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Research Paper

Desertification risk assessment in Yazd province with an emphasis on hydrology, climate, vegetation, and soil criteria using IMDPA model

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Abstract:
Desertification is one of the most obvious degradation processes of natural resources in the world, which impose more destructive effects in arid, semi-arid, and semi-humid than other regions. Over the past few decades, global efforts have been channeled to tackle and prevent this phenomenon. The aim of this study was to assess the status of desertification and generation of desertification maps in Yazd province using the IMDPA model. In order to use this model and perform desertification mapping in Yazd province, four criteria of climate, water, vegetation and soil were considered as key criteria. Using the above method, the scores of each index in the relevant criterion was determined. Each criterion is calculated as the geometric mean of its sub-indices, and then introduced to the GIS environment. By overlaying and integrating the raster layers of the above-mentioned criteria and calculating the corresponding geometric mean and data analysis, desertification intensity map was obtained using model IMDPA. The results show that among the defining criteria of desertification, the climate criterion with the average score of 2.77 and the groundwater level drop with the score of 3.45 have been respectively the most significant criterion and indices. According to the results, the area could be classified as moderately sensitive to desertification.

Keywords: Yazd Province, desertification intensity, criterion, indices, IMDPA

Introduction

It must be said that land degradation is a kind of instability and imbalance in the relationship between man and environment, and much of the world and the country is faced with this problem. Deserts are broadly recognized as degraded ecosystems, with reduced or lost biomass production (UNEP 1977). Desertification means land degradation in arid, semi-arid and sub-humid environments that stems from several factors, including climate change and human activities (Ahmadi, 2004). The first step in the implementation of desertification prevention relies on the recognition of the influential factors, and their interaction in a given area. Based on studies carried out by FAO and UNEP in 2001, more than one hundred countries and more than 33 % of the land is area affected by land degradation and desertification. So that approximately 93% of the arid rangelands along with 47% of the irrigated lands are exposed to degradation (FAO.UNEP, 2001). Desertification after the two challenges of climate change and scarcity of fresh water stands as the third global challenge in the 21st century. In order to check desertification, its criteria and indicators have to be identified prior to the modeling the regional desertification sensitivity. To assess desertification investigation, a multitude of studies has been conducted both inside and outside the country, which has resulted in the development of so many regional models. The most common global models are Lada, Glasvd, Taxonomy and MEDALUS. For this purpose, a projected was led by the Faculty of Natural Resources, Tehran University to identify the criteria and indicators influencing the process of desertification using the IMDPA model (Ahmadi, 2004). As one of the newly developed models in Iran, the IMDPA model has been proposed by the Faculty of Natural Resources of Tehran University in collaboration with the Forest Rangelands and Watershed Management Organization of Iran. One of the most significant advantages of this model compared to the previous desertification sensitivity assessment models, is improved accuracy in preparing desertification maps.

One of the recent assessments of the desertification status changes in the MinQin state in China has been conducted by San et al (2009). Desertification has been a widespread phenomenon in the state due to the dominance wind erosion. This has led to the escalation of salinization hazard in the area. The result of the assessment of landscape changes suggest that desertification process has been concomitant with defragmentation, complexity of landforms, and severe fluctuation in degradation rate in the proximity of villages (where perpetual fluctuations between cultivation and follow). Another case of the assessment of desertification status was found in the study of Hurcom et al (2003) in Rendma area in the southwest of Brazilian Amazon forests, by incorporating the data from MSS, TM, NOAA, and AVHRR satellites. This study has been conducted by the application of NDVI index during 1973-1999, where a degradation of more than 30% of the forest stands was reported. In an attempt to identify desertification mechanisms and processes in northern china in the course of 30 years, it was concluded that climatic factors have affected all processes in a meaningful manner. The results of the assessment of land degradation in a long-term period in Italy, demonstrated an evident increase in desertification intensity in a course of 50 years (Salvati, 2010).

