Gorgan University of Agricultural Sciences and Natural Resources

Environmemtal Resources Research (ERR)

Print ISSN: 2783-4832
Online ISSN: 2783-4670

Delineating suitable sites for plantation of *Nitraria schoberi* in winter rangelands of Golestan Province, Iran

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Article Info

Article type:
Research Article

Article history:
Received: April 2021
Accepted: December 2021

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Keywords:
Locating
Nitraria schoberi
Classic logic
Fuzzy logic
Rangeland rehabilitation

Abstract

Rangeland improvement and restoration increases the quantity and quality of forage production and optimizes the amount of livestock products. Land suitability assessment is an activity towards selection of the best sites for a specific plant species plantation. Application of optimal methods for accurately locating places for rangeland plantation, considering rangeland potential and characteristics, leads to long-term sustainable economic benefits. *Nitraria schoberi* is a drought-resistant species that is important in stabilizing of sandy soils and soil erosion control. Finding appropriate plantation sites for this species can play important role in the improvement of degraded-winter rangelands. In this research, the geographic information system and two methods of classic and fuzzy logic were used to locate areas suitable for this plant. According to the ecological requirements of *N. schoberi*, the layers for the classic method were grouped into two suitable and not suitable categories but for the fuzzy method we defined four classes for the layers including not- suitable, moderately suitable, suitable and highly suitable. Then, by combining the classifieds layers, the final maps were obtained using Boolean and fuzzy logic method. The results demonstrated that low precipitation, as well as, high salinity and temperature are the most limiting factors that must be considered in *N. schoberi* plantation projects. We found that the fuzzy logic gives better and more accurate results than the classic method, so it is recommended for selecting suitable areas for rangeland species plantation.

Cite this article: Hassan Malvandi, Somaye Azimi, Mina Sarvary Korojdeh. 2022. Mercury concentration in *Rutilus rutilus* from the Caspian Sea and assessment of health risks. *Environmental Resources Research*, 10 (2), 183-194.

DOI: 10.22069/IJERR.2022.6299
Publisher: Gorgan University of Agricultural Sciences and Natural Resources

Introduction

Rangelands in the arid and semi-arid regions of Iran are under pressure from frequent degradations, extreme climate conditions, drought events, weak community participation and the lack of clear land ownership principles which have affected trend and condition of rangeland ecosystems (Niknahad Gharmakher and Sharifiyan Bahraman, 2017; Azimi et al., 2020).

Considering the high rate of desertification in dry lands, the re-vegetation of rangelands provides a tool to restore the degraded lands as well as increase their productivity (Yirdaw et al., 2017). The use of suitable species, considering their ecological requirements and biological tolerance, has great importance in the successful achievement of re-vegetation projects. Because of the biological potential of shrub species, they are considered as suitable plants in rangeland improvement projects particularly in areas with harsh conditions like the dry lands of the Middle East and Iran (Niknahad Gharmakher and Sharifiyan Bahraman, 2017). So, it is essential to select the suitable species and zones for rehabilitation of the degraded lands.

Due to rapidly increasing degradation of natural resources and desertification, it is crucial to adopt new techniques for management of natural resources (Mahdavi et al., 2017). Using Geographic Information System (GIS) help users to improve the decision-making processes.

There are several approaches to assess land suitability (Nasrollahi et al., 2017). Kazemi (2013) applied the Boolean method to evaluate the croplands in Gorgan Township, Iran in search of the best location for cultivation of hulless barley (*Hordeum vulgare*). Implementation of fuzzy logic and Boolean methods to identify the suitable sites for a pressurized irrigation system in the Kerman plain, Iran; demonstrated the suitability of the methods for recognition of the the suitable zones (Neshat, 2014). Riad et al., (2011) applied the weighted linear combination and Boolean logic methods to determinate the best groundwater artificial recharge locations in the Sadat industrial City, Egypt. The output of both methods suggested mostly the northern parts of the city for groundwater recharge as the suitable areas; however, the suitability map of the weighted linear combination was more accurate than the Boolean logic. Mahdavi and Jamshidifard (2014) determined the potential habitats of two rangeland species (*Salsola rigidia* and *Agropyron trichophorum*) in semi-desert area of Qasre-Shirin based on soil factors using GIS.

