Fuzzy Logic Model to Assess Desertification Intensity Based on Vulnerability Indices

Mohammad Hassan Sadeghiravesh[1], Hassan Khosravi[2*], Azam Abolhasani[2], Marzieh Ghodsi[3], Amirhosein Mosavi[4,5*]

[1]Department of Environment, College of Agriculture, Takestan Branch, Islamic Azad University, Takestan, No. 1. Enghelab Str, 31585-3314, Iran, m.sadeghiravesh@tiau.ac.ir

[2]Department of Reclamation of Arid and Mountainous Regions, Faculty of Natural Resources, University of Tehran, Tehran, No. 1. Enghelab Str, 31585-3314, Iran, hakosravi@ut.ac.ir, azam.abolhasani@ut.ac.ir

[3]Faculty of Geography, University of Tehran, Tehran, No. 1. Enghelab Str, 31585-3314, Iran, mghodsi@ut.ac.ir

[4]Atmospheric Science and Climate Change Research Group, Ton Duc Thang University, Ho Chi Minh City, Vietnam

[5]Faculty of Environment and Labour Safety, Ton Duc Thang University, Ho Chi Minh City, Vietnam, amirhosein.mosavi@tdtu.edu.vn

Abstract: Executive practices on desertification control should be based on recognizing the current desertification state and its severity. So, it is essential to assess the ways to give zoning based on logic, active principles, and theoretical foundation for the management of desert regions. For this aim, 30 useful indices on desertification were determined in two human and natural sections. The significance of indices relative to each other and each index's importance per work unit was determined using the Delphi method. The Bonissone method in the framework of the Fuzzy Multiple Attribute Decision Making (FMADM) method was used to combine indices and determine desertification intensity in each working unit. Then, data were converted to the Fuzzy layer using Chen and Wang method, and Fuzzy analysis was performed on data. Finally, Fuzzy data were changed to non-Fuzzy, and desertification intensity was estimated. The results showed that 9.35% of the study area was in a very high class regarding desertification intensity and 9.36% of the region was in relatively high class. Desertification with moderate intensity (50.64%) and a relatively moderate intensity (29.45%) had the most shares in the study area, respectively. The quantitative value of desertification potential in the whole area from all of the components was obtained as 0.083, relatively high. This study shows the efficiency and ease of Fuzzy logic application for assessing desertification intensity.

Keywords: fuzzy logic; Bonissone method; artificial intelligence; vulnerability; zoning

1 Introduction

Desertification means land degradation in arid, semi-arid, and dry sub-humid areas resulting from climatic changes or human activities [31]. According to the United Nations Convention to Combat Desertification (UNCCD), desertification will threaten more than 785 million people living in arid areas, accounting for 17.7% of the world's population [15]. In Iran, desertification is a severe threat because 16 provinces with 57.5 million hectares are located in desert regions [18]. In these communities, desertification is a primary restriction for sustainable development [30]. So identification of the status quo is a fundamental step to achieve balanced growth. Identifying the status quo and determining ecological capacity in each region prevent environmental degradation during development, ensure the additional value of national and regional investment in the most stable and appropriate state, and make it possible to achieve the desired goals and policies. Hence, methods of assessing desertification intensity and preparing a zoning map of desertification are considered the essential tools for planning and managing natural resources to achieve sustainable development [33]. Desertification assessment determines the most critical desertification component and provides a map of desertification intensity after assessing work units' indices. The application of these maps increases the efficiency of control, reconstruction, and rehabilitation projects of lands at risk of desertification and prevents capital loss. So, according to these maps' practical importance, providing quantitative methods with fewer errors, higher reliability coefficient, and achieving more accurate results is essential.

