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Land suitability assessment for maize farming using a GIS-AHP method for a semi- arid region, Iran

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ABSTRACT

The aim of this study was to generate land suitability maps for maize farming in calcareous and saline-sodic soils in the Marvdasht plain, Iran. An analytic hierarchy process (AHP) multi-criteria method integrated with GIS and geostatictic was employed to estimate weighting of soil properties, climate and topography data. The results indicated that soil texture showed the highest specific weight (0.20) for maize farming followed by electrical conductivity (0.121), slope (1 2 0) and pH (0.118). The land suitability map showed that 38.72% (76,646.7 ha) of the studied agricultural land were the best soils for the maize production i.e. high suitable class, 26.89% (53,216.0 ha) was for the moderately suitable class and 23.98% (47,473 ha) was for marginally suitable class. The 10.41% (20,586.4) of study region was classified as not-suitable for maize farming. It was concluded that soil property, climate and topography data combined with local expert opinion is a first step in site-specific crop farming.

1. Introduction

Local biophysical conditions play a critical role in determining which specific crops can be farmed, fertile soil management and help to identify the main potentials and limitations of the area (Mendas and Delali 2012; Kazemi, Sadeghi and Akinci 2016). Land suitability evaluation is a first step in developing and promoting land-use planning and protecting sustainable agricultural lands (Falasca, Ulberich and Ulberich 2012; Baroudy 2016). The soil properties, climate and topo-position variation are the main reasons to investigate land suitability for a certain crop in different parts of the study region. FAO (1990) reported that in the evaluation of agricultural land units, the most effective parameters i.e. soil, climate and topography data should be considered at a local scale. In recent decades, human activities have been gradually degrading land resources in Iran. Therefore, it is necessary that the potential and limitations of land, on a local scale, are identified and evaluated for farming a specific crop especially in semi-arid calcareous, saline and sodic soils conditions.

Land suitability evaluation is one of the most important phases in land-use planning for a farming a specific crop given local conditions (FAO 1993). Land suitability evaluation studies could be considering key factors that determine crop growth so that decision makers can generate the best management practices for achieving sustainable land productivity. FAO (1976) developed a framework for land-use planning (Recatal and Zinck 2008; Fontes et al. 2009). There are many effective agro-ecological factors which are used for land suitability evaluation, but using all of these factors increases the complexity of a long term sustainable management (Bandyopadhyay et al. 2009; Akinci et al. 2013). Hence, it is necessary to develop an advanced agro-ecological model to manage and determine land-use planning based on the local soil, climate and topography data to reduce the risk to the food supply without degradation to the land (Uphoff 2002). Several studies have applied multi-criteria evaluation by using the analytical hierarchy process (AHP) method developed by Saaty (1980) to evaluate land suitability for a specific crop. In a Geographic information

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systems (GIS) framework, the AHP has been used for crops such as for faba bean cultivation in the Gonbad-Kavous region, northern Iran (Kazemi, Sadeghi and Akinci 2016), for agricultural suitability in hilly zones, in India (Zolekar and Bhagat 2015), for rainfed farming (Kazemi and Akinci. 2018), for rapeseed production, in northwest Iran (Ostovari et al. 2019), for wheat and maize farming in east of Iran (Pilevar et al. 2020) and for the agricultural suitability in hilly zones, in Turkey (Akinci, Ozalp and Turgut. 2013).

The major staple field crop in Iran is maize (*Zea mays* L.) which is planted in the summer season. The maize occupies approximately 0.3 million ha of the total irrigated agricultural lands (about 6 million ha) (FAO 2005). Maize is the most important food source for both human food and animal feed. In countries such as Iran, >15% of the maize is used for human food and about 85% for animal feed. Maize grain contains about 5% fat, 10% protein, 75% starch, sugars account for 1–3% as well as fiber and minerals (Waston, 1987; Pedersen, Knudsen and Eggum 1989). Maize is a cereal crop and is grown widely throughout the world in a range of agro-ecological and environmental conditions. However, maize farming needs to adapt to local conditions including soils (calcareous, saline and sodic soils), climate and topography. The calcareous, saline and sodic soils are known for high calcium carbonate equivalent and pH (pH > 7.5), high electrical conductivity (EC > 4 $dS.m^{-1}$) and high sodium (ESP > 15), respectively (Brady and Weil 2002). The aims of current study are 1) to assess the land suitability of the Marvdasht plain for maize crop; 2) to generate an AHP method that determines the land suitability evaluation for maize farming in the calcareous, saline and sodic soils of southwest Iran.