Studying *Ferula assa-foetida* L. in northeastern Iran using the maximum entropy model indicated that the used model had good accuracy and factors including land unit components, seasonal temperature, geological formation, dominant slope, elevation and daily average temperature are important as the potential habitat of this species (Momeni Damaneh et al., 2021). Land suitability classification for development of *Glycyrrhiza glabra* using ANP Fuzzy model by Alikhah Asl et al., (2020) demonstrated that altitude, slope, soil depth and soil fertility factors are the most important layers respectively. Modelling spatial distribution of *Limonium iranicum* and *Aeluropus littoralis* species using logistic regression method showed that the most important variables in the *L. iranicum* habitat were lime and silt in the second depth in addition to sand of the first depth. The most important factors in the *A. littoralis* habitat were lime of the first depth and elevation.

Matinkhah et al. (2016) used Fuzzy method for site selection of *Haloxylon ammodendron* plantation based on soil factors. The results demonstrated that the coefficient of determination for the observed canopy cover percentage plotted against the predicted suitability values is higher than 98%, indicating the fuzzy decision-making approach is a powerful tool in site selection for this species.

As a result of over grazing, little rainfall and high evaporation, the winter rangelands of Golestan Province are ecologically fragile and rehabilitation of vegetation cover in the area is vital (Niknahad Gharmakher et al., 2015). *N. schoberi* is a perennial plant belonging to the Zygophyllaceae family, and is endemic to the central, northeast, and northwest of Iran. It mostly grows on sandy deserts, and is broadly found in the clayey and saline arid lands (Ahkani, 2002), it has a high utility and importance in rehabilitation of the degraded dry lands. *N.schoberi* provides a fairly high quality forage (Ehsani et al., 2020). Our main objective was to determin optimal zones for *N. schoberi* plantation in

the winter rangelands of Golestan Province, Iran using Boolean and Fuzzy methods.

Materials and methods

Study area

Golestan Province is one of the main agricultural areas in Iran where the northern part with poor condition is used as winter rangeland. The climate is arid to semi-arid with mean annual precipitation of 250 to 418 mm, falling mainly in the autumn and winter. Its topography is flat in the west and center to hilly in the east. The altitude ranges from -25 in the west to 620 m above sea level in the east (Niknahad Gharmakher et al., 2015 and Niknahad Gharmakher et al., 2017).

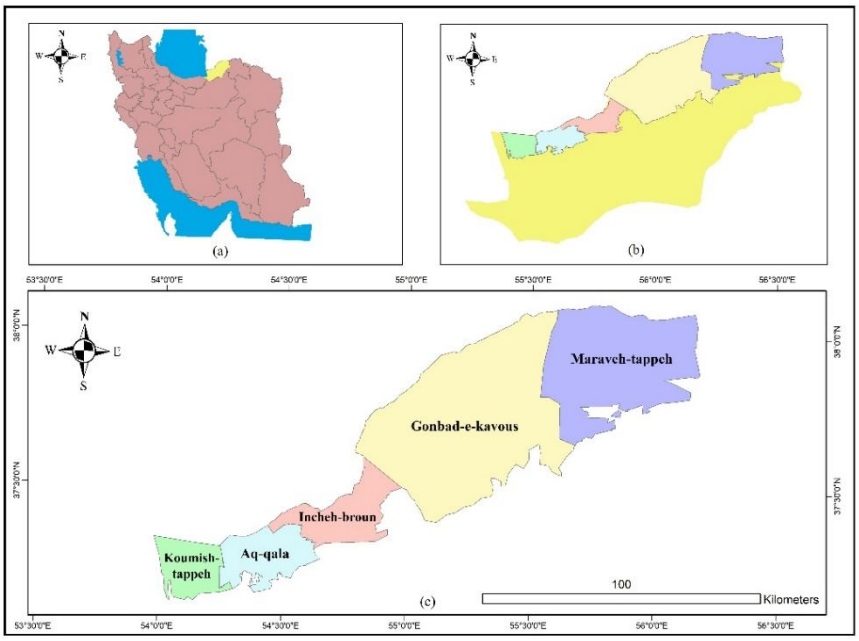


Figure 1. Location of rangelands in Iran and Golestan Province

Boolean Logic

For Boolean logic method, once all the needed thematic layers have been prepared, they are reclassified into one and zero showing true or false values for each land unit, specifying whether it is satisfactory or unsatisfactory, respectively (Bhowmick et al., 2014). Then the layers are combined using OR or AND logics.