In a study which led to the desertification monitoring of hydrological and climatic factors along the south-eastern coasts of Iran, showed that clmate has been the dominan factor in the area. In addition, among the indicators studied, the two indices of Transu dryness index and annual precipitation rate by the values of respectively 3.81 and 3.4 have been selected as the most influential factors compared with the sodium absorption ratio (SAR) as 1.17 as the least important factor (Rahdari et al, 2014). Desertification assessment in Derakht Senjed area in Iran using the IMDPA model and by incoprporating four criteria of climate, vegetation, soil, geology and geo-morphology showed low class represents 0.37% of the area; moderate class represents 80% of the area; and severe class represents 19.63% of the area. The vegetation criterion by 3.05 and geology by 1.8 were identified as the most and least important factors affecting desertification (Abrisham et al, 2014). Results of monitoring desertification in Garmsar plain with emphasis on two criteria of water and agriculture revealed that agriculture in 2002 with a weighted average of 2.17 and 2.27 in 2011, is the prevailing criteria of desertification in the study area. Results indicated that, the irrigation system in both periods had the greatest weight and impact on desertification. (Azareh et al., 2015). Assessment of Desertification in Shahrebabak's plain by incoprporating the IMDPA model showed that in the study area, the low class represents 61351 ha (14.92%), moderate class represents 138575 ha (33.7%); severe class represents 117685 ha (28.62); and very severe represents 93589 ha (22.76%). In addition, a weighted average of the entire region was estimated 2.06 that represents a middle desertification class in the region (Jahanshahifard et al., 2015). Results of the assessment of desertification in Yazd Ardakan during 1996-2014 with an emphasis on four criteria of water, climate, vegetation and agriculture showed that wate criterion by the score of 2.75 was the dominant factor in the studied area. Among the indicators studied, groundwater level drop was selected as the most influential factors by receiving the highest weight (Rafiei et al, 2016). Given the outcomes of the studies in desertification assessment context, this research attempts to identy the status of desertification in Yazd province using the IMDPA model for the present state, and by embracing four factors of water, climate, vegetation and soil.

Martial mad Methods

Study area

Yazd province is located in the central plateau of Iran, between 29 52 to 33 27 N and 52 55 to 56 37 E. By enclosing 73551 km^2 of the area of the state, Yazd ranks fourth in terms of area in Iran. Yazd is bordered to the north and west by Semnan and Isfahan provinces; to the east by Southern Khorasan and Kerman provinces; to the south by Fars province; and to the southeast by Kerman province. Yazd has various topographic features. This area covers a altitude range of 666m a.s.l. (Rig Zarin playa near Aghda) to 4075 m (Mount Shikouh). Precipitation fluctuates between 50 to 100 mm. Temperature cover a vast range of change during the day and night in the summer and winter, reaching to as high as 45 C and as low as 20 C. Daily average temperature fluctuates beween 11.9 to 20.7 C. a large proportion of this province is devoted to playas, sand dunes and desert environments.

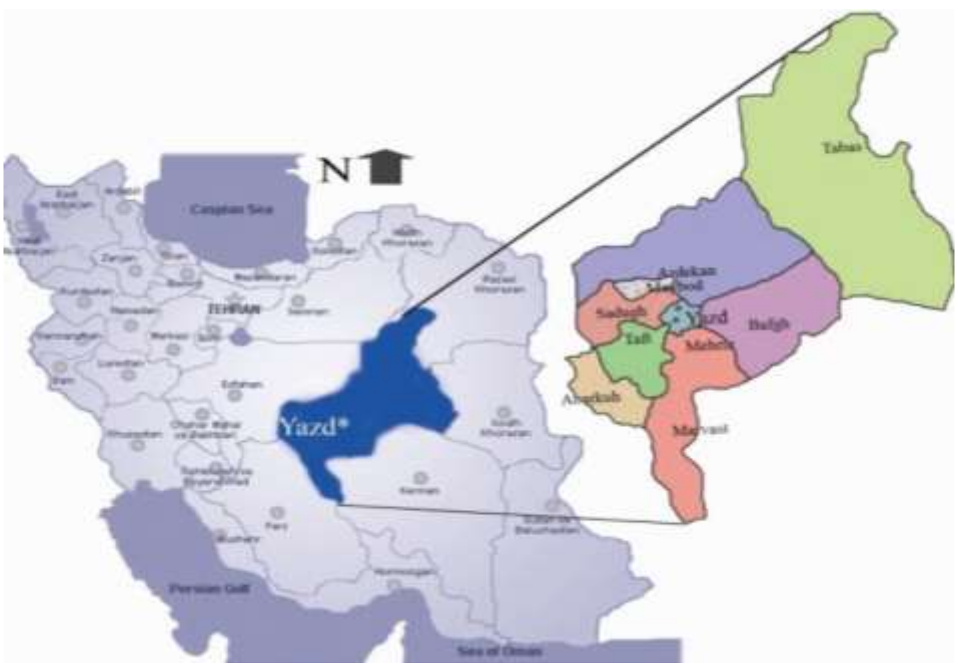

Fig. 1 the location of study area

Methodology

This study has used the IMDPA model for the sake of desertification sensitivity assessment. Among the nine criteria include the in model, based on the experts' opinions, a set of four criteria namely water, climate, vegetation and soil were considered for desertification assessment. Each criterion is also comprised of a number of indicators, as illustrated in figure 2.

