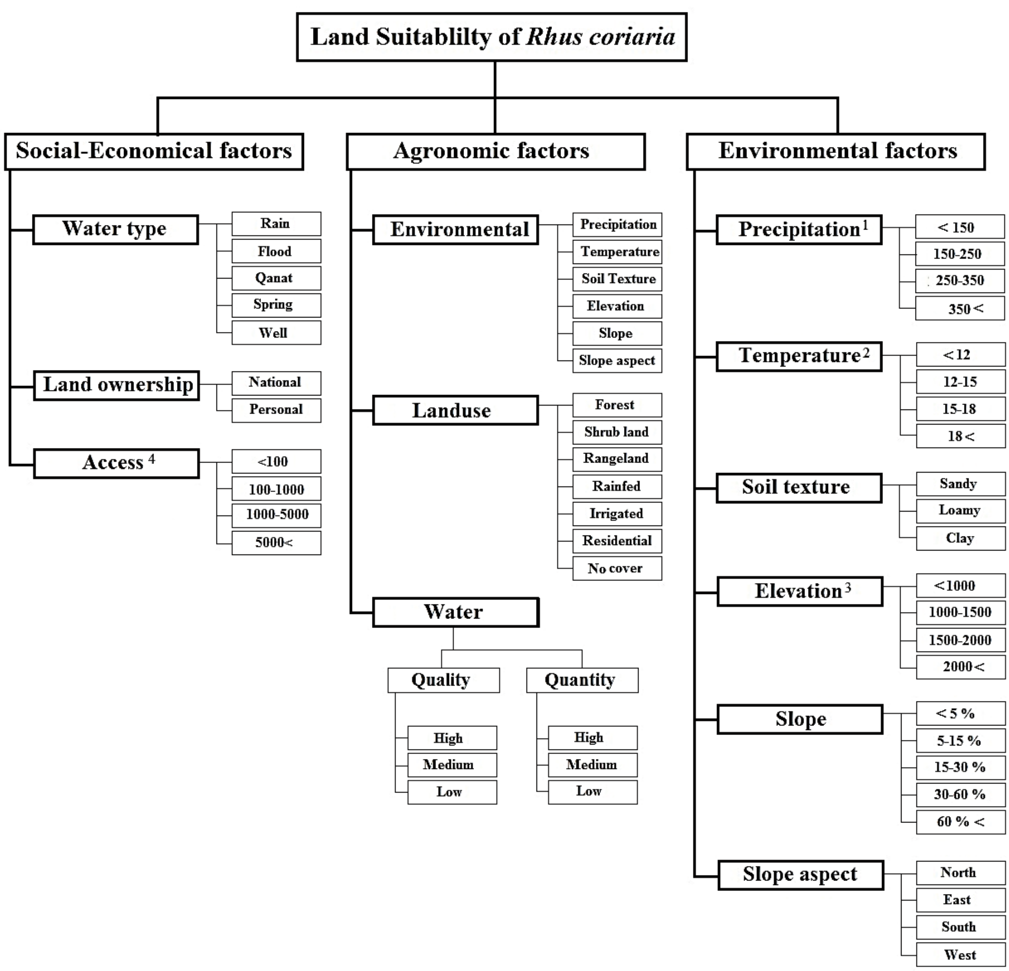

Figure 1: Analytical hierarchical model of the three main criteria and their specific indicator and classes in the AHP model for evaluating land suitability of *R. coriaria*, [1]: Average annual precipitation in mm, [2]: Average annual temperature in °C, [3]: Elevation range is in meter above sea level, [4]: Distance in meters (Saaty, 1980)