Many studies have been done about the assessment of desertification potential in different areas. For example, preliminary research for assessing classification map of desertification [12], Environment Sensitive Area to Desertification (ESA) [10], Iranian classification of desertification (ICD) [11], Iranian Model of Desertification Potential Assessment (IMDPA) [2], Modify Numerical Taxonomy (MNT) [21], Environmental vulnerability index (EVI) [22], Shannon Entropy Model [24], Principal Component Analysis (PCA) [27] and Multi-Attribute Utility Theory (MAUT) model [20]. In 1984, FAO-UNEP published a method entitled "preliminary research for assessing classification map of desertification." In this method, the current situation, rate, and risk of desertification are described. In this research, Desertification processes include the destruction of vegetation, wind erosion, soil structure erosion and degradation, reduction of soil organic matter, salinity and alkalinity, waterlogging, and accumulation of toxins. These processes are based on ground observations, aerial photos interpretation, and available information classified into four classes (low, moderate, high, and very high) using statistical modeling [12]. In 1996, Ekhtesasi and Mohajeri provided a method for classifying the type and severity of desertification in Iran. In this method, active factors in desertification are evaluating with the weight balance method, and criteria for assessing these factors are usually descriptive and qualitative [11]. In

1999, United Nation provided the ESA model in the Mediterranean Desertification and Land Use project (MEDALUS) to assess and map desertification. In this model, four indices, including soil quality, climate quality, plant cover quality, and management, were defined as the most essential desertification indices. Finally, a desertification map was obtained from the geometric average of the mentioned indices [10]. In 2006, the Iranian Model of Desertification Potential Assessment (IMDPA) was provided at the University of Tehran, Faculty of natural resources. This model tried to classify selective criteria and indices according to the environmental conditions of Iran. Therefore nine following criteria were considered: climate, geology, soil, plant cover, agriculture, erosion (wind and water), water and irrigation, socio-economic issues and industry, and urbanism. Also, 35 indices were considered by experts for assessing desertification potential. Criteria scoring was expressed as a ranking way to minimize the error of rating and ease of rating [2]. Sadeghravesh et al. (2009) provided a model entitled Modify Numerical Taxonomy (MNT) [21]. This model has a hierarchical structure and is based on paired comparisons. To reduce the error of indicators valuation, this method uses the incompatibility index for automatic control on judgments in addition to the Delphi method, which is based on questionnaires.

The studies conducted on these methods have shown some defects, including non-native and qualitative indices, the degree of error, the small-scale, impossibility of separating human and natural factors in conclusion, etc. Although these defects were resolved mainly in other models, especially in the Taxonomy model, these models have still significant weaknesses, so that in evaluating indices, only the absolute value of each index is considered per work unit, and their priority is not considered in creating the critical condition which leads to unrealistic results. Hence, Sadeghravesh presented three models, including the EVI (Environmental Vulnerability Index), Shannon Entropy Model, Principle Component Analysis model, and Multi-Attribute Utility Theory (MAUT) model during 2012-2020 [9]. Like the MNT model, these models have a hierarchical structure and estimate desertification potential or region vulnerability based on indices priority and each index importance per work unit. But these models have a restriction and ignore the Fuzzy judgment of decision-makers. Real phenomena are always Fuzzy, imprecise, and vague, and Fuzzy logic is more realistic and closer to human behavior when it's necessary to select and make a decision [6] [16]. Some studies with the application of Fuzzy logic are as follow: Assessment of water management projects [29], security management in production [8], selecting resources planning systems [7], staff selection [9] [13], the election of suppliers [32], assessing companies efficiency [3], selecting the location of waste disposal site [17], prioritization and ranking of desertification indices [20], assessment of energy resources [16], zoning of wind erosion potential [23] and evaluation of desertification strategies [25] [26].

The usual methods using definitive data are ambiguous in the evaluation and ranking of indicators. In other words, there is no rational framework for uncertainty in decision making. But in natural options, including the identification and evaluation of desertification indicators, the researcher faces uncertainty. According to investigations, it was apparent that the Fuzzy method has not been used in desertification intensity zoning, while this method quickly developed in different science. This study, using fuzzy logic and inaccurate and non-deterministic data, makes it possible to study the conditions of uncertainty in the ranking and prioritization of desertification indicators. Bonissone Fuzzy method was used to achieve zoning purpose in the framework of multiple attribute decision making models. In this model, desertification intensity is estimated based on indices' priority and importance in each work unit. The results can be the basis for a new method and modification of the proposed methods to manage risk, evaluate, and monitor desertification.