In the next stage, a weight, between 1 and 4, is assigned to each indicator. Weighting was conducted linearly, with 1 as the best and 4 as the worst score. Data visualization was also carried out in ArcGis 9.3. Scoring was performed in the working units (working units map is prepared from the topography, land-use and land-use layers) (Ahmadi, 1998). Scoring scheme is provided in tables 2 to 5. Each indicator was subsequently converted to a visualization layer. Indicators along their weights were integrated into their corresponding indicator, and the criteria were converted into a single score using the weited average formula as given in eq. 1:

(Inde x = [(Layer1). (layer2)… (Layer n)] l/n eq. 1

Where Index stands for the criterion of interest; layer stands for the indicators in the corresponding criterion; and n stands for the number of indicators. Therefore, four data layers were generated from the criteria, to further be integrated via the weighted average into a single measure of desertification status.

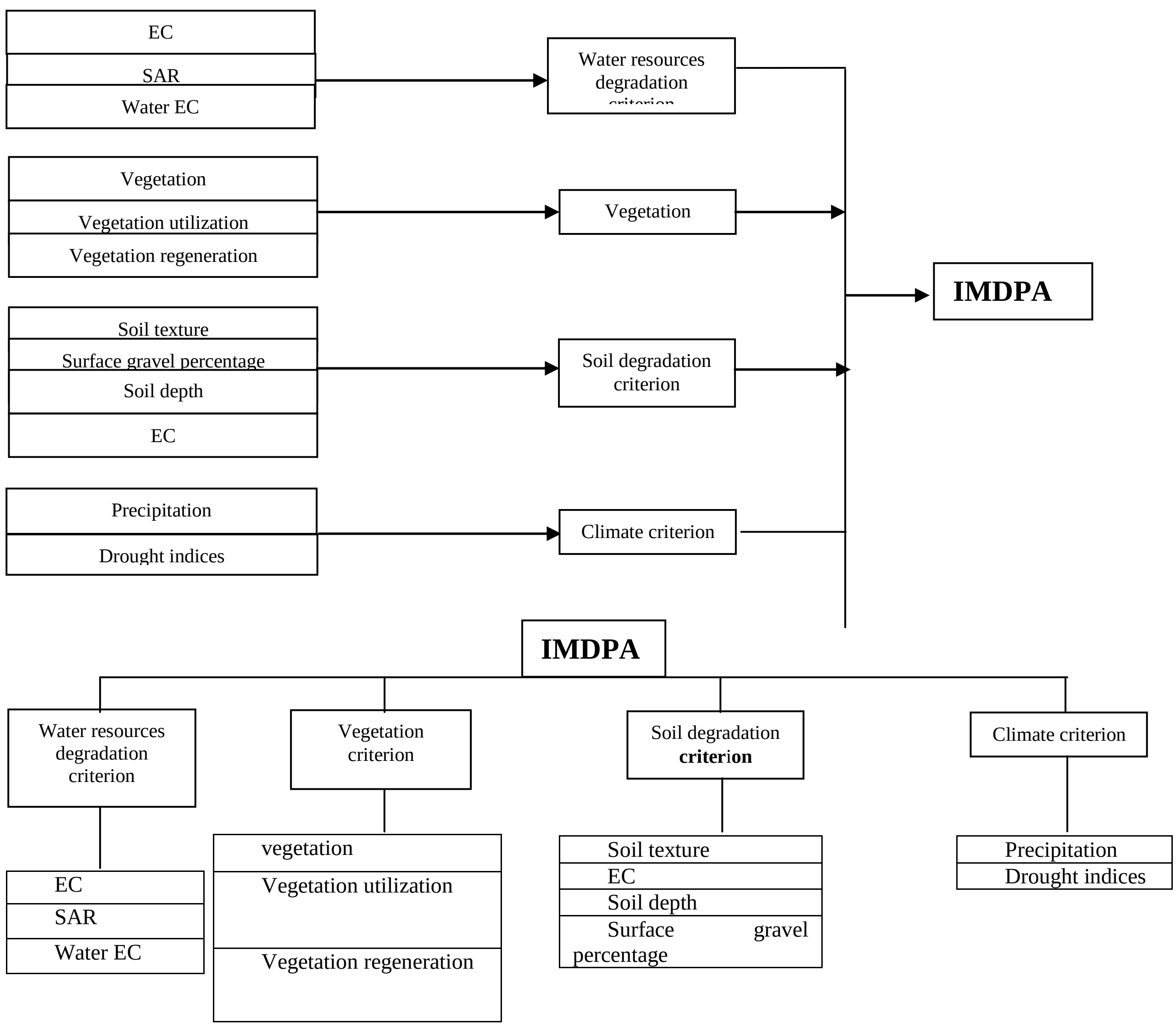

Fig. 2 schematic view of the criteria and indicators of desertification assessment in the study area

Table 1. Classification of desertification sensitivity score

Class	Range	Quality index
Low	0-1.5	1
Moderate	1.6-2.5	2
High	2.6-3.5	3
Very high	3.5-4	4

Climate criterion

Climate criterion involves two indicators, as follows:

Annual precipitation

Annual precipitation was calculated from the climatic records, available for 11 stations within the boundary of the study area. The time series were used for the reconstruction of climatic records during 1962-2015. Precipitation was classified as given in table 3. Annual precipitation was rated regardless of its distribution during the year, and the results indicated a severe sensitivity to desertification for the studied area.

Drought indicator

Drought monitoring was carried out by means of two indicators namely drought persistence index and UTI index.

UTI index

This index has been developed by Tehran University, which takes into account the daily precipitation records and its corresponding evapotranspiration, to indicate the biological dryness status. Based on this indicator, a dry day will be defined if the daily precipitation is less than a third of the corresponding potential evapotranspiration. For the sake of conformity with the currently used drought assessment techniques, WD will be defined as the number of days regarded as biologically dry.

$$WD = 365 - BG \quad \text{eq. 2}$$

Where BG represents the xerothermic coefficient or Bagnol-Gaussen coefficient; and, WD represents the number of wet days. The recent index depends on several factors, which are more compatible with nature. It should be noted that the index developed by Tehran University represents the duration of plant growth regardless of the type of plant and duration of frost.

Drought persistence