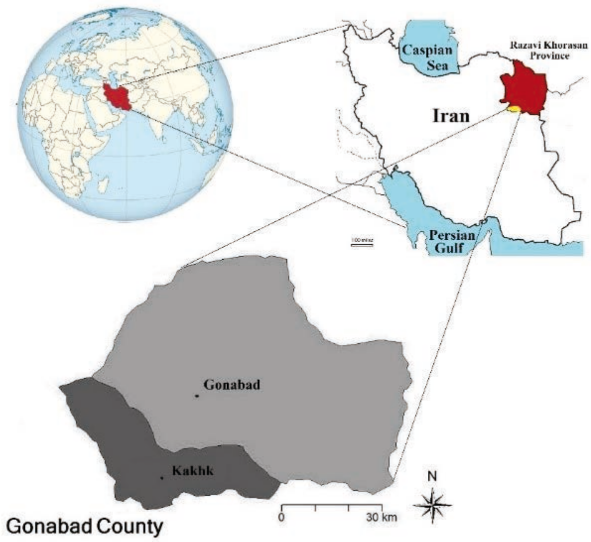

Figure 2: Location of the studied area

ic, logistic, and socio-economic aspects of a plant species for development (Barbaro et al., 2011). In this study, the main factors of them were also considered for cropping *R. coriaria*. Then, the synthesis weights them calculated by the AHP model. The synthesis weights of sub-criteria and classes are shown in Table 2. The results indicate the priority of the main factors in the development of *R. coriaria* planting. Table 3 shows the priority of the sub-criteria for cropping *R. coriaria* in the study area. Based on the results, the most important sub-criteria for cropping *R. coriaria* is precipitation (0.306) and the lowest importance of them was landuse (0.009).

Based on the results, the synthesis weights were imported on the classes of sub-criteria layers in ILWIS 3 and were created synthesis weighting maps (Figure 3). This figure shows the variation of the weight for cropping *R. coriaria* in the study area. For some sub-criteria such as precipitation, temperature, elevation, water resources, and slope a uniform and directional distribution can be considered for them, which shows that they are more influenced by the physiographic characteristics of the region. But some other sub-criteria such as soil texture, slope aspect, water resource type, land ownership, access, and landuse with non-distributed and no specific direction can be predicted for them.

This study, like the study of Barbaro et al (2011), provided a method for the decision-making process to develop a product on a regional scale. The results of Barbaro et al. (2011) for the development of medicinal plants in Italy, the parameters of elevation (above sea level) and distance of road had the greatest impact on locating suitable places for the development of medicinal plants. In this method, the role of elevation as a direct effect to calculate precipitation through the precipitation gradient and digital elevation model can be seen in the precipitation parameter. Therefore, it can be said that elevation is one of the most important parameters in the cultivation of medicinal plants such as *R. coriaria*. The results of Ghasemi Pirbalouti et al. (2011) confirmed that elevation alone did not affect land suitability, because this factor affected climatic, soil, and agronomic management variables. Also, Hirzel et al. (2001) has confirmed that climatic parameters are among the most important factors that control species' distribution. Therefore, topography mostly affects species indirectly through its correlation with climatic parameters.

As a main result, the factors derived from Digital Elevation Model (e.g. slope, aspect, precipitation, and temperature) are often crucial for the growth of plants, because they control local conditions of light, soil moisture, temperature, soil stability, and nutrient leaching, etc.

After integrating synthesis weights maps, the suitability map was created in the ILWIS 3. Figure 4 shows the final suitability map for *R. coriaria* in Gonabad County. This map showed that the maximum integrated weight for the growth of *R. coriaria* located in the south of the study area. Based on the results, the potential cropping surface for the *R. coriaria* was about 61410 ha (11.9 %), whereas 12819 ha (2.5 %) of these have been classified with very high and high suitability for *R. coriaria*.

Using the analytical hierarchical model showed that the areas that were more suitable for *R. coriaria* cropping had a higher weight in precipitation, soil texture, and water resources type sub-criteria (Figure 5). In particular, it can be seen that the most suitable areas for *R. coriaria* are the mountain areas. The studied was done by Morshedloo et al. (2018) showed that the habitat of the *R. coriaria* is a mountain of an arid, semi-arid, and inferior semi-arid region.

According to studies, the value of a factor can affect other parameters (Eshghizadeh et al., 2016). For example, Saghari et al, (2017) have expressed that the growth and development of *R. coriaria* at altitudes less than 2000 meters in the study area, make clear the effect of the slope aspect on it. Therefore, the method used in this research can be a suitable method for integrating different factors to calculate the final map of land suitability for *R. coriaria*. In similar research, Ghasemi Pirbalouti et al. (2011) were used a GIS-based suitability model by agro-ecological variables such as soil, climate, and topographical environmental components to identify suitable areas for chamomile (*Matricaria chamomilla* L.) production in Iran. Also, this result, like the studies conducted by Eshghizadeh et al. (2015), Eshghizadeh and Noura (2013), Hajkowicz and Collins (2007), showed that the AHP can be used in the studies of natural resources.