2. Material and methods

2.1. Study area

This study was carried out in the Marvdasht plain, between latitudes 29° 44′-30° 26′ N and longitudes 52° 17′-53° 30′ E which is located in the northeast of Fars province, Iran (Fig. 1). The approximate area of the study region is 197,923 ha. The most common land use in this area include farming maize, wheat and vegetables, although maize grain farming has also been increasing in recent years. The surrounding regions of study area are mainly hilly, and the central region is predominantly flat. The parent material in this region is limestone which is enriched by calcium carbonates. Also, alluvial soils have formed by the accumulation of transported material through concentrated flow. The most common soil orders are Inceptisols, Entisols and Mollisols based on the American soil classification (USDA 2010).

2.2. Climate factors

The average monthly precipitation and temperature distribution in the period 2001–2018 are shown in Fig. 2 (a) and (b). The study area climate is classified as semi-arid and average annual precipitation and temperature are reported as 291.7 mm and 17.5 °C, respectively. The majority of rain occurs during winter season (i.e. December, January, February months) (Figure (a)).

2.3. Topography factors

The DEM (digital elevation model) of the study area (with a cell size of 10 × 10 m) was obtained from the agricultural research service of Fars province. The DEM data was used to derive the elevation and slope factors. Elevation in the study region varies between 1574 and 3121 m above sea level (Fig. 3). Most of the environmental data such as soil water content, precipitation, radiation and temperature will vary as the elevation factor changes. Elevation

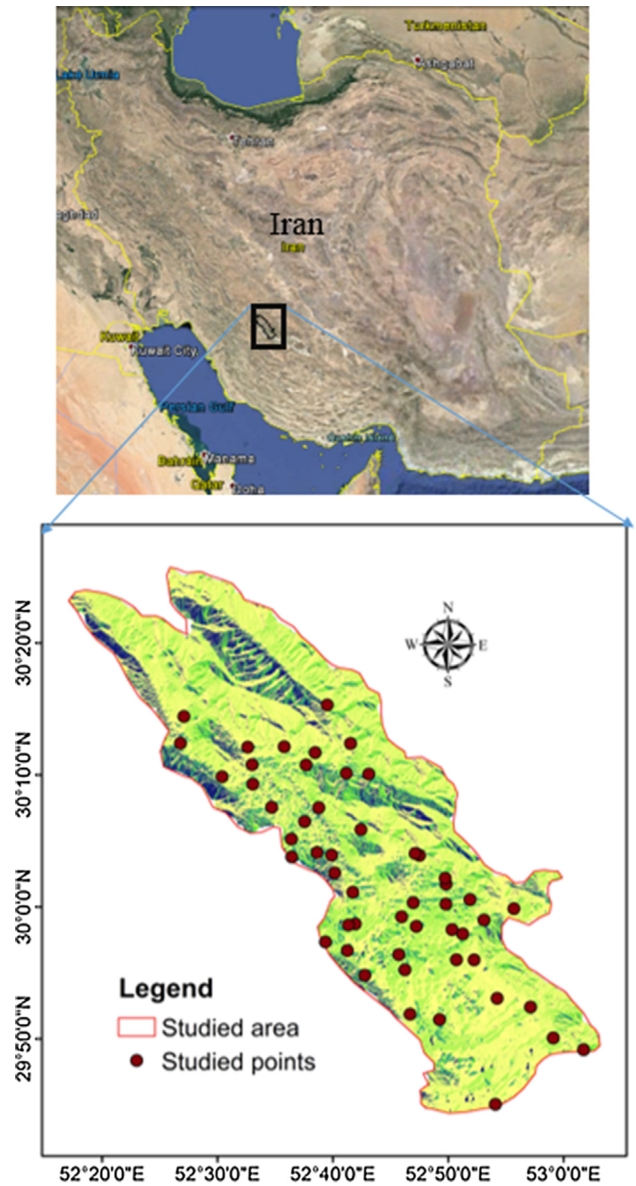

Fig. 1. Location of study area in the northeast Fars province, Iran and distribution of sample points.

from sea level plays a crucial role on the crop yield, growth and distribution. In 80,781 ha (40.8%), 18,658 ha (9.4%), 9,353 ha (4.7%), 6,231 ha (3.1%) and 82,900 ha (41.9%) of the study region were located slope classes including 0–2, 2–6, 6–12, 12–16 and > 16%, respectively (Fig. 3). Generally, low slope land is more suitable for maize farming (Fu et al. 2011).