Drought persistence phenomenon is independent of the amount of annual precipitation. Classification of the drought persistence index and the assigned weights are provided in (Table 3). Upon the preparation of data layers, the geometric weights for the score of each of the data layers were calculated from eq. 3 for each station and the entire region.

Climate criterion= (annual precipitation x dryness x drought persistense) $^{1/3}$

Table 3 determination of the scores in the climate criterion based on the IMDPA model

indicator	class	negligible	low	moderate	severe	Very severe
	score	0.01-1	1.01-1.50	1.51-2.50	2.51-3.5	3.51-4
Annual precipitation (mm)		600≤	280-600	150-280	75-150	75<
UTI index		150-180	120-150	90-120	0-90	
Drought persistence		Less than 3 years	3-4	5-6	6-7	7<

Water criterion

In order to investigate water criterion, three indices of EC, groundwater level drop, SAR were developed from their data layers (table 4).

Table 4 determination of the scores in the water criterion based on the IMDPA model

indicator	class	low	moderate	severe	Very severe
	score	1-1.50	151-2.50	2.51-3.5	3.51-4
Ground water level drop		<20	20-30	30-50	50<
EC (µmhos/cm)		<750	750-2250	2250-5000	5000<
SAR (µmhos/cm)		<15	15-26	26-32	32<

Soil criterion

The data used in the analysis are collected from the soil analysis map of the area, in terms of four indices of soil depth, texture, percentage of gravel, and salinity (table 5). These indicators were selected for the sake of simplicity. A number of soil profiles were excavated in the unknown working units in order to fill the gaps in the soil database. It was attempted to decide upon the location of the profiles to both fill the gaps and help interpret the available data on other profiles in the area.

Table 5 determination of the scores in the soil criterion based on the IMDPA model

indicator	class	low	moderate	severe	Very severe
	score	1-1.50	151-2.50	2.51-3.5	3.51-4
Soil depth (cm)		80<	50-80	20-50	<20
Soil texture		Clay-sandy clay-silty clay	Silty loam-loam-silty clay loam-sandy clay load	Sandy loam-loamy sand	Sandy – clay content >60%
Gravel (%)		<15	15-35	35-65	65<
EC(ds/m)		<4	4-8	8-16	16<

Vegetation criterion

Based on the IMDPA model, vegetation criterion includes vegetation cover, utilization and regeneration. Table 6 denotes the indicators along with the weight assigning procedure. In the present study, in order to visualize and accentuate the differences among vegetation types, the normalized vegetation index (NDVI) was used. As an important index, the NDVI index is used for detecting the changes in the ground phenomenon, especially vegetation. This index is calculate from the following formula (Darvish Sefat, 2009):

$$NDVI = \frac{(NIR - R)}{(NIR + R)} \qquad \text{Eq. 4}$$

Where NIR is the near infrared band, and R is the red band. This indicator varies in the range of -1 to +1, where 1 represents the good and dense vegetation condition, while -1 represents degraded or cleared vegetation.