2 Materials and Methods

2.1 Study Area

Khezr Abad region with an area of 78180 ha is located 10 km west of Yazd. This region extends from 53° 55' to 54° 20' eastern longitude and from 31° 45' to 32° 15' northern latitude. The region's average height is 1397 m, and 84.79% of the study area (663 km^2) has a slope lower than 10%. So the most extent of this area includes flat land with an average gradient of 9.41%. The region's soil resources are usually Entisols containing salt and gypsum formed under physical degradation and are affected by water and wind erosion and degradation. Soil temperature regime is thermic, and soil moisture regime is aridic. The climate of this region is cold and arid based on the Amberje climate classification method. The annual mean precipitation of this region is 121 mm. The dominant wind direction is Northwest, with an occurrence frequency of 16.97% and a maximum speed of 16.3 km/hr. About 130 km^2 (16.5%) of the region include dunes. Ashkezar erg, site of sandstorms occurrence, with an area of 89 km^2 and eroded and degraded faces located in the north part of the study area. About 1,995 ha (26.5%) of all agricultural lands of the region consists of degraded lands resulting from human activities and natural factors. These characteristics of the area show its typical desertification condition and a requirement to identify and prepare a desertification vulnerability map.

2.2 Methodology

There are different quantitative techniques for estimating and zoning desertification, facilitating planning, and assisting in decision-making. In this research, the Multiple Attribute Decision-Making method was used considering the number of useful indices in desertification zoning; also, fuzzy logic was used for combining indices. The usual process within the MADM method and Fuzzy logic consists of 6 stages: determining effective indices, determining work units, determining the importance of indices, and each index importance in each work unit, Fuzzy data making, Fuzzy process, and converting Fuzzy data to non-Fuzzy.

2.2.1 Determining Effective Indices to Assess Desertification Intensity

Thirty effective indices on desertification were determined in two human and natural sections based on the gained data through natural resources assessment and field study (Table 1). To select indices, three main factors, including the relationship with desertification, ease of access, and ease of updating, were considered in the framework of time and expense factors [19] [22] [26].

Table 1

Effective indices on desertification vulnerability of the study area

Natural, effective indices on vulnerability	Human effective indices on vulnerability
Annual mean precipitation (mm)	Tilling and fallow
Average wind speed (m/s)	Irrigation method
Aridity index (P/ET_p)	Irrigation efficiency (%)
Soil texture	Irrigation system
Soil salinity (EC-mmhos/cm)	Groundwater depletion
Soil drainage (in/h)	Soil moisture
Soil depth (cm)	Use of machinery, chemical and organic fertilizer
Slope (%)	Cropping pattern & production
Wind and water erosion	People's participation
Water salinity (EC-μmohs/cm)	Literacy (%)
The depth of groundwater level (cm)	Employment status
Vegetation cover density (%)	Population biological density (N/Km^2)
Shrubs and trees removing (%)	Land-use changes
Carrying capacity rangelands (AU/100 day)	Awareness of degradation results
Livestock pressure (capacity of rangeland/ existing livestock)	The land division into small parts

Climatic indicators were considered based on the ability to affect the available water of plants. These indicators include average annual rainfall, wind speed, drought, etc. The yearly average rainfall index was assessed because rainfall equivalent to 300 mm is considered a critical threshold in the process of soil erosion and plant growth [28]. Estimating the most critical parameter, water availability to the plants needs a lot of information on soil conditions. Therefore, the FAO drought index was used in this study. The drought index is the annual rainfall ratio to annual potential evapotranspiration [28]. Investigation of wind erosion was done using the IRIFER method [1]. In this method, nine effective wind erosion parameters, including lithology, land formation and topography, wind speed and condition, soil condition and its surface cover, canopy type and percentage, soil moisture, soil surface erosion forms, land management, and land use were considered. For the investigation of water erosion, the PSIAC method was used [1]. In this method, parameters such as lithology, soil, climate, runoff, morphology, vegetation, and land use were considered. For estimating excessive grazing, which causes soil erosion, an animal unit (AU) was used. In this study, the animal unit was calculated based on the areas occupied by livestock [19]

2.2.2 Determining Work Units

Work units were determined using the geomorphology method to provide a proper framework for preparing a vulnerability zoning map of desertification [1]. For this aim, after collecting data from the interpretation of aerial photos, available digital data in map format, and reports of organizations and offices, digital data were entered into ArcGIS software. Finally, maps of geomorphology, land use, and vegetation types were obtained. These layers were overlapped, and then the final layer of work units was formed (Fig. 1). Twelve work units were selected according to the study goals.