Table 2: Calculated synthesis weights of sub-criteria and classes by AHP model

sub-criteria and classes	synthesis weight	sub-criteria and classes	synthesis weight
Precipitation (mm) = 0.306		Slope aspect = 0.064	
> 350	0.168	North	0.041
250-350	0.099	East	0.015
150-250	0.028	South	0.004
< 150	0.011	West	0.004
Soil texture = 0.261		Elevation (m) above sea level = 0.057	
Sandy	0.128	> 2000	0.033
Loamy	0.116	1500-2000	0.018
Clay	0.018	1000-1500	0.004
		< 1000	0.002
Temperature °C = 0.042		Slope % = 0.021	
> 15	0.002	> 60	0.001
15-18	0.004	30-60	0.008
12-18	0.018	15-30	0.018
< 12	0.018	5-15	0.002
		< 5	0.001
Environmental of agronomy = 0.078		Water = 0.038	
Soil texture	0.035	Quality = 0.019	
Precipitation	0.023	High	0.013
Slope aspect	0.002	Medium	0.005
Elevation	0.004	Low	0.001
Temperature	0.007	Quantity = 0.019	
Slope	0.006	High	0.013
		Medium	0.004
		Low	0.001
Landuse = 0.009		Water resource type = 0.099	
Forest	0.003	Rain	0.048
Irrigation agriculture	0.002	Flood	0.037
Shrubland	0.002	Spring	0.007
Rainfed	0.001	Qanat	0.006
Range	< 0.001	Well	0.003
Residential	< 0.001		
Rocky and unusable	< 0.001		
Land ownership = 0.015		Access (m) = 0.010	
National land	0.013	> 5000	< 0.001
Personal land	0.002	1000-5000	0.002
		100-1000	0.002
		<100	0.006

Table 3: Priority of the sub-criteria for cropping R. coriaria in the study area

Priority	Sub-criteria	Priority	Sub-criteria
1	Precipitation	7	Temperature
2	Soil texture	8	Water
3	Water resource type	9	Slope
4	Environmental of agronomy	10	Land ownership
5	Slope aspect	11	Access
6	Elevation	12	Landuse