Table 6 determination of the scores in the vegetation criterion based on the IMDPA model

indi cator	c lass	low	moderate	severe	Very severe
	s core	1-1.50	151-2.50	2.51-3.5	3.51-4
condition		Invasive species are Less than 5% of plant composition. Less than 25 percent of plant composition are annual species.	Invasive species form 5-20% of plant composition. 25-50 percent of plant composition are annual species.	Invasive species form 20-50% of plant composition. Annual species dominate most of the plant composition.	Invasive species form more than 50% of plant composition. Annual species dominate the plant composition.
		Areal cover more than 30%	Permanent areal cover 15-30%	Permanent areal cover 5-15%	Permanent areal cover less than 5%
utilization		No signs of plant uprooting	Signs of uprooting bushes, shrubs, and trees more than annual biomass production	Evident signs of uprooting bushes, shrubs, and trees	excessive uprooting of bushes, shrubs, and trees
		Moderate grazing intensity in the proper season	25% excessive stoking rate	25-50% excessive stoking rate	50% < excessive stoking rate
regeneration		Natural regeneration	Vegetation regeneration possible at low costs	Vegetation regeneration possible at high costs	Troubled or ceased vegetation regeneration. Corrective measures not cost-effective
		No need for corrective measures	Effective measures have been taken	measures taken have been fairly effective	measures taken have not been effective

Results

Results of the analysis show that based on the weighted geometric average values for the climate criterion, the UTI index with the score of 3.44 represent the most significant factors in terms of desertification intensification in the area. Table 7 shows the Geometric mean numerical value and the classes of desertification. Figure 3 also provides and illustration of desertification intensity in terms of climate criterion, which denotes that moderate class prevail the area.

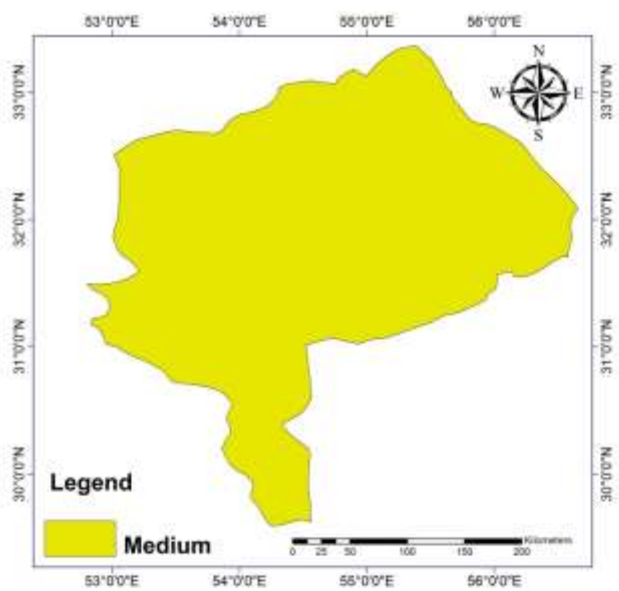

Fig. 3 sensitivity to desertification based on the climate criterion

Table 7. Geometric mean numerical value and the classes of desertification in terms of climate

indicators	Numerical value	Desertification class
Annual precipitation	2.94	III
UTI dryness index	3.44	III
Drought persistence	2	II

Water criterion

A total of 154 piezometric wells were examined in order to investigate the changes in groundwater level along with water quality indices of EC and SAR. A weight was assigned to each index based on table 7, and area was zoned in terms of water criterion accordingly (figure 4). The results of the weighted geometric average values suggest that groundwater level drop by the score of 3.45 is the defining factor of desertification in terms of water criterion. The results provided in table 8 are the geometric average values along with the classes of desertification in terms of water criterion.