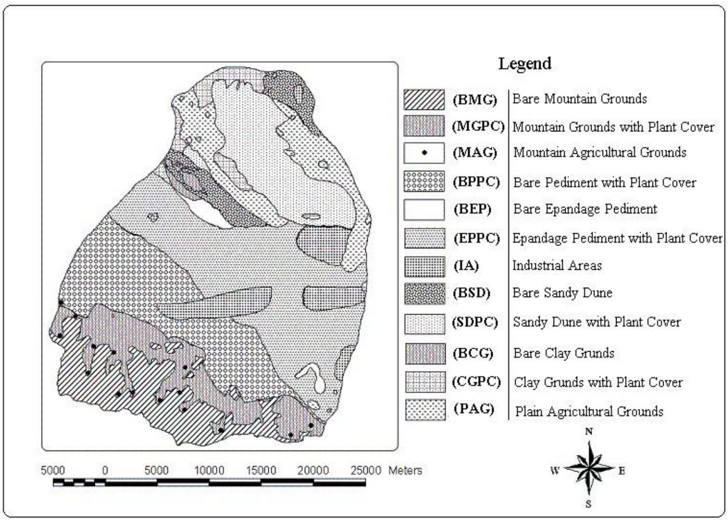

Figure 1

Work units of Khezr Abad

2.2.3 Determining the Importance of Effective Indices on Desertification Relative to Each Other and Also in Each Work Unit

The significance of indices relative to each other (w_j) and the importance of each index per work unit (r_{ij}) was determined using the Delphi method in the framework of MADM. To assess w_j and r_{ij}, a questionnaire was prepared and filled based on Chen and Wang's seven-rank scale by experts familiar with the study area.

Table 2
Fuzzy preference and importance degree, Chen and Wang method

Linguistic indicators	Numerical value	Number of Linguistic indicators			
		2	3	5	7
Very Low	0≤, >1			(0, 0, 0, 1.2)	(0, 0, 1, 0)
Low	1≤, >2		(0, 0, 0,2, 0.4)	(0.1, 0.25, 0.25, 0.4)	(0.1, 0.2, 0.2, 0.3)
Relatively Moderate	2≤, >3				(0.2, 0.3, 0.4, 0.5)
Moderate	3≤, >4	(0.4, 0.5, 0.5, 0.8)	(0.2, 0.5, 0.5, 0.7)	(0.3, 0.5, 0.5, 0.7)	(0.4, 0.5, 0.5, 0.6)
Relatively High	4≤, >5				(0.5, 0.6, 0.7, 0.8)
High	5≤, >6	(0.5, 0.8, 0.8, 1)	(0.6, 0.8,1 , 1)	(0.6, 0.75, 0.75, 0.9)	(0.7, 0.8, 0.8, 0.9)
Very High	6≤, >7			(0.8, 0.9, 1, 1)	(0.8, 0.9, 1, 1)

Then judgments were combined using a geometric mean (Eq.1), and a pairwise comparison matrix was gained. It was assumed that all experts' comments have the same importance degree.

$$\bar{a}i = \left(\overset{K=1}{\underset{N}{\pi}} \; ai^{k} \right)^{1/N} \tag{1}$$

a_i^k is related to k^{th} person in estimating the importance degree of each index.

