Journal of Nature and Spatial Sciences (2023) 3(1), 12–24

Available online at https://jonass.meybod.iau.ir/

Journal of Nature and Spatial Sciences

Journal homepage: https://jonass.meybod.iau.ir/

Case Study

A hybrid method of parametric-factor analysis in land suitability evaluation for *Ferula communis*

Ali Bagherzadeh[a,*], Alireza Anvarkhah Hokmabadi[b], Maryam Tatari[c], Majid Rahimizadeh[d]

[a] *Associate professor, Department of Agriculture, Mashhad Branch, Islamic Azad University,Iran*
[b]*Ph.D. student, Faculty of Agriculture, Shirvan Branch, Islamic Azad University, Shirvan, Iran*
[c]*Assistant Professor, Faculty of Agriculture, Shirvan Branch, Islamic Azad University, Shirvan, Iran*
[d] *Assistant Professor, Department of Agriculture, Bojnord Branch, Islamic Azad University, Bojnourd, Iran*

ARTICLE INFO

Article history:
Receive Date: 03 August 2022
Revise Date: 29 January 2023
Accept Date: 06 February 2023

Keywords:
Ferula
GIS
Hybrid Method
Land Evaluation
PCA

ABSTRACT

Background and objective: Lack of knowledge of the vital factors in the production and cultivation of crops in unsuitable areas can increase the use of chemical fertilizers to avoid reducing the yield of crops. Due to the constant decline in arable land, it is important to identify the best areas for sustainable agriculture. This study aimed to assess land suitability zoning of 36700 points for the Ferula plantation in the Khorasan province in the north of Iran.
Materials and methods: In the present study, the factor analysis (FA) by principal component analysis (PCA) method as multivariate statistical was applied to evaluate the Land suitability zonation of 36700 points for Ferula plantation in North Khorasan Province, NE Iran. For this purpose, extracted 16 variables were processed, resulting in four factors that explain about 90 % of the total variance.
Results and conclusion: The explained variances of these factors varied from 25.519 to 9.078 % for factors 1 and 4 after the Varimax rotation, respectively. The zonation map of land suitability revealed that 27.02% (6885/93 km^2) of the surface area was moderately suitable, 67/20% (17125/36 km^2) was marginally suitable and 5.78% (1474.52 km^2) of the region was unsuitable for Ferula production. The moderate suitability class of S2 was mainly distributed within the middle, and northeastern parts of the province, while the southern part of the study area and some scattered parts within the northwest exhibited unsuitability for Ferula production.

1. Introduction

Due to the constant decline in arable land, it is important to identify the best areas for sustainable agriculture (productive and profitable agriculture that protects the environment and is socially just). This requirement has led to the development of land suitability scenarios for agriculture (Abdelkaderand Delali, 2012). Land evaluation procedures increasingly focus on the use of quantitative methods to improve the qualitative interpretation of land resource studies. Crucial to 's assessment of land suitability

* *Corresponding author.* Tel.: +98 9155182701
E-mail address: abagherzazdeh@mshdiau.ac.ir
Peer review under responsibility of Meybod Branch, Islamic Azad University
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DOI: https://doi.org/10.30495/jonass.2023.1964745.1052

is the adaptation of land characteristics to the requirements of expected land use types. Land evaluation results from a complex interaction of physical, chemical, and bioclimatic processes, and evaluation models are reliable enough to accurately predict land behavior (Held et al., 2003; Ball and De la Rosa, 2006). Land evaluation (FAO, 1976) is defined as "the process of evaluating the performance of land when used for specific purposes". The FAO (1976) first developed a common framework for land evaluation based on biophysical factors and the socioeconomic characteristics of an area. However, this approach was difficult to apply to large areas before the development of geographic information systems (GIS), which allowed the use of computational techniques to assess and map soil suitability.