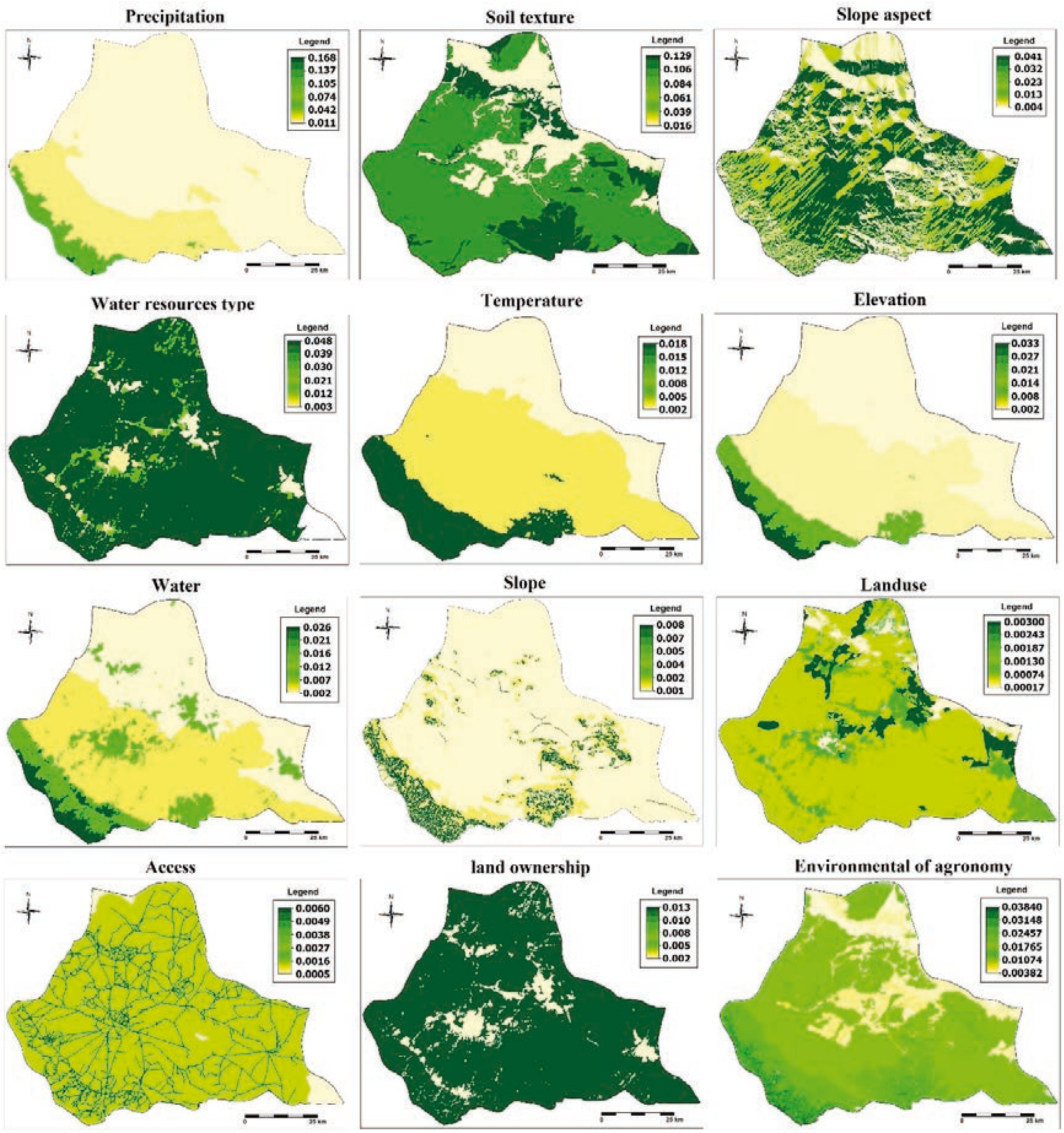

Figure 3: Synthesis weight maps of multi-specific indicator (sub-criteria) for *Rhus coriaria* in the study area. A higher value represents more suitable conditions for the growth of *Rhus coriaria*

The total area of *R. coriaria* in the studied area has been reported 1050 ha (Ministry of Agriculture Jihad, 2017). Based on the results, the HSM showed that all lands in the studied area with the very high suitability for the planting of *R. coriaria* have been implemented before time by native stakeholders based on native knowledge. However, only 6.7 % of the lands with high suitability have been cultivated by them. The fruits of *R. coriaria* have great economic importance as a natural resource of bioactive compounds and its consumption has been increasing around the world (Abu-Reideh et al., 2014; Kizil & Turk, 2010; Shabbir, 2012).

However, the total production of *R. coriaria* in the studied area has been reported as 162.5 tons/year (Ministry of Agriculture Jihad, 2017). By cultivating *R. coriaria* in lands with high and very high suitability, the production of it can be reached up to 3200 tons/year. Moreover, vegetation, directly and indirectly, affects runoff, erosion, and sediment (Eshghizadeh et al., 2016). The canopy cover, litter, and roots of *R. coriaria* can reduce surface runoff and soil loss. To develop a spatial crop in a region, Barbaro et al. (2011) emphasize that a crop-land suitability analysis must be done as a prerequisite to achieving sustainable agricultural production. However, the results

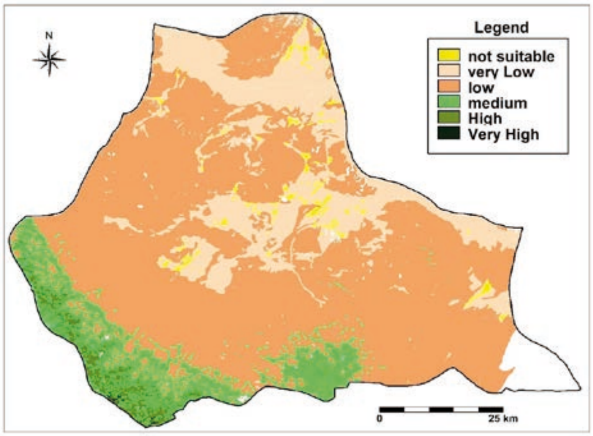

Figure 4: Suitability map for *Rhus coriaria* in the study area

of an HSM directly depend on the input data, selected factors, and evaluation procedure. Therefore, different factors and weights will determine different output habitat suitability maps. However, the main limiting factors in an HSM that can be considered are the geomorphology (slope and elevation), climate (precipitation), and agronomic management. Also, the evaluation model for this purpose does not include other aspects such as competition with other crops that could be considered in the assessment of the study area.