Fuzzy Logic

In fuzzy logic method, each region is assigned a membership between 0-1, or 0 – 255 that represent the degree of suitability of that area. This means that each area with a higher membership value is more suitable (Rastgar et al., 2015). Since land capability for any particular land use vary at each location and follows a certain range; therefore, we can show these changes with fuzzy functions. The main idea here is to standardize layers and results into maps with nor sharp boundaries (Hansen, 2005).

Parameters used in the suitability analysis

To determinate land suitability for *N.schoberi* plantation, environmental criteria such as topographic conditions, soil properties and climate characteristics were studied (Table 1). A digital elevation model (DEM) with a 30m × 30m spatial resolution was downloaded from "The Advanced Land Observing Satellite (ALOS)" website and used to calculate the slope of the study area. The soil properties including salinity, acidity, and texture were also obtained from the rangeland management planning booklets of the natural resources' office of Golestan Province and were verified through soil sample points in field work. The interpolation method for the soil properties was radial basis function

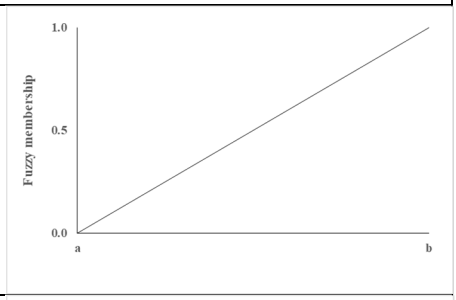
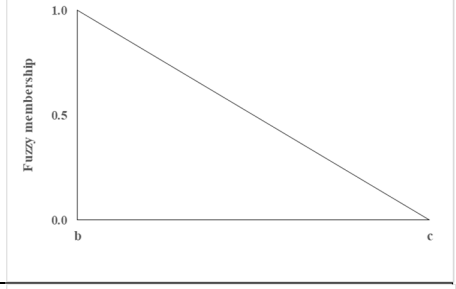
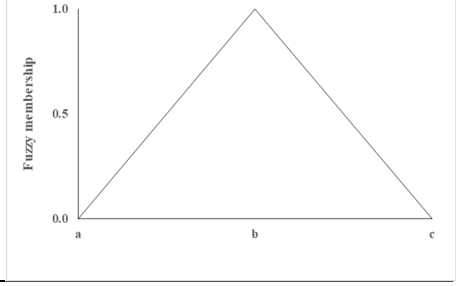
interpolation (RBF) method. The rainfall and temperature data from 1979 to 2016 were acquired from 32 weather stations in Golestan Province; they are also interpolated through the inverse distance weighted (IDW) method. All the data were converted to 100m spatial resolution.

Table 1. The important criteria in the land suitability of *N.schoberi**

Features	Appropriate classes (value: 1)	Inappropriate clases (value: 0)
Precipitation (mm)	100 – 350 and 350<	< 100
Average temperature (◦C)	12.5 – 18.5	< 12.5 and 18.6<
Slope (%)	< 20	20 <
EC ($dS.m^{-1}$)	< 20	20 <
pH	7-9	<7 and >9
Soil texture	Loamy-sandy / Sandy / Silty-clay / Clay-loam	Clay

*Baghestani Meybodi, 1996; Naseri et al, 2011; Momeni Damane and Panahi, 2015; Azarnivand, and.Zare Chahouki, 2012