These techniques have become increasingly important as integral parts of agricultural production (Olivas et al., 2007), habitat selection (Manton et al., 2005), and environmental planning (Oleszczuk, 2007). The land suitability evaluation consists of a model that assigns a score to each quality and property of the soil. Soil quality is a complex attribute of land that affects its suitability for a particular type of use, while land properties are any measurable properties of land that can be used to characterize a land unit. Land suitability evaluation examines the degree of suitability of land for a selected use type (Sys et al., 1991) and a general method or estimate of potential land productivity (Rossiter, 1996). Bagherzadeh et al. (2021) assessed the qualitative evaluation of land suitability for planting ash and spruce in the Mashhad plain in the NE Iran. Mansouri Daneshvar et al. (2013) conducted agrometeorological suitability zones in Khorasan Razavi in northeastern Iran. For this purpose, the soil suitability classification was carried out using the hybrid method Parametric-Factor Analysis. The land suitability is the process of predicting the potential use of land based on its characteristics.

The land suitability methodology based on FAO guidelines covers most aspects of climate, soil requirements, and terrain (including soil physical properties, soil fertility, and chemical properties, soil salinity and alkalinity, topography, risk of erosion and humidity) for each culture (Sys et al., 1991; Sys et al., 1993). Factor analysis has been widely used in studies of agroclimatic zoning based on specific meteorological parameters measured in a network of stations or grid points over a long period (Bartzokas and Metaxas, 1995). Principal component analysis (PCA) was first applied to climate classification by Steiner (1965) in the United States. McBoyle (1973) used the technique to obtain the climatic regions of Australia. Russell and Moore (1976) used this approach in their studies of the climates of South Africa and Australia.

In recent years, this type of classification has spread in parallel with the growth of the quantitative revolution in geography (Murray, 1999; Yussof et al., 2004). The basis of the present methodology lies in the qualitative evaluation of the land qualities/properties a compared to the requirements of each specific crop to find the suitability class of the land for the same crop (FAO, 1976). The methodology consists of two main steps: Step 1 is to identify land units with similar terrain and soil conditions, Step 2 is to match the properties of the land units with crop requirements including the traditional matching process, as described in the FAO qualitative land evaluation system (FAO, 1976, 1983, 1985). It used to compare the climate, land terrain properties, soil physical and chemical properties, salinity, and alkalinity for each specific crop requirements developed by Sys et al. (1991). The use of medicinal plants has a long history in Iran. Identifying and determining the ecological characteristics of these plants is a requirement for sustainable and economic exploitation of the existing talents in the field of natural resources. Ferula plant is one of the medicinal species of the mountainous regions of Iran, which is also of great importance from an industrial point of view.

Ferula is one of the most important medicinal plants, which is widely used in the pharmaceutical, perfume and glue industries. So far, about 27 Ferula habitats have been identified in Khorasan province. The present study aims to apply the hybrid method of parametric-factor analysis to estimate the land suitability evaluation for Ferula production in North Khorasan Province, northeast of Iran.

2. Materials and methods

2.1. Geographical position of the study area

The study region with a total area of 25,485.81 km^2 is located between 55° 52′ – 58° 20′ east longitude and 36° 34′ – 38° 17′ north latitude in North Khorasan Province in northeastern Iran (Fig. 1). The climatic characteristics of the study area are predominantly semi-arid with a long-term average annual precipitation of 262.3 mm.

The topographical altitude varies between 270 m above sea level in the Atrak River in the northwest and the 3035 m a.s.l. in the center and east of the study area (Fig. 2). The average annual temperature varies between 19.1 and 28.4 °C with an increasing tendency from east to west. The highest slope gradients belong to heights from east to west of the study area and vary between 0.0 to 46.3 degrees in flatlands and mountainous regions, respectively (Fig. 3).