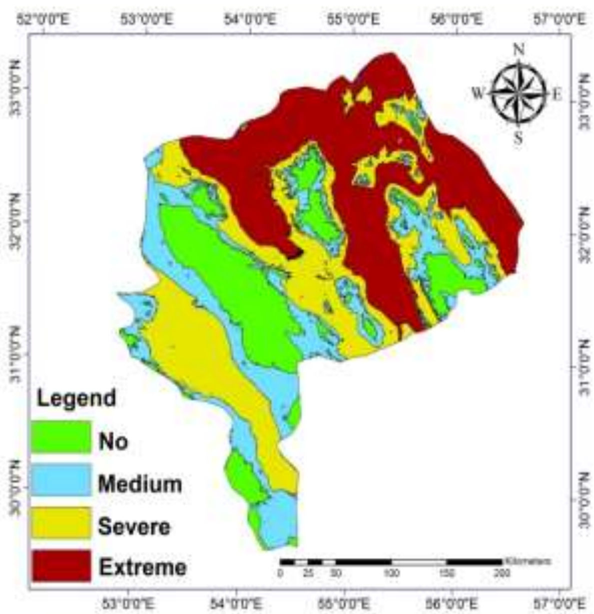

Fig. 4 sensitivity to desertification in terms of water criterion in the study area

Based on the results provided in table 4, the low class of sensitivity to desertification represents 17.42% of the area; the moderate class represents 21.23%; and, the severe class represents 32.31%.

Table 8 geometric average values for the indicators of desertification under the water criterion

indicator	Numerical value	Desertification class
Groundwater level drop	3.45	III
SAR	2.53	III
EC	2.76	III

Soil criterion

Results of the analysis of the soil criterion indicated that EC with the score of 2.55 has been the most important factor for the intensification of desertification. Table 9 provided a description of the numerical values along the classes of desertification intensity in terms of soil criterion.

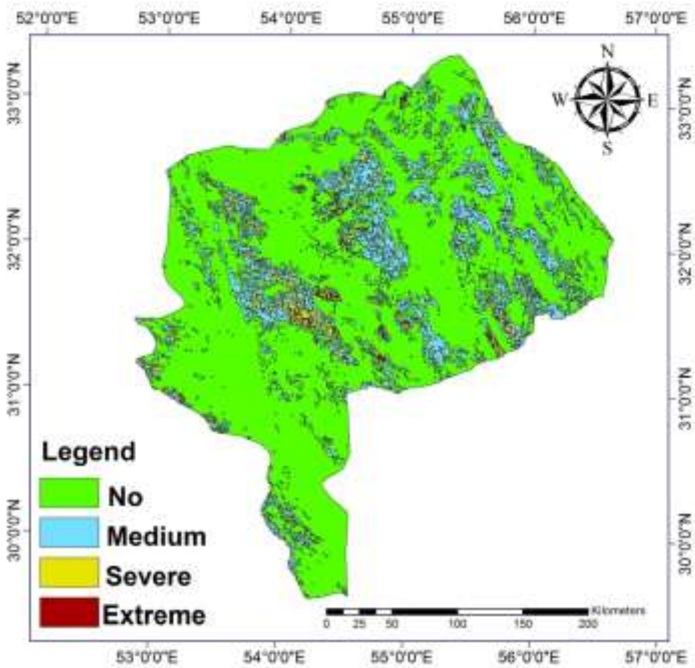

Fig. 5 sensitivity to desertification in terms of soil criterion

Based on the results illustrated in figure 5, it could be said that: the low class of sensitivity to desertification represents 76.7 % of the area; the moderate class represents 19.18%; the severe class represents 4.02%; and, the very severe class represents 0.1% of the total area.

Table 9 geometric average values for the indicators of desertification under the soil criterion

indicator	Numerical value	Desertification class
Soil depth	1.15	I
Soil texture	1.26	I
Gravel (%)	1.45	I
EC	2.55	III

Vegetation criterion

The results of the elaboration of vegetation indicators indicated that utilization could be regarded as the most significant determiner of desertification in the area with the score of 2.91. Table 10 gives the numerical values obtained via the geometric average and the classes of desertification. These results area illustrated in figure 6, where the low class depicts 30.3% of the area; the moderate class 41.4%; and, severe class 28.3%.