Then, using the concept of normalization (Eq. 2) and weighted mean or the average of each row in the normalized matrix (Eq. 3), the importance of indices (W_j) was estimated (Table 3) [5].

$$z_{ij} = \frac{a_{ij}}{\sum_{i=1}^{M} a_{ij}} \tag{2}$$

$$W_i = \frac{\sum_{i=1}^{N} z_{ij}}{N} \tag{3}$$

Table 3
The normalized matrix of the importance of indices relative to each other and determining the priority of each index

Indicator (I_i)	I_1	I_2	…	I_n	[2]W_i
I_1	[1]z_{11}	Z_{12}	…	Z_{1N}	W_1
I_1	a_{21}	a_{22}	…	Z_{2N}	W_2
:	:	:	…	:	:
I_M	Z_{M1}	Z_{M2}	…	Z_{MN}	W_M

2.2.4 Making Fuzzy Data

This process includes shifting and converting inputs by the Fuzzy controller. The process has two stages, including membership and rating functions. Membership function has different forms, such as triangular, trapezoidal, and arched. In this study, a trapezoidal-shaped membership function was used.

The basis of Fuzzy logic is Fuzzy sets, which are a general state of sets theory. These sets range from discontinuous set {0, 1} to continuous sets {0, 1}.

In the Fuzzy sets, each variable's assessment is performed using linguistic variables by importance degree and based on normal logic generalization to multi-valued or continuous logic. Linguistic variables performance of a reference set like U in a trapezoidal function operates according to Eq. 4.

$$\tilde{A}(x) = \begin{cases} \frac{(e-x)}{(L-M)}e & L < x < M \\ e & M \le x < M' \\ \frac{(U-x)}{(U-M')} & M' \le x \le U \\ 0 & \end{cases} \quad (4)$$

Otherwise, the membership function is trapezoidal-shaped.

Due to the multiplicity of linguistic variables, the Fuzzy numbers corresponding to them were used. Different methods have been provided for converting linguistic variables to the Fuzzy numbers corresponding to them. In this study, the seven-ranking scale of Chen and Wang was used (Table. 2).

According to the type of selected Fuzzy numbers (trapezoidal), The Bonissone method was chosen among multiple attribute decision-making methods. In this method, it's assumed that algebraic operations on Fuzzy trapezoidal numbers (L-R) can be estimated as parametric. Bonissone showed each Fuzzy trapezoidal number ($\tilde{D}$) with four parameters (L, M, M′, and U) as the following equations:

The first Fuzzy number: $\tilde{D}_1 = (L_1, M_1, M_1', U_1)$ (5)

The second Fuzzy number: $\tilde{D}_2 = (L_2, M_2, M'_2, U_2)$ (6)

Algebraic operations on these numbers are defined as the following equations (7-10):

$$\tilde{D}_1 + \tilde{D}_2 = (L_1 + L_2, M_1 + M_2, M'_1 + M'_2,\ U_1 + U_2) \quad (7)$$

$$\tilde{D}_1 - \tilde{D}_2 = (L_1 - U_2, M_1 - M'_2, M'_1 - M_2,\ U_1 - L_2) \quad (8)$$

$$\tilde{D}_1 \times \tilde{D}_2 = (L_1 \times L_2, M_1 \times M_2, M'_1 \times M'_2, U_1 \times U_2) \quad (9)$$

$$\frac{\tilde{D}_1}{\tilde{D}_2} = \left(\frac{L_1}{U_2}, \frac{M_1}{M'_2}, \frac{M'_1}{M_2}, \frac{U_1}{L_2}\right) \quad (10)$$

2.2.5 Converting Fuzzy Data to Non-Fuzzy and Assessment of Desertification Intensity

2.2.5.1 Determining the Utility of Each Work Unit (Ui)

A fuzzy utility index was used to assess efficiency. This index is a combination of indices' relative Fuzzy importance compared to each other (W_j) and each index Fuzzy influence in each work unit (R_{ij}) regarding desertification. It was calculated based on equation 11 in each work unit [4] [6].

$$U_i = \sum_{j=1}^{n} W_j \cdot R_{ij} \quad (11)$$

2.2.5.2 Calculating the Importance Degree of Any Trapezoidal Fuzzy Utility Number from Another Fuzzy Number

It's necessary to arrange all U_i to determine the work units' weight or desertification intensity. So the importance degree of each Fuzzy number relative to other Fuzzy numbers was computed using equation 12, and the matrix of each work unit's magnitude degree was formed.

$$\begin{cases} V(D_1 \geq D_2) = 1, \\ M_1 \geq M'_2 \\ V(D_1 \geq D_2) = hgt(D_1 \cap D_2) = \frac{U_1 - L_2}{(U_1 - L_2) + (M_2 - M'_1)} \\ Otherwise \end{cases} \quad (12)$$