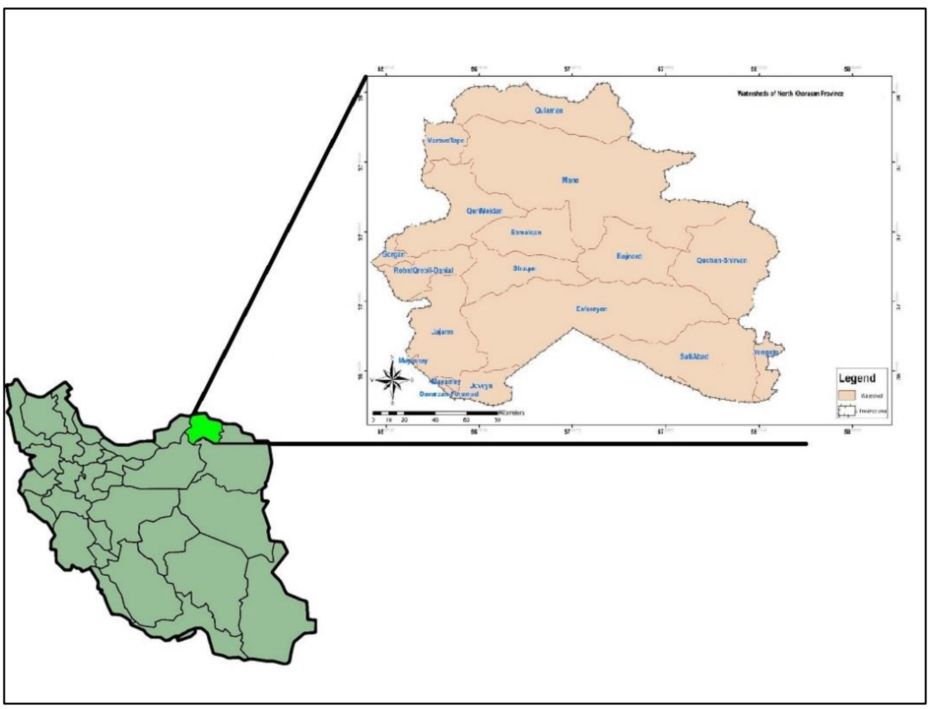

Fig. 1- The geographical position of the study area

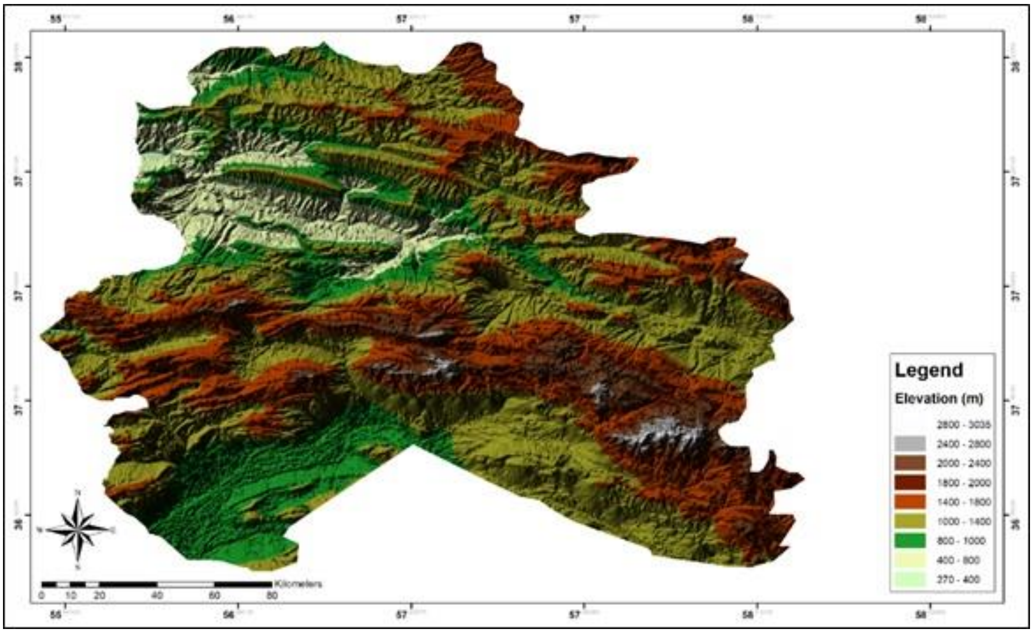

Fig. 2- Topography and elevation map of the study area

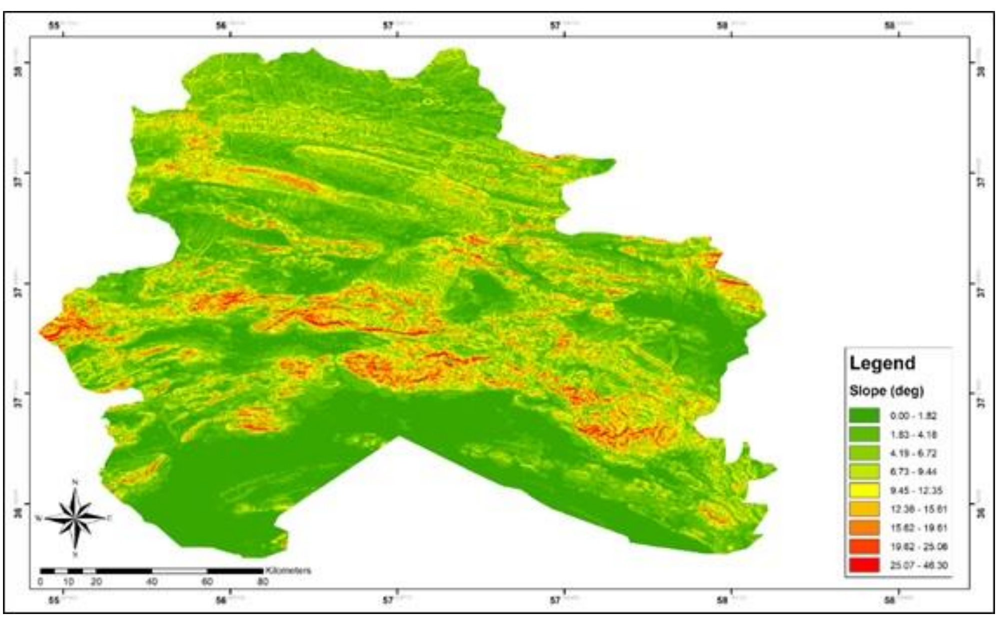

Fig. 3- Slope degree of north Khorasan province

2.2. Application of factor analysis

Many climates and soil chemical-physical and fertility factors may affect land suitability evaluation. In practice, principal and representative factors are usually applied to simplify and reduce all factor information (Ouyang, 2005). Applying the multivariate statistical approaches including Factor Analyse (FA) reduced the variables to a couple of factors. Factor analysis is understood as a strong method for drawing major factors influencing the observed data. The main reason to hold out a factor analysis is data reduction to determine the quantity and character of linearly independent variables (factors) which might precisely express the interdependence of the initial variables.

Factor analysis as a generic term includes principal component analysis (PCA) or empirical orthogonal function analyses (Bukantis, 2002) that are functionally very similar and are used for the same purpose of data reduction (Gorsuch, 1983; Loehlin, 1998). Factor analysis was performed in a sequence with the following major steps: (1) selecting and coordinating the variables after land suitability purposes, (2) computing the matrix of correlations among the variables, and (3) extracting and rotating the factors by the Varimax method, (4) interpreting the rotated factor matrix to get the loading values.

2.3. Data collection

Due to climatic data shortage in and around the study area, climatic factors were extracted from WorldClim (ver.2) in spatial resolutions of 30 seconds (~1 km^2). The most important implication in estimating soil physical and chemical properties within the study area was reliable soil data; hence, we used soil data from SoilGrids 250 m (ver.2.0), which uses digital soil mapping of worldwide collections of soil profiles.

It is a set of soil properties including soil physical and chemical attributes in 36700 points up to 100 cm soil depth or to a restricted layer. The terrain values including elevation, slope, and aspect were estimated from the 30 m DEM of the study area. The shapefiles of flood hazard and erosion risk in Iran were used and processed by ArcGIS (ver.10.7) to point out plantation limitations within the study area.