Table 2. Fuzzy function used for each parameter

Parameters	Fuzzy function type	Function formula	Function shape
Precipitation	Linear increase	$x \le a \rightarrow 0$ $a < x \le b \rightarrow \frac{(x-a)}{(b-a)}$ $x > b \rightarrow 1$	
EC Slope	Linear decrease	$x \le b \rightarrow 1$ $b < x \le c \rightarrow \frac{(c-x)}{(c-b)}$ $x > c \rightarrow 0$	
Temperature pH Soil texture	Triangular	$x \le a \rightarrow 0$ $a < x \le b \rightarrow \frac{(x-a)}{(b-a)}$ $b < x \le c \rightarrow \frac{(c-x)}{(c-b)}$ $x > c \rightarrow 0$	

Land suitability analysis for N. schoberi plantation using Boolean Logic

The environmental requirements of *N.schoberi* were recognized through scientific literature review and local expert's opinion; based on questionnaires. The requirements were classified into two appropriate and inappropriate categories. Accordingly, in the next step, based on Boolean logic and the environmental requirements of *N.schoberi*, each of the layers were classified into appropriate (value: 1) and inappropriate (value: 0). Finally, the suitability map of *N.schoberi* was calculated through the overlay of the main effective factors.

Land suitability analysis for *N. schoberi* plantation using Fuzzy Logic

Depending on the environmental requirements of *N.schoberi*, the degree of fuzzy membership (between 0-1) was determined, and then the formula and its fuzzy diagram were generated using Excel software. In the next step, a fuzzy formula was executed for each layer using the Con tool in ArcMap$_{10.5}$ software, so fuzzy layers including precipitation, average temperature, slope, EC, pH and soil texture for *N.schoberi* were prepared. Finally, to assess the land suitability, the layers were combined using the Raster Calculator tool and the final map was generated in four classes: not suitable, moderately suitable, suitable and highly suitable. The fuzzy function for each parameter is presented in Table 2. Finally, the output data were analyzed using FreeViz method (Demsar et al., 2007).

Results and discussion

Based on the Boolean logic, the precipitation in the studied winter rangelands is suitable for *N.schoberi* plantation, while the results obtained using Fuzzy logic demonstrated that Aq-qala, Incheboroun and most parts of Gonbad-e-kavous rangelands were moderately suitable (Figure 2).

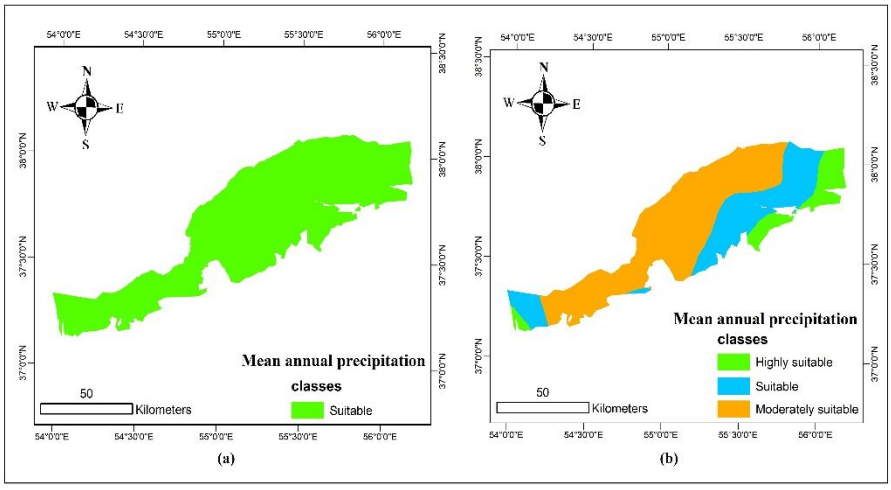


Figure 2. Land classification based on the mean annual precipitation using Boolean (a) and Fuzzy logic (b)