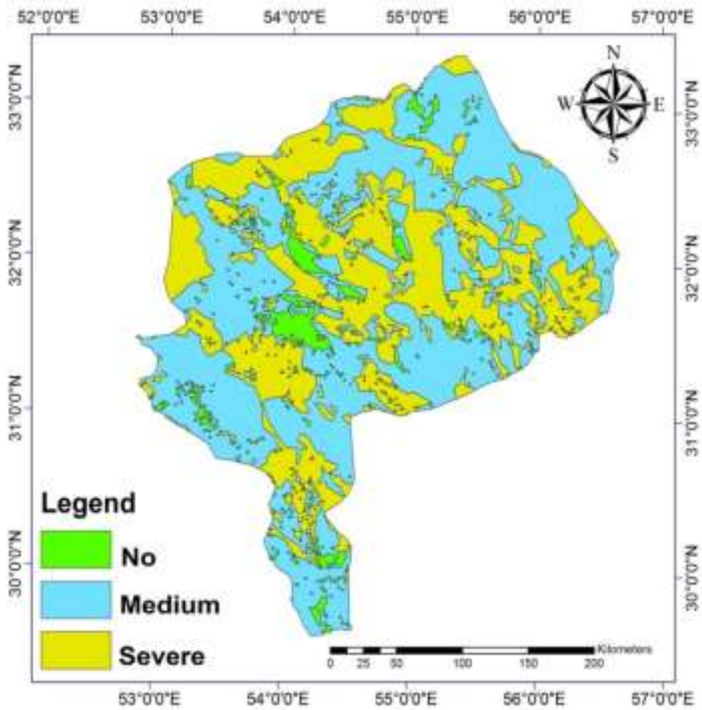

Fig. 6 desertification classification based on the vegetation criterion

Table 10 geometric average values for the indicators of desertification under the vegetation criterion

indicator	Numerical value	Desertification class
Soil depth	2.56	III
Soil texture	2.91	III
Gravel (%)	2.6	III

The maps of the four criteria of climate, water, soil and vegetation were superimposed to obtain the overall status of desertification (fig. 7). The results suggest that climate criterion has the prevailing role in the intensification of desertification (by 2.77); with the soil criterion receiving the least importance (by 1.47). Table 11 and figure 7 provide details on the numerical values and geographic distribution of desertification classes in the area.

Table 11 the geometric average values and desertification classes in the studied area

criteria	Numerical value	Desertification status
water	2.75	severe
soil	1.47	moderate
vegetation	2.39	moderate
climate	2.77	severe