2.4. Land data analysis

The terrain and soil suitability were evaluated by considering the soil requirements of the *Ferula communis* in terms of growth and biomass production. The values of climate, soil, and terrain characteristics of the region included mean annual temperature, mean temperature during the dormancy, mean temperature during the germination, and mean temperature during the flowering, annual precipitation, slope, elevation, soil depth, coarse fragments, pH, Caco3, calcium carbonate content (CEC), organic carbon (OC), EC, and ESP Table 1. The next step was a land evaluation by comparing land qualities/characteristics with the *Ferula communis* requirements and classifying land suitability for each species Table 2.

Table 1- The statistical description of climate and soil characteristics in North Khorasan province

	Unit	Min	Max	Average	STD	CV
Mean Annual temp.	◦C	22.11	31.45	27.33	9.33	0.08
Mean temp. during the Dormancy	◦C	6.94	18.13	13.18	11.19	0.20
Mean temp. during the Germination	◦C	9.67	20.20	15.63	10.53	0.16
Mean temp. during the Flowering	◦C	23.02	31.63	27.90	8.61	0.08
Annual Precipitation	mm	219.83	273.86	250.30	54.04	0.05
Slope	%	0.01	38.14	5.12	38.13	0.91
Elevation	m	271.02	2979.39	1279.51	2708.38	0.32
Soil Depth	cm	0.00	149.97	20.12	149.97	0.91
Coarse Fragment	%	0.00	46.00	15.93	46.00	0.37
pH	_	6.70	8.30	7.95	1.60	0.02
$CaCO_3$	%	0.30	40.00	17.71	39.70	0.45
CEC	Cmol/kg	8.00	41.00	18.01	33.00	0.18
OC	%	0.00	4.50	0.37	4.50	0.58
EC_e	dS/m	0.00	4.00	0.55	4.00	0.99
ESP	%	1.00	33.00	9.60	32.00	1.09

Table 2- Climate, Terrain, and soil requirement for Frula (Ferula communis) plantation

Climatic characteristics	Unit	S1	S2	S3	N
		100-85	**85-60**	**60-40**	**40-0**
Mean temperature during growing cycle	◦C	12-8	8-4 12-16	4-2 16-20	<2 >20
Mean temperature during the breaking Dormancy stage (January, February)	◦C	-5–0	0–3	3–10	>10
Mean temperature during the Germination stage (March)	◦C	10-5	10–15 0 - 5	15-20	<20
Mean temperature during the Flowering stage (July)	◦C	25-20	25-30 20-15	30-35	<35
Annual Precipitation	mm	>300	300-250	250-200	<200
Slope	%	0-30	30-40	40-60	>60
Elevation	m	>1800	1800-1500	1500-1000	<1000
Soil Depth	cm	>100	100-50	50-30	<30
Gravel	%	0-30	30-50	50-60	>60
Soil Texture		L, SL	Si, SiL, LS	S, CL, SCL, SiCL	C,SC,Sic
pH		7.5-7.8	7.8-8.0	8.0-8.7	>8.7
		7.5-7.0	7.0-6.0	6.0-5.5	<5.5
CaCO3	%	0-10	10-20	20-30	>30
CEC	Cmol/kg	>16	16-12	12-8	<8
OC	%	2-1	1-0.8	0.8-0.5	<0.5
EC_e	dS/m	0-1	1-2	2-4	>4
ESP	%	0-8	8-15	15-20	>15

2.5. Parametric approach in land suitability evaluation

In the present study, the specific soil and climate requirements for *Ferula* were determined based on the adaptation and abundance of *Ferula* in natural habitats Table 2. For the parametric approach, we used the "Framework for Land Evaluation" (FAO, 1976) and "land evaluation for forestry" (FAO, 1984), which distinguish the climatic conditions and land features such as topography, wetness, soil physical and chemical properties, erosion hazard, soil salinity and alkalinity for each specific tree. The parametric approach determines the land suitability index and class based on the limitation rate of climate and land qualities/characteristics requirements for *Ferula* ranging from 0 to 100 Table 2. The limitation value for every limiting factor is calculated by the subsequent linear interpolation equation 1(Dale, 2004).

$$y = a + \frac{(b-a)(x-c)}{(d-c)} \qquad (1)$$

where, if the observed value of each land quality/characteristic (x) falls into the interval [a, b] in each limitation class it gets a limitation rate (y) that falls into the interval [c, d] which are the lower and upper threshold values defined for that limitation class.