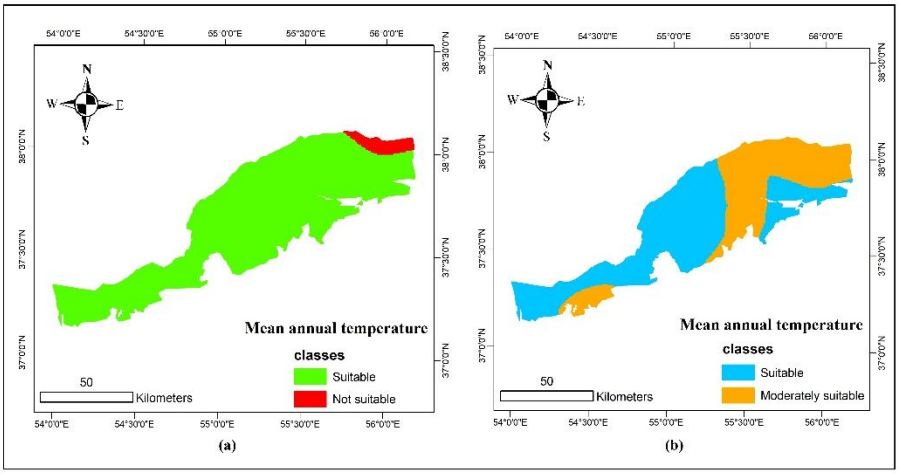


Figure 3. Land classification based on the mean annual temperature using Boolean (a) and Fuzzy logic (b)

According to the results (Figure 3) and based on the Boolean logic, the mean annual temperature in the studied winter rangelands (except for a small part of Maraveh- tappeh rangelands) is suitable for *N.schoberi* plantation, while the results obtained using Fuzzy logic revealed that the studied winter rangelands are recognized as suitable and moderately suitable classes (Figure 3). It is well-known that precipitation and temperature are the most effective factors in plant growth process.

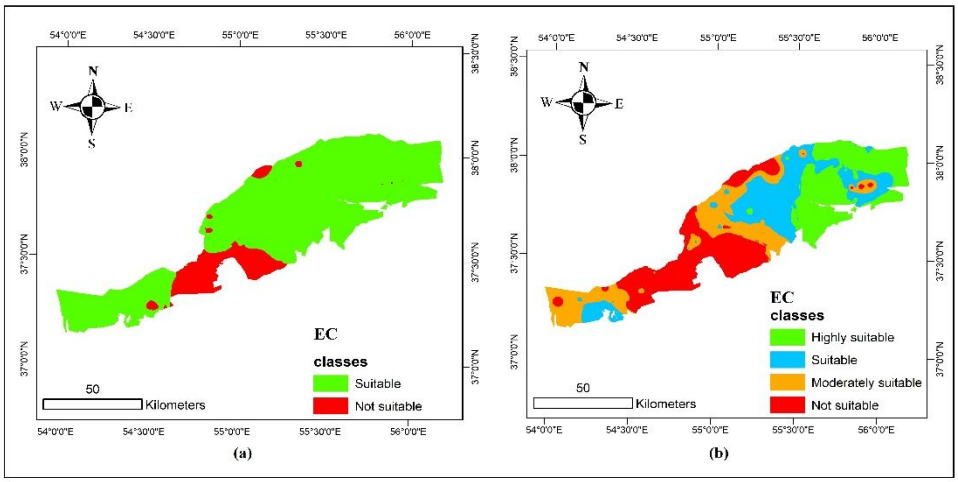


Figure 4. Land classification based on soil salinity using Boolean (a) and Fuzzy logic (b)

