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Original article

Efficiency comparison of ESAs and IMDPA models in evaluation and mapping of desertification status (a case study in Boushehr Province, SW Iran)

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A R T I C L E I N F O

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A B S T R A C T

Desertification is the consequence of processes in which climate change and human activities are the most effective factors in arid and semi-arid regions, especially in a major part of Iran. The present study aims to quantitatively assess the desertification situation based on ESAs (Environment Sensitive Areas to Desertification) and IMDPA (Iranian Model of Desertification Potential Assessment) models in southwest of Iran. IMPDA model considers five indicators such as climate, soil, vegetation, erosion, water resources as main coefficients to evaluate the desertification situation. ESAs model takes the physical environment and land management characteristics such as soil, vegetation, climate, and land management for classification of desertification intensity. These layers were extracted and manipulated from the available topographic map data, geologic map, satellite image, and field survey data analyses. Spatial analyst function in ArcGIS software was used for matching the thematic layers and assessing the desertification index, of which the map of environmentally sensitive areas of study area is produced. Based on the results obtained from the IMDPA model, %49.11 of the study area is classified as severe desertification class, and %49.89 in moderate class, and quantitative value of desertification intensity for whole the study area was obtained as [1]DSI =1.55 that is indicative of average desertification intensity in the region. Based on the results obtained from ESAs method, %3.87 of the study area is classified as the fragile class (F2), %38.78 in the average critical (C2) and also nearly %56.42 in the severe critical class (C3). The comparison results

[1]desertification sensitivity index

show that the IMDPA model have better performances in evaluation current desertification status from ESAs model in Iran. By noticing the evaluated factors, it is understandable that the climate factor has the intensive effect on desertification throughout the study region that they are out of control by human being.

1. Introduction

Desertification is global phenomenon's that can occur anywhere and lead to substantial damages and losses. In a global contest, Desertification is defined by the UNCCD as “Land degradation in arid, semi-arid and dry sub humid areas resulting from various factors, including climatic variations and human activities” (Thomas 1997; Kassas 1995). This degradation is caused by uncontrolled forest destruction, water pollution, wind and water erosion, salinization, and inadequate soil management under both cultivated and uncultivated regimes. One of the major problems affecting the soil is the severity with which the degradation processes reduce soil biological potential. An unsustainable, rapid reduction, which cannot be mitigated using appropriate mechanisms, leads, consequently, to desertification (Thornes, 1988). In fact, desertification is the reduction of ecologic and biologic processes on the earth surface, which might happen naturally, or by man-made activities. This process influences arid and semi-arid and humid border areas (Jain, 1995). Land degradation (soil salinity, sodicity, acidity and erosion) is a reduction of current or future capacity of soil to produce (Dregne, 1987). It can be occurred because of erosion, decline in fertility, changes in aeration and moisture content, salinization, or a change in soil flora or fauna (Barrow, 1997). 40% of the earth’s land, or 5.2 billion hectares, is threatened by desertification (UNEP, 2002) and Iran is such a country that is located in the arid and semi-arid belt of the world and its third is exposed to desertification (Iranian Forest, Rangeland and Watershed Management Organization. 2005). According to the new definition of desert, except a narrow strip in north of Iran, other parts of the country encounter desertification problem (Shakerian et al, 2011). Therefore, accurate assessment of the status and trend of desertification is essential in implementation of global preventive measures and activities to prevent desertification. By considering the increasing development of deserts on Iran, it is necessary to identify desertification prone areas before implementing desertification mitigation and control measures. Destructive impacts of desertification can be investigated and measured by qualitative and quantitative models. The model-based studies are inevitable in understanding desertification status and in effectively combating desertification. For assessment of desertification processes various model have proposed. Such as FAO/UNEP (Grumblat, 1991; Harasheh & Tateishi, 1998), ESAs (Basso, et al. 1999; Ladisa, 2002), MEDALUS (European Commission, 1999; Nicholas, 2001, IMDPA (Ahmadi, 2004; Jafari et al, 2011) and etc. The main objectives of this study were; (1) to prepare the map of current desertification status of Bordekhun region by IMDPA and ESAs models, (2) Recognition the destruction factors of land and its effects on desertification, and (3) to compare performances of IMDPA and ESAs models in evaluation and mapping of current desertification status of the study area.

2. Materials and methods

2.1. Study area

The study area pertains to 51°42′ to 51°30′ and 28°21′ to 28°55′ longitude and latitude, respectively. It covers 526.24 km2, is located near the Persian Gulf with maximum elevation is 1525 meters above sea level. In the southwest parts of Boushehr Province, the low precipitation, arid climate, water resources restrictions, decrease of groundwater level, extension of water and soil salinity, and vegetation degradation influence the stability and productivity of the desert ecosystem.