2.4. Soil sampling and analysis

A stratified random sampling method was used to select the locations of 65 cropland soil samples which were taken from a depth of 0–30 cm (Fig. 1). The soil samples were air-dried in laboratory conditions. For soil analysis, a 2 mm sieve was used to prepare the air-dried samples. Soil texture has a significant effect on most soil property variation including pH, salinity, organic carbon, nutrient availability, soil structure and microbial biomass (Mustafa et al. 2011; Bhagat 2014). For this reason, the clay (<0.002 mm), silt (0.05–0.002 mm) and sand (0.05 –2 mm) content was determined using the hydrometer method

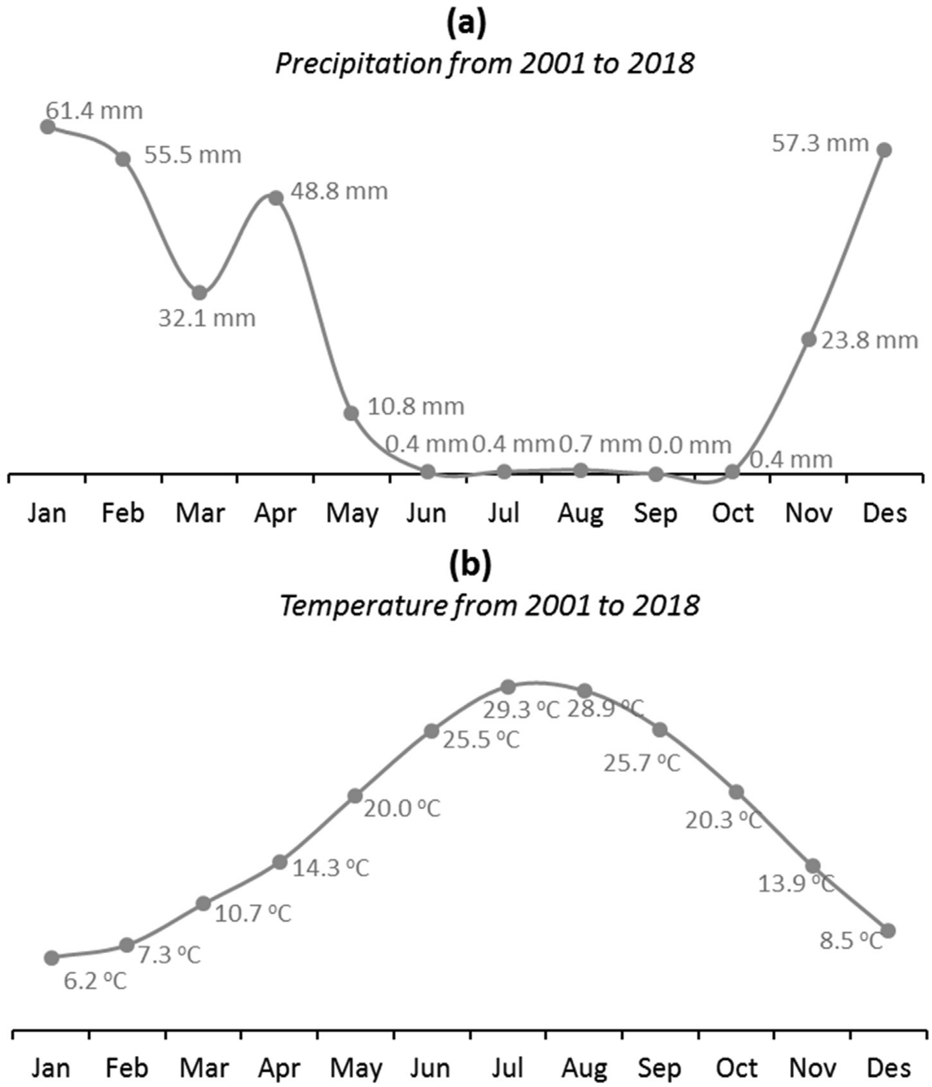

Fig. 2. Average monthly precipitation and temperature (from 2001 to 2018).