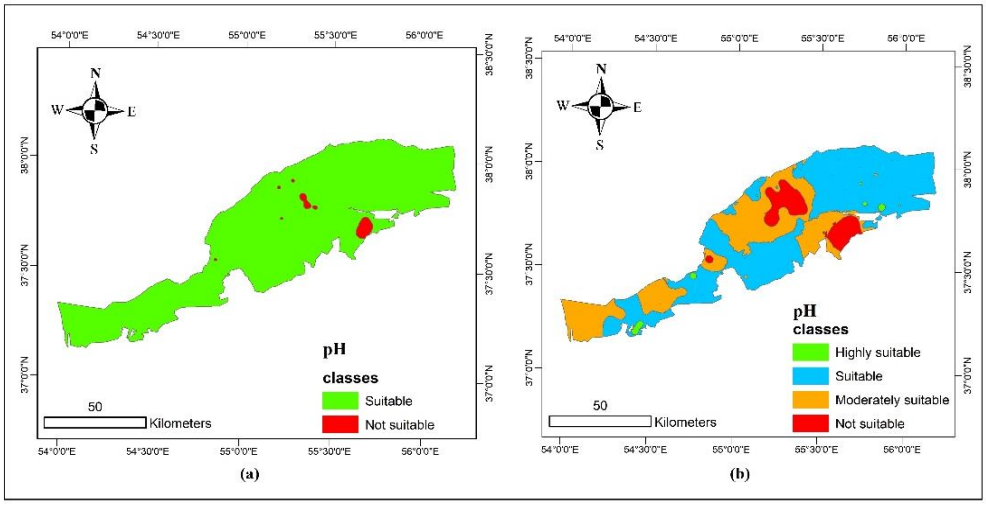


Figure 5. Land classification based on soil pH using Boolean (a) and Fuzzy logic (b)

The Boolean logic results using soil salinity in Figure 4 demonstrated that Inche-broun rangeland and small parts of Aq-qala and Gonbad-e-kavous rangelands are not suitable for *N.schoberi* plantation. The studied rangelands were classified into four classes, and as such Maraveh-tappeh rangeland was found to be suitable and highly suitable, while, other winter rangelands were classified as moderately suitable and not suitable classes.

Based on soil pH and using Boolean logic, nearly all of the studied rangelands fell in the suitable class for *N.schoberi* plantation (Figure 5). The results

revealed that using Fuzzy logic, Maraveh-tappeh rangeland was classified as highly suitable but nearly all of Koumish-tappeh rangelands, as well as western parts of Gonbad-e-kavous rangelands were found to be moderately suitable or not suitable at all.

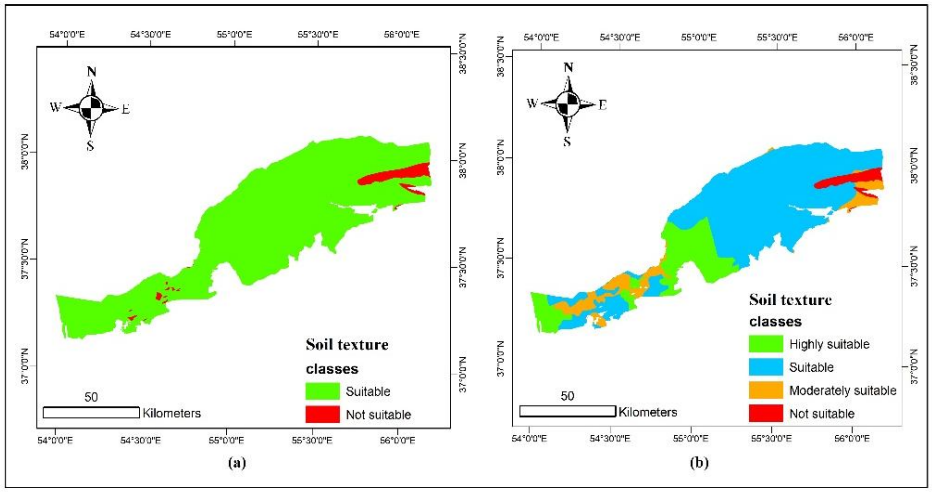


Figure 6. Land classification based on soil texture using Boolean (a) and Fuzzy logic (b)

Based on Boolean logic, soil texture was not a limiting factor in land classification for *N.schoberi* plantation (Figure 6). However, using the fuzzy logic, the studied winter rangelands were classified from not suitable to highly suitable class.