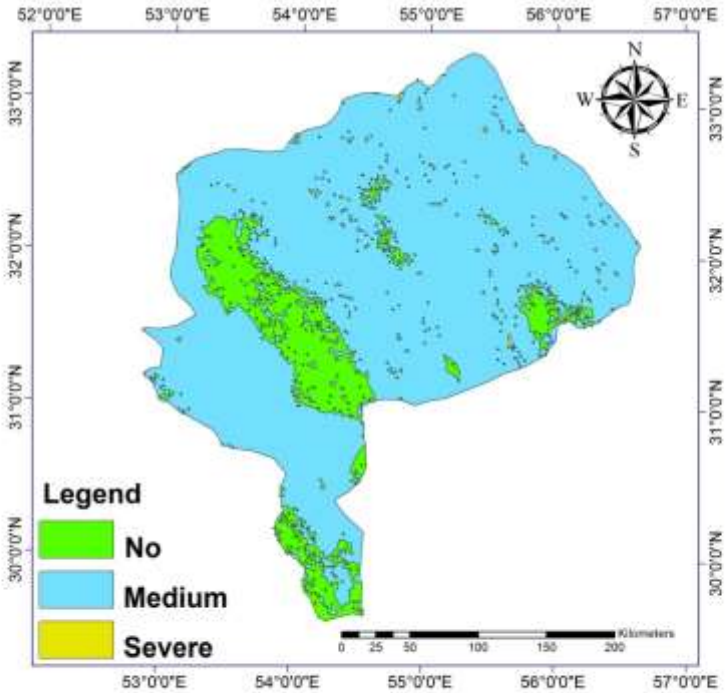

Fig. 7 status of desertification in the studied area

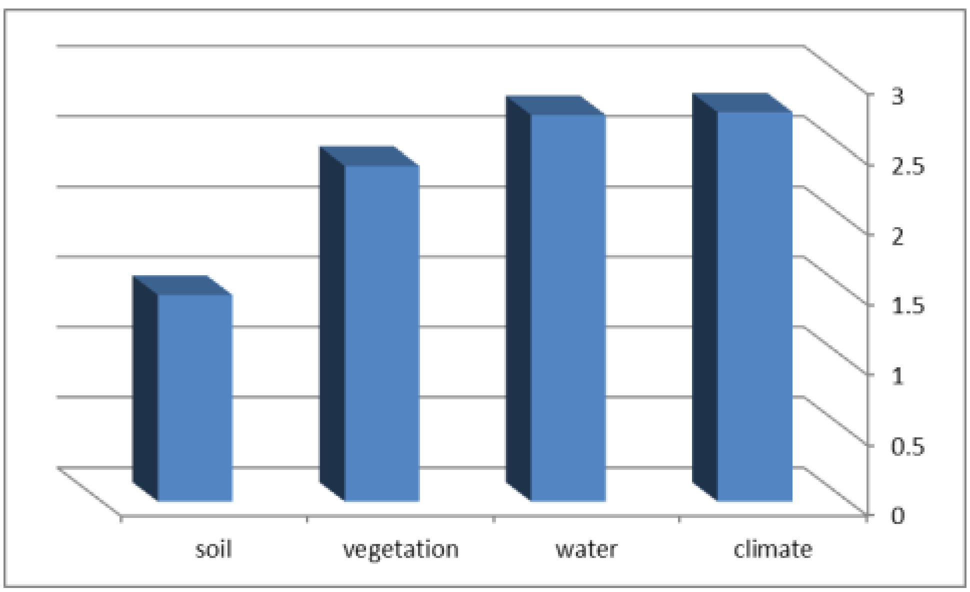

Fig. 8 the numerical values and geographic distribution of desertification classes in the area

Conclusion

The results of the analysis of four criteria of desertification assessment, indicated that climate criterion with the score of 2.77 falls into the moderate class is the most significant determiner of desertificaiotn, which owes its importance to the role of the UTI index reciegin the score of 3.44. These findings agree with the results of Yang (2008), and Rahdari et al. (2014). The authors believe that the coastal deserts in the southeastern part of Iran are defined in terms of their climate. Yazd province is located in the central plateau of Iran and suffered moisture deficiency due to the distance to the source of moisture. On the other hand, the Zagros Mountains to the west and the Alburz Moutins to the north acts as the barrier and do not allow moist frontiers to enter the area. At the local scale, though, the Shirkouh Mountains further impede the entrance of the sources of moisture to the area. Other factors such as high frequency of sunny days, the azimuthal angle of radiation, and the reflectance ration (albedo) give this province a dry and hot climate. The prevalence of subtropical high pressure or even dry low pressure systems play an important part in creating a dry environment in the province. The map of the status of desertification shows that the severe class represents 0.64% of the area; the moderate class 85.66%; and the low class 13.7%. On the basis of the four criteria involved in this research, desertification obtained the value of 2.32 which gives indication of a moderate status, in correspondence to the findings of Abrisham (2014); Azareh (2015) and Jahanshahi (2015).

Among these criteria, the climate criterion received the highest importance with the score of 2.77. Among the indicators, however, the groundwater level drop by 3.45 and soil depth by 1.15 were the most important cases. In this regard, Ekhtesasi and Mohajer (1995) in an area enclosing 10 million hectares located in the central to southern parts of the country suggested that overgrazing the excessive utilization of water resources are the most critical factors defining desertification. Jafari (2006) also identified that over exploitation of groundwater resources and the application of inappropriate methods of irrigation (traditional techniques) have resulted in severe desertification in Kashan plain. In another study, Rafiei Emam (2003) suggested the roles of the application of inappropriate irrigation techniques, application of brine waters, and over exploitation of groundwater resources as the factors affecting desertification in Varamin area. In anutshcel, two kind of factors namely natural and anthropogenic factors affect desertification, where in case of Yazd province, soil and climate could be regarded as the natural factors while vegetation and water act as the anthropogenic factors. Over the past several decades, groundwater level drop has been the dominant factor in the area due to the expansion of agricultural activities, deterioration of water resources, burgeoning population, industrial development, conversion of low-productive lands into rain fed agriculture, land abandonment, overexploitation of groundwater reservoirs via traditional and modern techniques.

The results simply indicate that there are cases that working units are converting into a higher state of desertification, which could complicate the current condition in the upcoming years. Although classified as moderate, desertification is expected to enter a more serious state, if no corrective measures are taken now. It is highly recommended that no further development of wells should be allowed in the area in order to sustain the current level of exploitation, impose a more state of control and surveillance on the beneficiaries of groundwater resources. This is possible via the installation of water meters and imposing harsh penalties for the offenders of the water extraction allocations' certificates. A key policy priority should therefore be to highly monitor or even prohibit the wells, which are located in the prohibited plains.

Acknowledgment

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