2.2.5.3 Calculating the Importance Degree of Any Trapezoidal Fuzzy Utility Number from Other k- Fuzzy Trapezoidal Numbers (Pi)

After determining each Fuzzy number's magnitude degree relative to different Fuzzy numbers, the importance of any trapezoidal Fuzzy utility number from other k- Fuzzy trapezoidal numbers (P_i) was calculated using equation 13.

$$P_i = min \quad V(D_1 \geq D_K), \quad i, k = 1,2, \dots, n \tag{13}$$

The numbers gained from this process shows abnormal weights of work units.

2.2.5.4 Normalization of Abnormal Weights of Work Units and Assessing Desertification Potential

Finally, using equation 14, abnormal weights of work units were normalized to estimate desertification potential in each work unit [4] [6].

$$N_i = \frac{P_i}{\sum_{i=1}^{k} P_i} \quad i = 1,2, \dots, n \tag{14}$$

3 Result

After determining effective indices (Table 1) and preparing maps of work units (Fig. 1), a group matrix of the indices' importance relative to each other (W_j) and the importance of each index in each work unit (r_{ij}) was formed (Table 4).

Table 4

Group matrix of each index importance relative to each other and in each work unit regarding desertification

Desertification index	1	2	…	29	30
Group matrix of the indices importance relative to each other					
Importance	0.89	3.9	…	4	5.5
Linguistic words	Very low	Moderate	…	Relatively high	high
Trapezoidal Fuzzy component ($\tilde{D}$)	(0, 0, 0.1)	(0.4,0.5, 0.5, 0.6)	…	(0.5, 0.6, 0.7, 0.8)	(0.7, 0.8, 0.8, 0.9)
Group matrix of each index importance in each work unit					
BMG	3.5	3.8	…	0.75	0.78
MGPC	4.6	3.8	…	0.63	0.5
.	…	…	…	…	…

.	…	…	…	…	…
IA	4.4	3.8	…	0.35	0.95
MAG	3.6	3.8	…	0.5	4.8

Then, to make Fuzzy data, Chen and Wang scale (Table 2) were used (Tabs. 4-5).

Table 5

Fuzzy group matrix of each index importance in each work unit

TMUs \ I	1	2	…	29	30
(BMG)	(0.4, 0.5, 0.5, 0.6)	(0.4, 0.5, 0.5, 0.6)	…	(0, 0.1, 0)	(0, 0.1, 0)
(MGPC)	(0.5, 0.6, 0.7, 0.8)	(0.4, 0.5, 0.5, 0.6)	…	(0, 0.1, 0)	(0, 0.1, 0)
.	…	…	…	…	…
.	…	...	…	...	...
(IA)	(0.5, 0.6, 0.7, 0.8)	(0.4, 0.5, 0.5, 0.6)	…	(0, 0.1, 0)	(0, 0.1, 0)
(MAG)	(0.4, 0.5, 0.5, 0.6)	(0.4, 0.5, 0.5, 0.6)	…	(0, 0.1, 0)	(0.5, 0.6, 0.7, 0.8)

Then Fuzzy utility index (U_i) of all work units was estimated using equation 11, and a utility matrix was formed (Table 6).

Table 6

The utility of each work unit based on Fuzzy logic

TMUs \ Fuzzy numbers	U	M′	M	L
(BMG)	7.03	4.45	3.91	2.76
(MGPC)	7.2	4.47	3.99	2.77
(BPPC)	7.02	4.14	3.65	2.43
(BEP)	5.95	3.33	2.91	1.95
(EPPC)	6.44	3.53	3.26	2.21
(PAG)	11.28	8.02	6.91	4.62
(CGPC)	7.53	4.68	4.14	2.82
(BCG)	6.64	3.9	3.39	2.28
(BSD)	6.21	3.51	3.13	2.07
(SDPC)	7.08	4.23	3.82	2.58
(IA)	7.48	4.49	3.86	2.48
(MAG)	12.5	9.14	7.99	5.5

Finally, to determine desertification intensity, the magnitude degree of each Fuzzy number relative to other Fuzzy numbers was calculated using equation 12. The matrix of all work units' magnitude degree close to each other was formed. Then, the abnormal weight of all work units (P_i) was determined using equation 13. These weights were normalized (N_i) using equation 14 (Table 7).