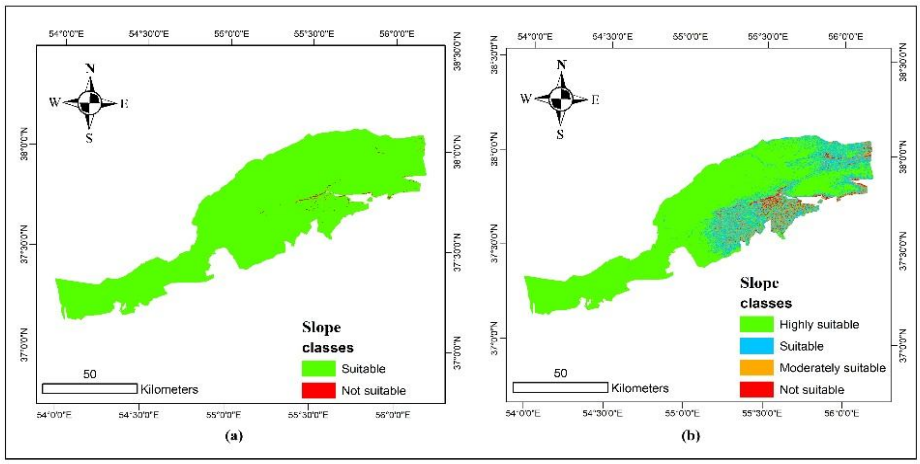


Figure 7. Land classification based on the land slope using Boolean (a) and Fuzzy logic (b)

According to the output of Boolean logic in Figure7, slope was not a limiting factor for *N.schoberi* plantation in the winter rangeland. The output of Fuzzy logic revealed that western part of Maraveh-tappeh rangelands in addition to the south-western parts of Gonbad-e-kavous rangelands have high variability in land suitability class for *N.schoberi* plantation. Other parts of the studied rangelands were classified as highly suitable for *N.schoberi* plantation.

Suitable area for N.schoberi plantation using Boolean logic

The relatively large extent of the study area (5323.78 km^2) was classified in suitable class for *N.schoberi* plantation using Boolean logic (Figure 8 and Table 3).

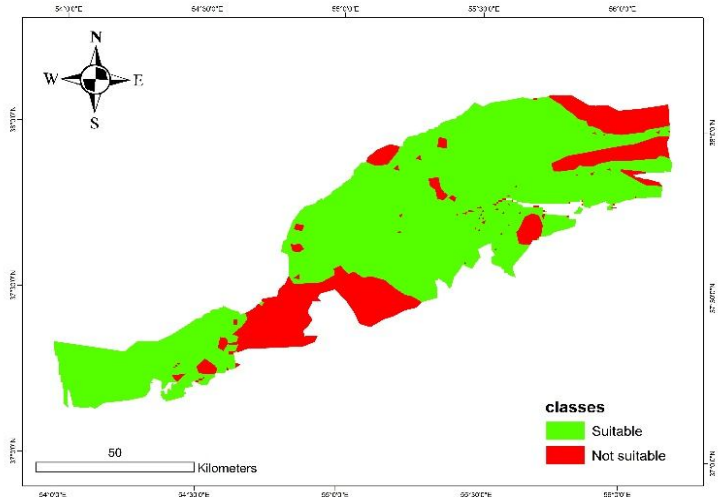


Figure 8. Suitable area for *N.schoberi* plantation using Boolean logic

The results obtained using Boolean logic demonstrated that soil salinity is the main limiting factor for *N.schoberi* plantation in the studied area.

Table 3. Suitable and not suitable areas in terms of environmental factors for *N.schoberi* plantation (Boolean Logic)

Environmental factors	Suitable area (km2)	Not suitable area (km^2)
Precipitation (mm)	6772.85	-
Temperature (◦C)	6521.67	251.18
EC	5935.06	837.79
pH	6676.4	96.45
Texture	6524.21	248.59
Slope	6748.52	24.205
Final layer of feasibility	5323.78	1448.78

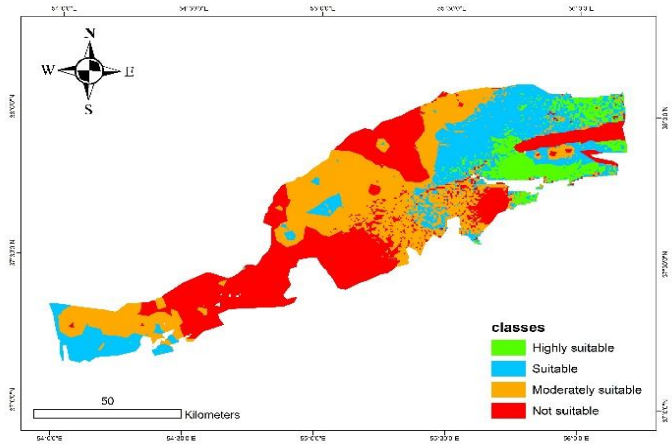


Figure 9. The suitability of studied area for *N.schoberi* plantation using Fuzzy logic