(Gee and Bauder 1986). The soil pH and electrical conductivity were determined in the extracted saturated soil. The optimum pH value for crop growth is between 6.5 and 7.0 (Thompsion and Troeh, 1973). The ESP parameter was determined by the ratio of sodium cation content to the sum of sodium and other cations such as calcium, magnesium, potassium, etc… at soil solution (Brady and Weil 2002). The CCE (calcium carbonate equivalent) parameter was measured by back-titration methods (Nelson and Sommers 1986). Soil parameter thematic maps were generated using the ordinary kriging interpolation method in ArcGIS v10.3. The empirical variogram was generated by Eq. (1) (Webster and Oliver 2001).

$$\mathrm{Y(h)} = \frac{1}{2\mathrm{N(h)}} \sum_{i=1}^{\mathrm{N(h)}} [\mathrm{Z(x_i)} - \mathrm{Z(x_i + h)}]^2$$

where $Z(x_i)$, $\mathrm{Y}(h)$, and $N(h)$ are measured soil properties at location of $\mathrm{x_i}$, the variogram for a lag distance h between $Z(x_i)$ and $Z(x_i + h)$ and the number of data pairs, respectively and then subsequently a variogram model estimated. The ordinary kriging equation is given by Eq. (2) (Webster and Oliver 2001).

$$\widehat{\mathrm{Z}}(\mathrm{x_i}) = \sum_{i=1}^{N} \lambda_i \mathrm{Z}(\mathrm{x_i})$$

where λ_i and $\widehat{\mathrm{Z}}(\mathrm{x_i})$ are the weight of a specific point and predicted soil parameters at the selected point/location, respectively.

2.5. Land suitability assessment

In the study area, the environmental and agro-ecological requirements for maize farming in the Marvdasht plain were investigated and applied to assess land suitability. The diagram of the land suitability assessment procedure is indicated in Fig. 4. Scientific resource information was investigated and used to determine the agro-ecological and environmental data requirements for maize farming (Table 1). To classify the data, information was collected from 25 local experts within the study area, with maize farming expertise. For the study area, the FAO (United Nations Food and Agriculture Organization) classification system for land suitability was applied i.e. S1 (highly suitable), S2 (moderately suitable), S3 (marginally suitable) and N (not-suitable) based on the environmental and agro-ecological requirements for maize farming (Table 1).

One popular and well-used approach for classifying factors which are arranged in a hierarchal structure is Analytical Hierarchy Process (AHP) method. To determine the most suitable land

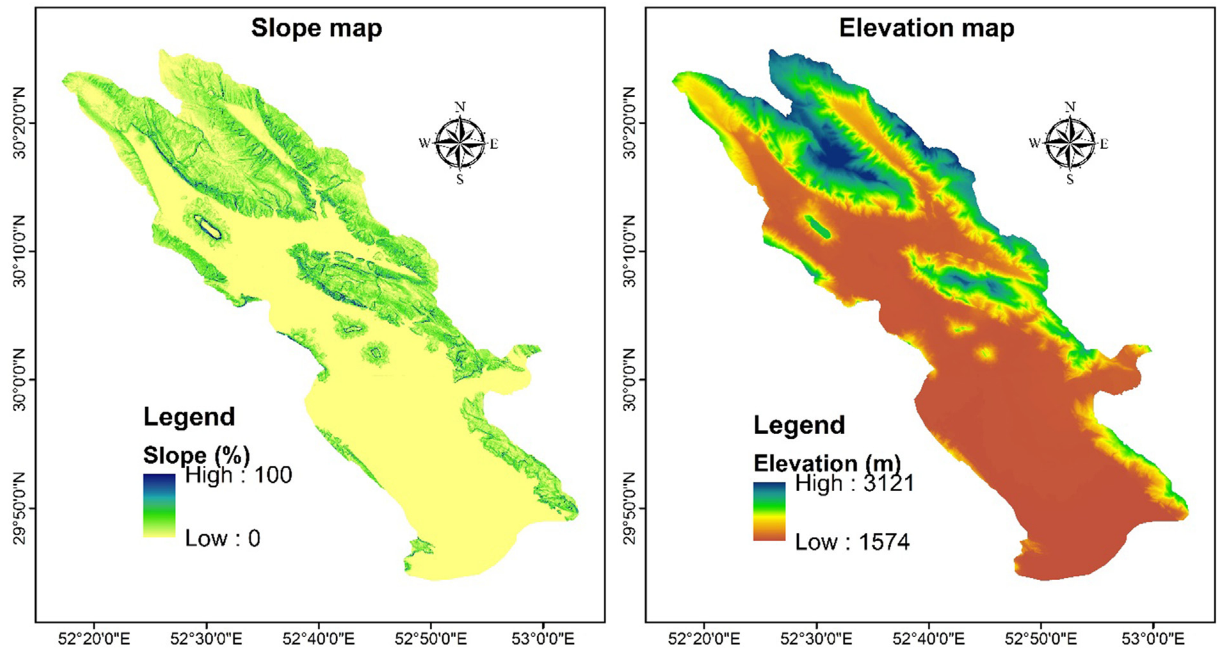

Fig. 3. Topographic maps including elevation and slope maps of study area.