Table 7
The matrix of each work unit magnitude degree

TMUs	(BMG)	(MGPC)	…	…	(IA)	(MA)	P_i	N_i
(BMG)	1		…	…	1.1548	0.3029	0.3029	0.066
(MGPC)	1.1384	1	…	…	1.1428	0.3244	0.3244	0.071
…	…	…	…	…	…	…	…	…
…	…	…	…	…	…	…	…	…
(IA)	1.1400		…	…	1	0.3613	0.3613	0.079
(MAG)	1	1	…	…	1	1	1	0.22

Estimated values of desertification intensity (N_i) using equation 14 are continuous values, estimated due to the ease of reading and understanding the results. Based on Table 8, the desertification intensity of the study area was classified into six levels.

Table 8
Classification of desertification intensity in Khezr Abad region and the area of each class

Class	Desertification intensity	Class	Area	
			Km^2	%
Low	$0.025 \leq N_i$	I	0.943	1.2
Relatively Moderate	$0.05 \leq N_i < 0.025$	II	23.113	29.45
Moderate	$0.075 \leq N_i < 0.05$	III	39.756	50.65
Relatively high	$0.1 \leq N_i < 0.075$	IV	7.339	9.35
High	$0.125 \leq N_i < 0.1$	V	-	-
Very High	$0.125 > N_i$	VI	7.336	9.35

Each work unit was located in one of the desertification classes. Eventually, from combining the work units with the same classes, the final map of desertification potential with a scale of 1.50000 was gained using ArcGIS (Fig. 2).

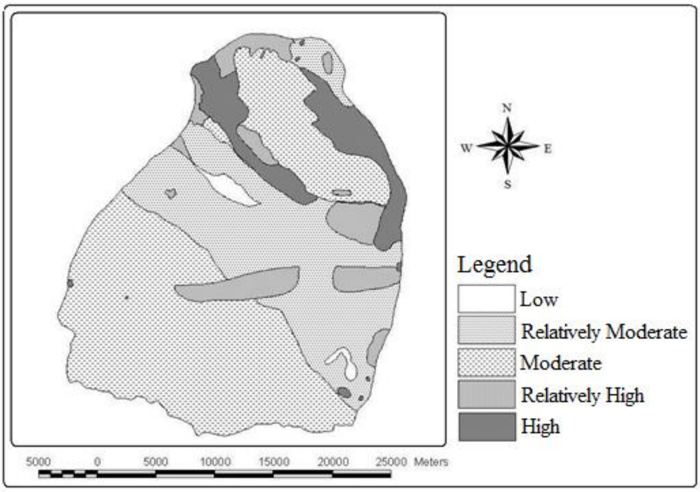

Figure 2
Zoning map of desertification intensity in Khezr Abad

4 Discussion

The following results were gained based on assessing desertification intensity in each work unit. In terms of vulnerability caused by desertification, mountain agricultural grounds (MAG) and plain agricultural grounds (PAG) units were in very high class, with the most quantitative value equal to 22%. Clay grounds with plant cover (CPGC) with a quantitative value of 0.083, and industrial areas with a quantitative value of 0.079 were in relatively high class. Other work units were located in moderate, relatively moderate, and low classes.

In determining the importance of indices relative to each other, the groundwater level's quantitative values, irrigation system, irrigation method, and soil depth were estimated equal to 7 or very high. The quantitative costs of irrigation efficiency, tilling and fallow, the land division into small parts, cropping pattern and production management, biological population density, carrying capacity of rangelands, and livestock pressure were estimated equal to 6 or high. Other indicators were not crucial in the assessment of desertification, according to experts. The essential human indices affecting desertification in units include inappropriate tilling and fallow (30-50% of lands are not cultivated due to different factors), improper and low use of agricultural machinery, overuse of pesticides and fertilizers, traditional and inappropriate irrigation method with low efficiency (less than 40%), a severe drop of groundwater table (45 cm/year), high population density (between 200 to 550 people per square kilometer), improper land-use changes, unemployment, the insignificant extent of agricultural lands and low participation of native people. The most important natural indices affecting desertification in units include an extended dry period in which much of the area has a no wet month, several days with Aeolian sand (more than ten days per year), winds with a velocity more than the threshold velocity of erosion (39%), the low ratio of precipitation to evapotranspiration (0.03- 0.05).