3. Results and Discussion

3.1. Data preparation

In the statistical processing of data through factor analysis by principal component analysis (PCA), the extracted 16 variables were reduced into 4 factors consistent with Varimax rotation, which maximizes the total variance of the squared loading variables (>90 %) with eigenvalues greater than 1 Table 3. The advantage of a Varimax rotation is that it keeps the principal components uncorrelated (Jolliffe, 2022; Wilks, 2011; Paschalidou et al., 2009).

The scree plot of 16 analyzed components by defined eigenvalues is shown in Fig. 4. In factor analysis, the factor scores for every case were calculated by the Varimax rotation with Kaiser Normalization, principal component analysis method, and rotation convergence in 10 iterations Table 4. The final step of the multivariate approach is to protect the data on the rotated significant factors.

Table 3- Total variance explained

Components	Initial eigenvalues			Extraction sums of squared loading			Rotation sums of squared loading		
	Total	% of variance	Cumulative %	Total	% of variance	Cumulative %	Total	% of variance	Cumulative %
1	791/5	192/36	192/36	791/5	192/36	192/36	083/4	519/25	519/25
2	718/2	987/16	180/53	718/2	987/16	180/53	621/3	630/22	148/48
3	498/1	360/9	539/62	498/1	360/9	539/62	008/2	552/12	701/60
4	158/1	239/7	779/69	158/1	239/7	779/69	453/1	078/9	779/69
5	914/0	712/5	491/75						
6	799/0	995/4	486/80						
7	663/0	143/4	629/84						
8	604/0	772/3	401/88						
9	551/0	445/3	846/91						
10	438/0	734/2	581/94						
11	345/0	156/2	737/96						
12	292/0	823/1	560/98						
13	166/0	040/1	601/99						
14	033/0	204/0	805/99						
15	020/0	125/0	929/99						
16	011/0	071/0	000/100						

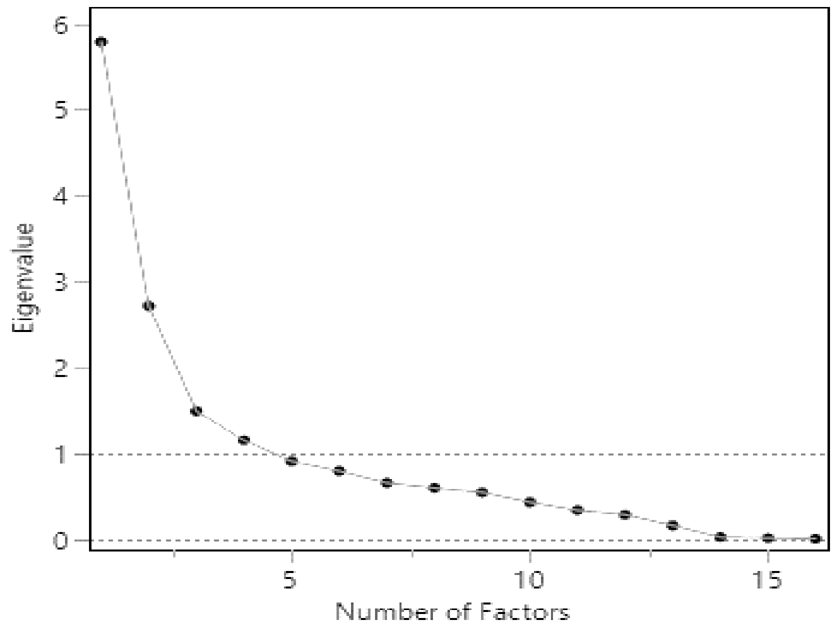

Fig. 4- The scree plot of 16 analyzed components by defined eigenvalues

Table 4-Rotated component matrix

	Component				Weight
	1	2	3	4	
Mean Temp. Growing	0.970				0/0988
Mean Temp. Germination	0.962				0/0980
Mean Temp. Flowering	0.956				0/0974
Soil depth		0.905			0/0922
OC		0.720			0/0733
pH		0.635			0/0647
Elevation		0.435			0/0443
Annual precipitation			0.837		0/0852
ESP			0.794		0/0809
CaCO3			0.682		0/0694
Soil texture				0.740	0/0753
CEC				0.672	0/0684
ECe				0.513	0/0522
Mean Temp. Growing	0.970				0/0988