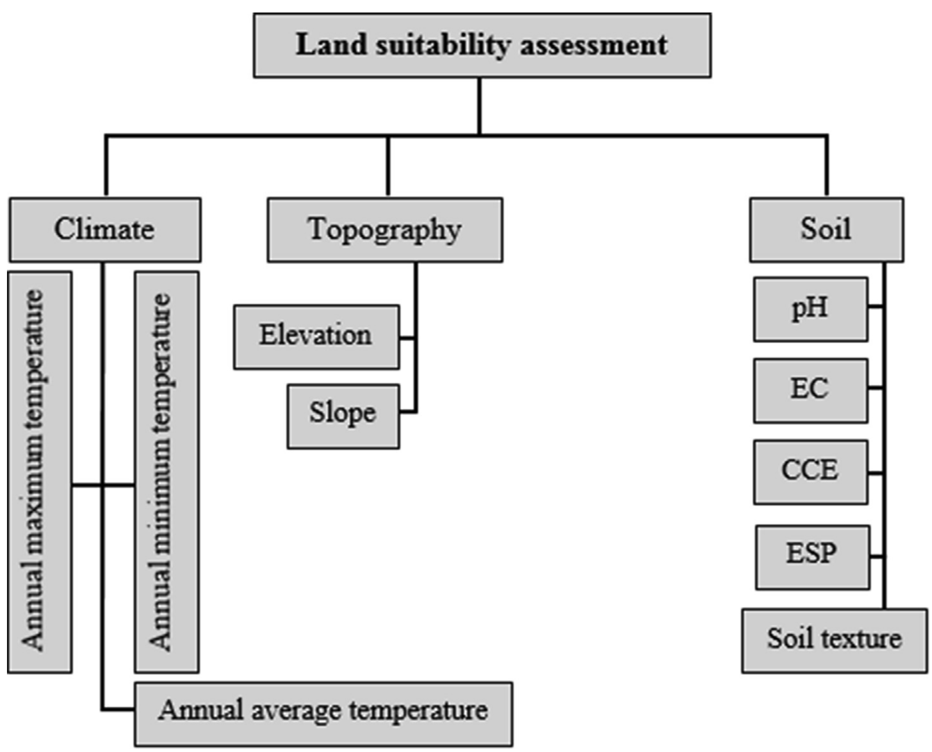

Fig. 4. Hierarchal structure of land suitability evaluation factors for maize farming.

for maize farming, some environmental and agro-ecological properties such as topography, climate, and soil data were used as presented at Fig. 4. The environmental and agro-ecological properties were ranked on a scale from 1 to 9 following the fundamental scale presented by Saaty (2008) (Table 2). For determining the weight of factors for maize farming in the Marvdasht plain, land suitability evaluation using a pairwise comparisons analysis with the Expert Choice 2001 software, the opinions of 25 local experts were collected. The weights of factors were in the range 0 to 1 (Malczewski 1999). Once the weights for each factor were determined, the weighted overlay method in the ArcGIS 10.0 software was applied to generate multi-criteria decision-making analysis maps (Girvan et al. 2003). Finally, multi-criteria decision-making analysis and the AHP method were used to generate a land suitability assessment map for maize farming based on the factor weights. The classes of the land suitability assessment were calculated according to Eq. (3) using the ArcGIS software,

Table 1
Criteria for delineating land suitability of maize crops in Marvdasht plain of Iran.