Low rainfall (less than 60 mm/ year), soils with medium to fine texture and poor drainage (0.5 to 1 inch per hour), having limiting gypsum and limestone layers in soil depth especially in units CGPC, BCG and PAG, dunes movement (up to 10 meters per year), high amount of salt and chlorine in groundwater (7620 mmohs/cm and 2350 mg/liter respectively), poor plant types of rangeland with the negative tendency due to overgrazing and livestock pressure (3.7 to 5.1 times more than the tolerable level) and digging plants (40% to 50%). The results of assessing desertification intensity based on Fuzzy logic were compared to the effects of the Environmental Vulnerability Index [22], Shannon Entropy model [24], Principle Components Analysis model [27], which estimate desertification intensity based on indices priority relative to each other and also each index importance in every work unit. In all four models, mountain agricultural ground unit (MAG) and plain agricultural ground unit (PAG) have the most potential of desertification, and in the next stage, clay ground with plant cover (CGPC) and industrial areas are located. So, this study's results were consistent with the results of EVI, Shannon Entropy, and Principle Component Analysis models. But the quantitative values of various models are different. This occurs because of the models nature, which provides quantitative values in different ranges and also the different classifications of quantitative values based on the range of acquired values in each study. The final significance in the fuzzy model, like other desertification intensity zoning decision-making models, was estimated based on the linear sum of the significance coefficient of the indicators relative to each other (Wj) in the weights of each index in each work unit (rij). Estimating the weights of the indicators in each work unit was based on the Delphi method and consulting experts in all of these models. Also, in this method, unlike the Shannon Entropy model and Multi Attribute Utility Theory (MAUT) model in which the importance of indices is gained from the Entropy method and without considering the expert's judgment, the influence of indices was acquired using the Delphi technique, like EVI and PCA models. In the Fuzzy way, the significance of indices was assessed based on Chen and Wang scale, while in EVI and PCA models, the final influence was gained based on the nine-Saaty scale, normalization logic, weighted mean, and rotated principal component vector, respectively. The results of this study seem to be more accurate owing to the use of Fuzzy logic for determining the importance of indices relative to each other and also each index importance in each work unit.

The vital point in this research is the importance of accuracy in determining the weights related to each criterion, which plays an essential role in the results.

Accurate estimation of these weights leads to more realistic and reliable results. The fuzzy technique in the framework of multi-criteria decision models with prioritization of effective indicators from Delphi method and group judgment and also by providing the zoning based on this prioritization, as well as taking into account the relationships between the criteria and the closeness of the criteria comparisons to human thinking has a significant role in results accuracy. The results show that the evaluation of indicators and map of desertification intensity is dynamic and continuous. Different intensity classes are changeable, and the ranges of intensities can be redefined in various land management and reclamation scenarios. According to the evaluation of desertification intensity in work units, the quantitative value of desertification for the whole region was equal to 0.083 (class IV or relatively high).

Conclusions

Generally, the results showed that from the entire region, 7336 hectares (9.35%) was in class VI or very high, 7339 hectares (9.36%) was in IV class or relatively high, 39756 hectares (50.65%) was in class III or medium, 23113 hectares (29.45%) was in class II or relatively medium, and 943 hectares (1.2%) was in I or low desertification intensity class (Table 5 and Fig. 2). These results can be considered in future evaluations to invest in sustainable development, ensure the additional value of investments, and also protect marginal ecosystems of the study area. On the other hand, these results help the manager of desert areas to utilize limited facilities and stock allocated to the control of desertification phenomenon in regions with more vulnerability and prevent the waste of national funds. To use this model in other regions, influential factors in desertification should be considered inherent vulnerability indices, and also the impact of each parameter on desertification should be emphasized.

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