Suitable area for *N.schoberi* plantation using Fuzzy logic

The suitability classes of winter rangelands in the study area for *N.schoberi* plantation using Fuzzy logic is shown in Figure 9 and Table 5. The smallest class belonged to the highly suitable areas (562 km^2) and the largest one belonged to the not suitable class (2343 km^2).

The results in Figure 9 demonstrate that among the studied winter rangelands, Maraveh-tappeh rangelands have high proportion of suitable or highly suitable rangelands for *N.schoberi* plantation.

Table 4. Suitable and not suitable areas in terms of environmental factors for *N.schoberi* plantation using Fuzzy Logic

Environmental factors	Not suitable (km^2)	Modertely suitable (km^2)	Suitable (km^2)	Highly Suitable (km^2)
Precipitation (mm)	-	4036	1964	774
Temperature (◦C)	-	2759	4014	-
EC	1774	1527	1694	1777
pH	531	2231	3956	55
Texture	232	646	4603	1292
Slope	116	357	1164	5135
Final layer	2343	2305	1563	562

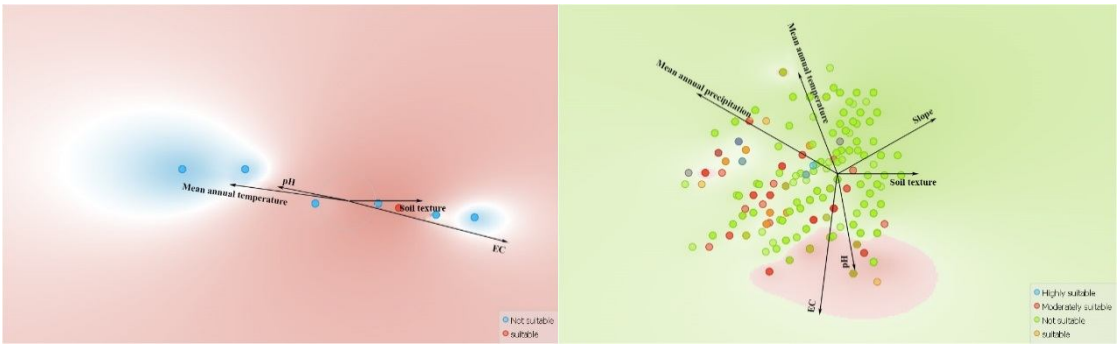


Figure 10. FreeViz analysis for *N.schoberi* plantation using Boolean logic (left) and Fuzzy logic (right)

The results of FreeViz analysis (Fig.10), using Boolean logic, demonstrated that high soil salinity, soil texture and mean annual temperature have significantly negative impacts on *N.schoberi* plantation in the study area. However, using Fuzzy logic results we found significant negative effects of mean annual precipitation, soil salinity and mean annual temperature on the habitat of this plant species. It was also found that the fuzzy logic gives us better and more accurate results than the Boolean logic method (Alami et al., 2014).

The results demonstrated that a large part of the study area is suitable for *N.schoberi* plantation which is due to the high resistance of this species to the severe environmental conditions, so it can be used in combination with native (Niknahad Gharmakher et al., 2015) or introduced species (Ahmadi- Beni et al., 2016), particularly in rangelands rehabilitation projects.

Conclusion

Soil properties except its texture, play the most effective role in suitability of *N.schoberi* plantation area. However; mean temperature and precipitation are also somewhat effective. The use of water harvesting techniques and soil conditioners in winter rangeland planting projects using *N. schoberi* are suggested. The findings of the present study can help rangeland managers and planners in the process of decision-making, so we recommend using the results of this research in rangeland improvement operations.

Funding

The data for this article were extracted from Vahid Aranian's dissertation and did not receive any specific grant from funding agencies in the public, commercial, or not-for-profit sectors.

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