Parameters	Highly suitable (S1)	Moderately suitable (S2)	Marginally suitable (S3)	not-suitable (N)
Climatic factors				
Annual average temperature (°C)	22–26	18–22 and 26–32	14–18 and 32–35	<14 and > 35
Annual minimum temperature (°C)	16–18	14–16	14–12	<12
Annual maximum temperature (°C)	24–28	28–32	32–36	>36
Topography factors				
Elevation (M)	<1700	1700–2000	2000–2300	>2300
Slope (%)	0–2	2–6	6–12	>12
Soil factors				
PH	6.5–7.5	5.8–6.5 and 7.5–7.8	5.5–5.8 and 7.8–8.2	<5.5 and > 8.2
EC (dS m^{-1})	0–4	4–6	6–8	>8
ESP (%)	0–15	15–20	20–30	>30
CCE (%)	0–15	15–30	30–50	>50
Soil texture	Loam, clay loam, sandy clay and clay	Sandy loam and sandy clay loam	Loam sandy, silty loam and silty clay loam	Silty clay, sandy and silty

References: Sys et al., 1991, Ramirez-Cabral, Kumar and Shabani (2017), Sanchez et al. (2014) and Abagyeh, Idoga, and Agber. (2016).

Table 2
The fundamental scale for pairwise comparison used for the AHP.

Intensity of importance	Definition of preference score
1	Two attributes preferred equally
3	Judgment slightly favors one attribute over another
5	Judgment strongly favors one attribute over another
7	Judgment very strongly favors one attribute over another
9	Extreme preference of one attribute over another
2, 4, 6 and 8	Intermediate values between the two adjacent judgments

$$S = \sum_{i=1}^{n} WiXi$$

where S, Wi, Xi and n are the land suitability classes (i.e. highly suitable, moderately suitable, marginally suitable and not-suitable), the weight factors (i.e. topography, climate, and soil data), the sub-factor score of i factors and the total number of factors.

3. Results

3.1. The descriptive statistics of soil properties

Descriptive statistics of some soil properties which impact land suitability for maize farming are indicated in Table 3. The silt, EC (Electrical conductivity) and ESP (Exchangeable sodium percent) parameters show a negative skewness. Whereas clay, sand, CCE and pH parameters all showed a slight positive skewness. However, statistical analysis showed that all of the soil parameters in the study area were distributed normally ($p < 5\%$) when the Kolmogorov-Smirnov test was applied. In addition, a CV (Coefficient of variation) test with a categorization suggested by Wilding (1985) was also used in this study. Based on this method, soil properties that have a CV > 35% are considered as high variability factors, between CV > 15% and CV < 15% are considered moderate variability factors and CV < 15% as low variability factors. According to the Wilding (1985) categorization, silt, sand and pH properties showed a low variability (Table 3). Clay content and CCE parameters indicated moderate variability (Table 3). The EC and ESP parameter indicated a high variability. However, a soil factor which has a broad range of data could be a relevant factor for modelling land suitability for maize farming.

3.2. Land suitability assessment

The weights or impact of each environmental and agro-ecological data including topography, climate and soil properties are shown in Table 4 according to the local experts' opinions. Using the AHP method, determining the weight for each factor is the first step. The results of this study indicate that the main factor, as a limiting factor for maize farming is soil texture (0.200). The other highest specific weighting for maize farming for this study region are electrical conductivity (0.121), slope (0.120), pH (0.118), respectively (Table 4).

Assessing land suitability for maize farming was characterized using the important factors such as topography, soil and climate data. Land suitability maps were produced by overlaying the 10 raster layers for factors listed in Table 4. Finally, an optimum land suitability map for maize farming in the Marvdasht plain is presented in Fig. 5. As can be seen from Fig. 5, the S1 class land unit (highly suitable land) are located over large areas of the study area such as the south, southeast and central parts. The S1 class, 76,646.7 ha (38.72%) (Table 5), is identified using environmental and agro-ecological factors such as annual average temperature 22–26 °C, annual minimum temperature 16–18 °C, annual maximum temperature 24–28 °C, slope < 2%, elevation < 1,700 m, soil textures: loam, clay loam, sandy clay and clay, pH 6.5–7.5, EC 0–4 dS/m, CCE 0–25% and ESP 0–15% (Table 1). The S2 class (Moderately suitable land) is located mainly in the south and around the S1 class over all parts of the study region (Fig. 5). This S2 class, with a total area 53,216.0 ha (26.89%) (Table 5), is characterized by annual average temperature 18–22 °C and 26–32 °C, annual minimum temperature 14–16 °C, annual maximum temperature 28–32 °C, pH 5.8–6.5 and 7.5–7.8, soil textures: sandy loam and sandy clay loam, ESP 15–20%, CCE 25–40% and EC 4–6 dS/m (Table 1). The marginally suitable class (S3), according to the results of Fig. 5 are located mostly in the northern areas of the study area. In the study area, this class covers 47,473.7 ha (23.98%) (Table 5). Class (S3) characteristics include annual average temperature 14–18 °C and 32–35 °C, annual minimum temperature 12–14 °C, annual maximum temperature 32–36 °C, pH 5.5–5.8 and 7.8–8.2, soil textures: loamy sand, silty loam and silty clay loam, ESP 20–30%, CCE 30–50% and EC 6–8 dS/m (Table 1). The land suitability analysis for maize farming indicated that some small areas of the study region were classified as not-suitable land (N class) 10.41% (20,586.4 ha) (Table 5). The N Class characteristics include annual average temperature < 14 °C and > 35 °C, annual minimum