3.2. Zonation map of the land suitability

The geostatistical interpolating procedure of inverse distance weighting in ArcGIS become applied to estimating the variable values in the studied area.

Our results indicated that four factors explain about 90 % of the total variance with eigenvalues greater than 1 (Table 4, Fig. 4). The explained variances of these factors varied from 25.519 to 9.078 % for factors 1 and 4 after the Varimax rotation, respectively (Table 3). Also, each factor showed different loadings for each variable (Table 4).

Factor 1 with 5 variables comprised climatic characteristics including mean temperature during the germination stage, mean temperature during the flowering stage, mean temperature during breaking dormancy stage, mean temperature during the growing cycle, and elevation which explained 25.519 % of the total variance with an eigenvalue of 4.083. Factor 2 with 3 variables including soil depth, OC, and pH which explained 22.630 % of the total variance with an eigenvalue of 3.621. Factor 3 with 3 variables including ESP, Annual precipitation, and CaCO3 which explained 12.552 % of the total variance with an eigenvalue of 2.008. Factor 4 with 3 variables including soil texture, CEC, and ECe which explained 12.552 % of the total variance with an eigenvalue of 1.453. The distributions of components in each factor were reasonably homogenized from 1 to 4.

The land suitability classes for Ferula cultivation were categorized into a moderate suitable class of S2, a marginally suitable class of S3, and unsuitable class of N. The zonation map of land suitability revealed that 27.02% (6885/93 km^2) of the surface area was moderately suitable, 67/20% (17125/36 km^2) was marginally suitable and 5.78% (1474.52 km^2) of the region was unsuitable for Ferula production (Table 5).

The most important limiting factors for the Ferula plantation in the study area were climatic and terrain components. The moderate suitability class of S2 was mainly distributed within the middle, and northeastern parts of the province, while the south part of the study area and some scattered parts within the northwest exhibited unsuitability for Ferula production (Fig. 5). Also, the zonation map of land suitability exhibited that, along with elevating limitations in the south and northwest parts of the study area, the suitability classes were reduced accordingly (Fig. 5).

Table 5-Suitability index and class and corresponding areas

Land suitability class	Land index	Area	
		Km^2	%
S2	80-60	93.6885	27.02
S3	60-40	36.17125	20.67
N	40-0	52.1474	78.5
Total		25485/81	100