4 CONCLUSIONS

This research reports the creation of a methodology to evaluate land suitability of *R. coriaria* and can be used to biological management in natural resources. A weighted map of land suitability for *R. coriaria* shows the maximum and minimum potential of areas for its planting. This information helps to compare and rank subcatchments, catchments, basins, and watersheds for the development of its cultivation.

The presented method has some specific characteristics: i) It is not specific to a particular plant and can be used for different plant species; ii) it can be easily repeated in different areas; iii) the repeatability allows a reduction in the costs of the procedure implementation and easy repetition of the procedure in the case of missing or incorrect input data.

This methodology, based on data layers, can consider environmental adaptation, productivity, quality of the production, and logistics requirements for specific plant production. Also, it can provide information for local governments to select optimum landuse plans at a regional scale. The method used in this research can be easily adapted to different plants. For the application of it, a dataset of grid layers of land characteristics and defining the special parameters for a specific plant are required as

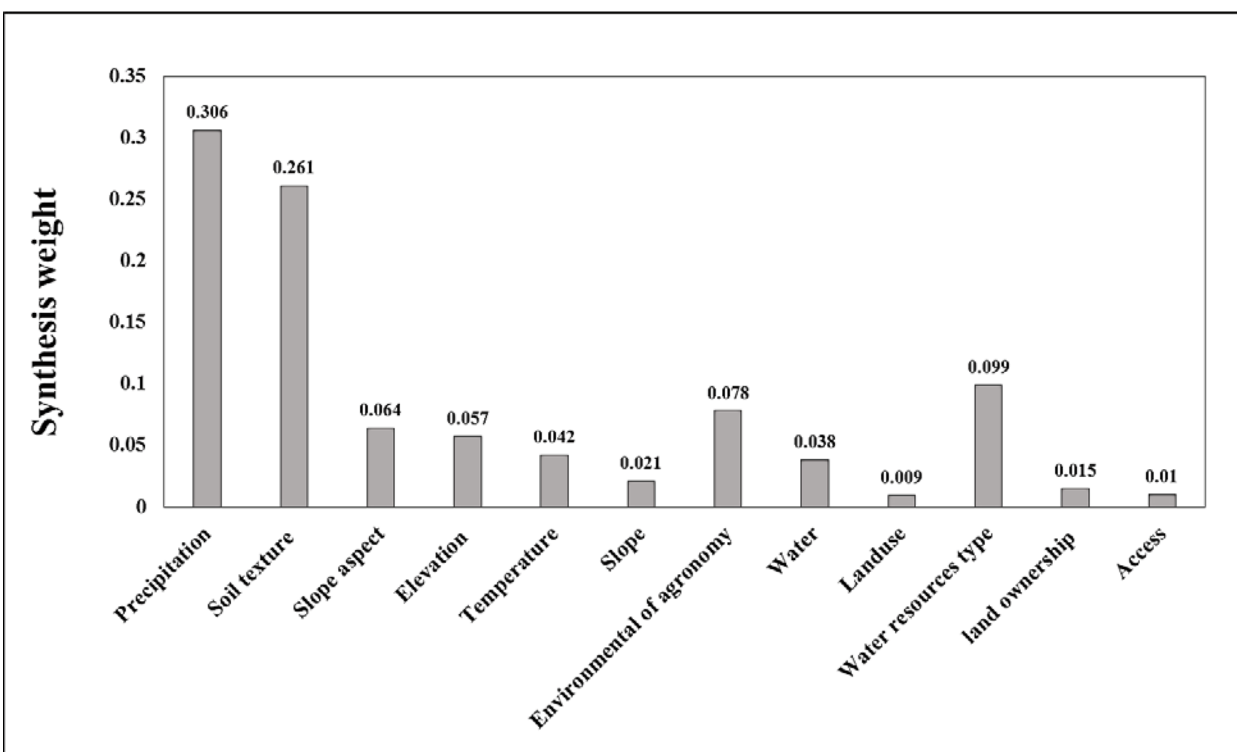

Figure 5: Synthesis weight of multi-specific indicator (sub-criteria) of the three main criteria

inputs. Spatially, biological measures in watershed management plans can be used to select and prioritize the lands for planting species. Therefore, the success rate of these projects can be increased.

5 CONFLICT OF INTEREST

The author declares that there is no conflict of interest regarding the publication of this manuscript.

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