Table 3
Descriptive statistics of study soil.

Properties	Min	Max	Mean	Median	Std. dev	CV
Clay (%)	17.9	40.0	26.5	27.3	4.53	17.1
Silt (%)	24.0	40.0	31.7	31.6	3.20	10.1
Sand (%)	30.1	55.0	41.8	42.1	4.94	11.8
CCE (%)	11.5	66.3	43.5	45.0	12.05	27.7
pH	7.0	8.8	7.8	7.9	0.21	2.7
EC (dS m^{-1})	0.04	12.7	2.4	2.2	2.24	93.3
ESP (%)	1.0	84.5	15.4	14.3	13.6	88.5

CV: Coefficient of variation; CCE: Calcium carbonate equivalent; EC: Electrical conductivity; ESP: Exchangeable sodium percent.

Table 4
The results of AHP method for land suitability in maize farming.

Parameters	Weight	Rank
Climatic factors		
Annual maximum temperature (°C)	0.049	8
Annual average temperature (°C)	0.038	9
Annual minimum temperature (°C)	0.034	10
Topography factors		
Elevation (M)	0.114	5
Slope (%)	0.120	3
Soil factors		
PH	0.118	4
EC (dS m^{-1})	0.121	2
ESP (%)	0.105	6
CCE (%)	0.101	7
Soil texture	0.200	1

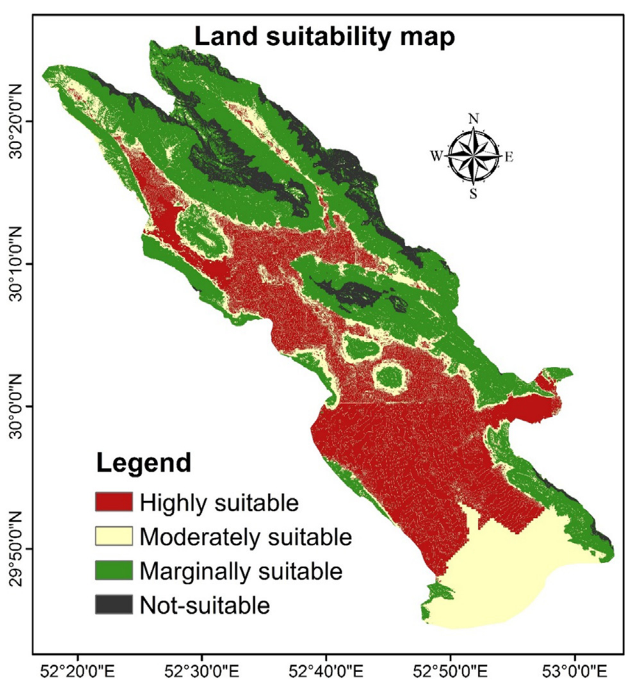

Fig. 5. Land suitability map for maize farming in Marvdasht plain, northeast Fars province, Iran.

Table 5
The distribution of land suitability analysis results for maize farming in Marvdasht plain of Iran.

Highly suitable (S1)	76,646.7	38.72
Moderately suitable (S2)	53,216.0	26.89
Marginally suitable (S3)	47,473.7	23.98
Not-suitable (N)	20,586.4	10.41

temperature < 12°C, annual maximum temperature > 36 °C, pH < 5.5 and > 8.2, soil textures: silty clay, sandy and silty, ESP > 30%, CCE > 50% and EC > 8 dS/m (Table 1). All of the land suitability classes for maize farming on the Marvdasht plain are presented in the Fig. 5.