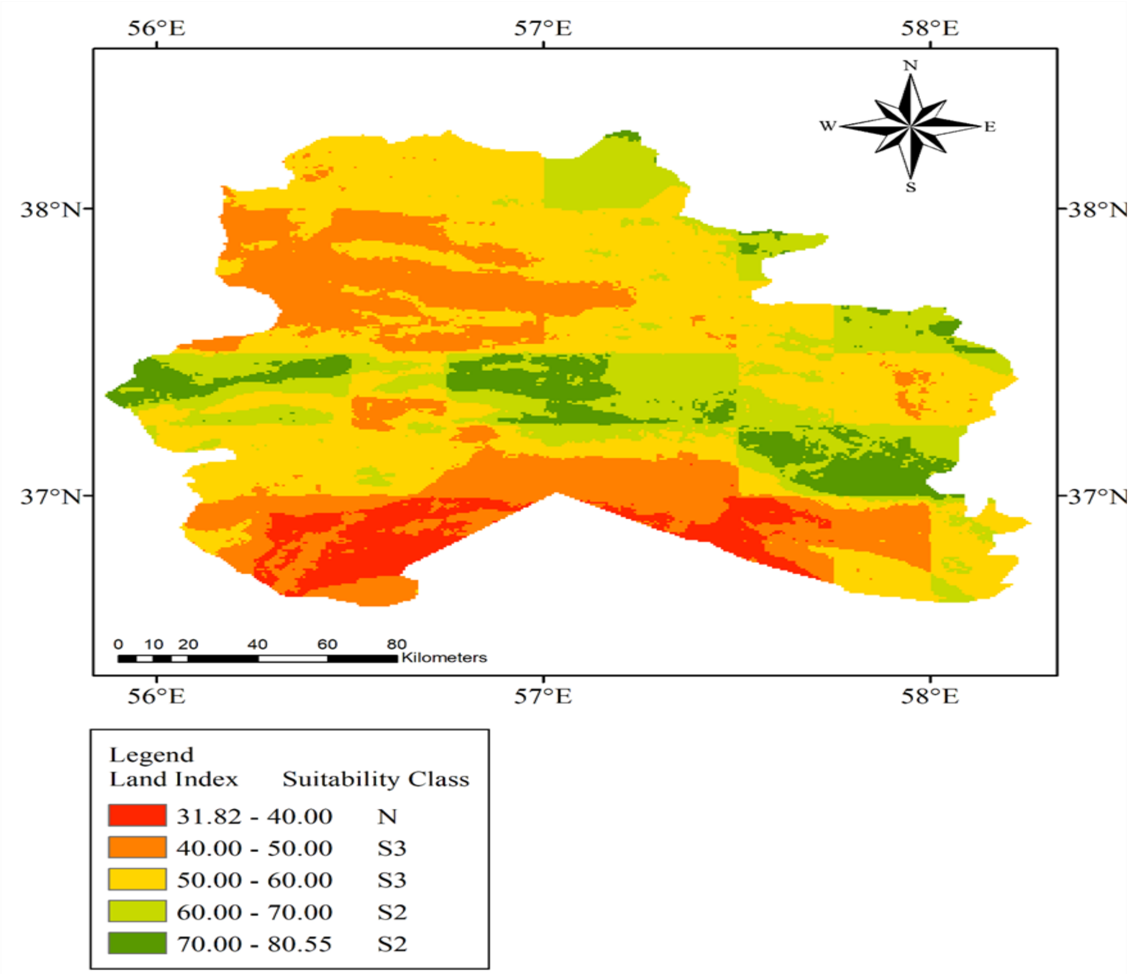

Fig. 5- The zonation of land suitability index for *Ferula communis*

4. Conclusion

Selection of medicinal plant species adapted to the arid and semi-arid areas and better usage of natural resources with high efficiency in these areas is extremely necessary for sustainable agriculture. One of the primary steps in the cultivation of any plant is consideration of the regions and requirements of the plant that is going to be planted there. Applying the hybrid method of parametric-factor analysis through principal component analysis (PCA) reduced the variables to a few factors and classified the research cases into specific clusters. Within the present study, the extracted 16 variables were processed, leading to four factors that explain about 90 % of the total variance and eigenvalues greater than 1. The geographical distribution revealed that the points with moderate suitability are laid within the middle, and northeastern parts of the study area, while the south of the study area and some scattered parts within the northwest exhibited unsuitability for *Ferula communis*. The most important limiting factors for the Ferula cultivation within the study area were climatic and terrain components.

Declarations

Funding Information (Private funding by authors)

Conflict of Interest /Competing interests (The authors certify that they have NO affiliations with or involvement in any organization or entity with any financial interest (such as honoraria; educational grants; participation in speakers' bureaus; membership, employment, consultancies, stock ownership, or other equity interest; and expert testimony or patent-licensing arrangements), or non-financial interest (such as personal or professional relationships, affiliations, knowledge or beliefs) in the subject matter or materials discussed in this manuscript)

Availability of Data and Material (Data are available when requested)

Consent to Publish (Authors consent to publishing)

Authors Contributions (All co-authors contributed to the manuscript)

Code availability (Not applicable)

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