4. Discussion

It is essential to estimate suitable land for specific crops so as to maximize the yield. For this reason, there are a number of works that study land suitability in the available literature (FAO 1976; Recatal and Zinck 2008; Fontes et al. 2009; Bandyopadhyay et al. 2009; Grassano et al. 2011; Akinci, Ozalp and Turgut. 2013; Zolekar and Bhagat 2015; Kazemi, Sadeghi and Akinci 2016; Kazemi and Akinci. 2018; Ostovari et al. 2019; Pilevar et al. 2020). Crop production on irrigated land is mostly determined by climatic data, soil properties, topography factors and local expert opinion (Grassano et al. 2011). Therefore, it is necessary to evaluate the potential of the Marvdasht plain, northeast part of Fars province, Iran in the presence of calcareous, saline and sodic soils conditions for maize farming. In this study, factors such as soil texture, electrical conductivity, slope and pH parameters presented in Table 4 are significant for maximizing yield in maize farming.

Several studies in recent years have used the Analytical Hierarchy Process (AHP) method for determining the weights of effective factors (Lai et al., 2002; Zhang et al. 2015; Kazemi, Sadeghi and Akinci 2016). The AHP method is described in Sections 2.5. In this study, the weighting of factors, as Table 4 shows, can be compared with other studies such as Kazemi, Sadeghi and Akinci (2016) and Ostovari et al. (2019) that reported for faba bean and rapeseed farming in calcareous conditions, respectively. In these studies, the soil factors are identified as an important factor for modeling land suitability for maize farming under calcareous, saline and sodic soils conditions. However, according to the local experts' opinions, soil texture and electrical conductivity play a significant role in maize farming on the Marvdasht plain. After soil texture and electrical conductivity, the topography factor i.e. slope degree (Table 4) was the next most important factor in the study region. The in this region ranges between 0 and 100%. The slope degree has a large impact on determining irrigation type, drainage rate and mechanization during agricultural practices. In addition, the slope degree indirectly affects soil properties negatively and decreases crop yield.

The innovation of this study compared with other research studies that focus on land suitability assessment is the unique influence of saline, sodic and calcareous materials in the Marvdasht plain soils. The presence of saline, sodic and calcareous materials in Marvdasht plain soils is a serious problem for maize production. The range of CCE (Calcium carbonate equivalent) in the study area varied from 11.5 to 66.3% (Table 3). The high $CaCO_3$ saturation soils have high nutritional problems mainly micronutrients, especially zinc and iron elements. In these soils, the hydrolysis of carbonate ions creates OH^- in soil solution and controls soil pH (Foth 1990). The salinity in the study region ranged from 0.04 to 12.7 dS m^{-1}. Salinity could be affecting the uptake of nutrients, the microbiological activity, crop growth and yield of most crops especially maize (Brady and Weil 2002). According to studies such as Munns and Tester (2008) and Boyer et al. (2008) salt stress reduced the crop growth and yield by three mechanisms. (1) osmotically inhibiting water for cell enlargement, (2) Nutrient imbalance in specific cations needed for normal cell function such as K^{+}, Ca^{++} and $NO3^{-}$ ions. (3) Uptake of Na^{+} and Cl^{-} in an unregulated way by the plant. Moreover, sodic soil is a term used to describe sufficiently high sodium levels to negatively affect maize growth. In high sodium soils, after an irrigation or rainfall, clay soils swell excessively and result in convex surfaces. For this reason, the air and water movement through these soils are very limited (Brady and Weil 2002). Therefore, it is necessary to calibrate a land suitability evaluation model for the variable field conditions such as those found in the Marvdasht plain soils which are affected by saline, sodic and calcareous materials.

5. Conclusion

In current study, a GIS modeling approach to generate a land suitability map for maize cultivation is investigated in the calcareous, saline and sodic soils of the semi-arid regions of southwest Iran. First, for the sustainability of maize farming on the Marvdasht plain, evaluating land suitability using environmental and agro-ecological data is of high importance. Land suitability analysis for sustainable maize farming in study area showed that 38.72% (76,646.7 ha), 26.89% (53,216.0 ha), 23.98% (47,473 ha) and 10.41% (20,586.4) were of high suitable (S1), moderately suitable (S2), marginally suitable (S3) and not-suitable class, respectively. The results of this study are a good guide for future land-use management and to also positively impact crop yields in southwest Iran and other similar regions. Further work would focus on the quantifying of the potential and limitations for other crops which affected by saline, sodic and calcareous soils and could be cultivated in this region.

Declaration of Competing Interest

The authors declared that there is no conflict of interest.

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