In this study, two models of IMDPA and ESAs were selected to assess land degradation and desertification status according to local conditions of the study region. After separating work units (Geomorphologic facies), numerical value of each index for each work unit was determined, and an information layer was produced for each index, then the layer associated with each criterion was specified by calculating the geometric mean of its indices' scores. In the next step, desertification severity map of the study region was created by combination and determination of geometric mean of criteria. In general, various steps of the present study and evaluation of effective indices to create desertification severity map and also analyze the produced data are presented in Figure 1.

2.2. IMDPA method

IMDPA model, as a comprehensive desertification model, was presented by the faculty of natural resources, university of Tehran, under a project entitled determination methodology of desertification criteria and indices in arid and semi-arid regions of Iran. In this project, some international models of desertification such as FAO-UNEP (FAO/UNEP, 2001), GLASOD, LADA, AOOSD, MEDALUS (European Commission, 1999) as well as national models including ICD (Ekhtesasi, Mohajer, 1994) and MICD (Ahmadi, et al. 2006) were reviewed in this research and 9 criteria were chosen based on previous experiences for desertification intensity mapping (Ahmadi, 2004). A score ranging from 1 to 4 is assigned to each index based on weight of each factor. Finally the value of each criterion was obtained as geometric average of scores of single indices according to the formula:

Index−X = [(Layer−1). (layer−2)... (Layer−n)]1/n[1]

Where: Index-X denotes given criteria, Layer-n: Index of the criterion, n: number of indices for each criterion. Finally, the desertification intensity is estimated by using geometric average of 9 criteria as follows:

Desertification Intensity = (Water × Soil × Water erosion × Wind erosion × Climate ×Vegetation Cover × Agriculture × Technological development× Management) 1/9[2]

At the end, desertification risk map (final map) is produced on the basis of four classes represented in Table 1.

In the IMDPA method, with regard to low precipitation, arid climate, water resources restrictions, decrease of groundwater level, extension of water and soil salinity, and vegetation degradation of the study area, four criteria of climate, water, soil and vegetation were recognized as essential in the study of desertification intensity. Each criterion includes the following indices: soil (depth, Electrical Conductivity (EC), texture and gravel percentage),water(ground water table decrease, Electrical Conductivity (EC), Cl concentration, Sodium Absorption Ratio (SAR)),climate (annual precipitation, Aridity Index, drought) and vegetation cover(cover rehabilitation, cover efficiency, cover conditions). According to the factorial scaling technique, scores ranging from 1 (good conditions) to 4 (deteriorated conditions) is assigned to each index. Value "Zero" is assigned to the areas where are not appropriate for measurement.

After assigning a score to each index, the indices are grouped. The value of quality index for each elementary unit within an index is estimated as geometric average of scores for single indices. Table 2 illustrates the general characteristics, classes and scores of the IMDPA model indices.

2.3. ESAs method

In the ESAs model, four information layers including soils, climatic, vegetation and management quality indexes were used to assess desertification sensitivity and for mapping the environmentally sensitive areas (ESAs) in the study area. Each index layer was prepared in GIS environment and a weight between 1 and 2 was assigned on the basis of index's role on desertification, so that value 1 is the best and value 2 the worst weight. A certain weight is assigned to each of these parameters based on the standard tables as proposed by FAO/UNEP [Kosmas, 1999]. In addition, value zero was assigned to areas like settlement areas. Computation of the four above-mentioned quality indexes was made as described below:

SQI= (Parent material× Texture× Depth× Rock fragment× Slope ×Drainage) 1/6 [3]

VQI= (Erosion protection ×Fire risk ×Plant cover ×Resistance to drought) ¼ [4]

CQI = (Total annual rainfall × Aridity × Aspect) 1/3 [5]

MQI = (Type of land use × Management activities) ½ [6]

Desertification Sensitivity Index (DSI) was calculated in the polygonal attribute tables linked with the geographic coverage using the spatial analyst tool in Arc GIS 9.3 software. Based on the estimated value of DSI the classes of desertification sensitivity in the area can be described as illustrated in table 3. After preparing index map for each above mentioned parameters, desertification sensitivity index of the area created according to the following equation [Kosmas, 1999].

DSI = (SQI ×VQI×CQI×MQI) 1/4 [7]

Where SQI is the soil quality index, VQI the vegetation quality index, CQI the climatic quality index and MQI the Management quality Index.

3. Results and discussion

In order to assess the proposed methods in this study, with respect to all information mentioned in methodology and evaluation method, these methods for up to 523.64 Km2 of Dashteplang region was used and obtained data were analyzed.

3.1. Analysis of IMDPA method

Result obtained of status of desertification assess by IMDPA method are mentioned in the following:

Final result of soil criteria assess: Soil criterion with a weighted average of 2.14 was evaluated in desertification medium class. After studying mean value of factors involved in soil resources deterioration; it's indicated that subsoil gravel index with a geometric average of 3.05 which shows high class is the most effective factor in increasing soil degradation intensity of studied region. Figure 2 represents the layer of soil criteria of the study area as The soil erosion layer criteria of the area is shown in Figure 5, which indicates that 1.42%was in the low, 82.42% was in the medium, and 16.14% was in the high desertification intensity class.

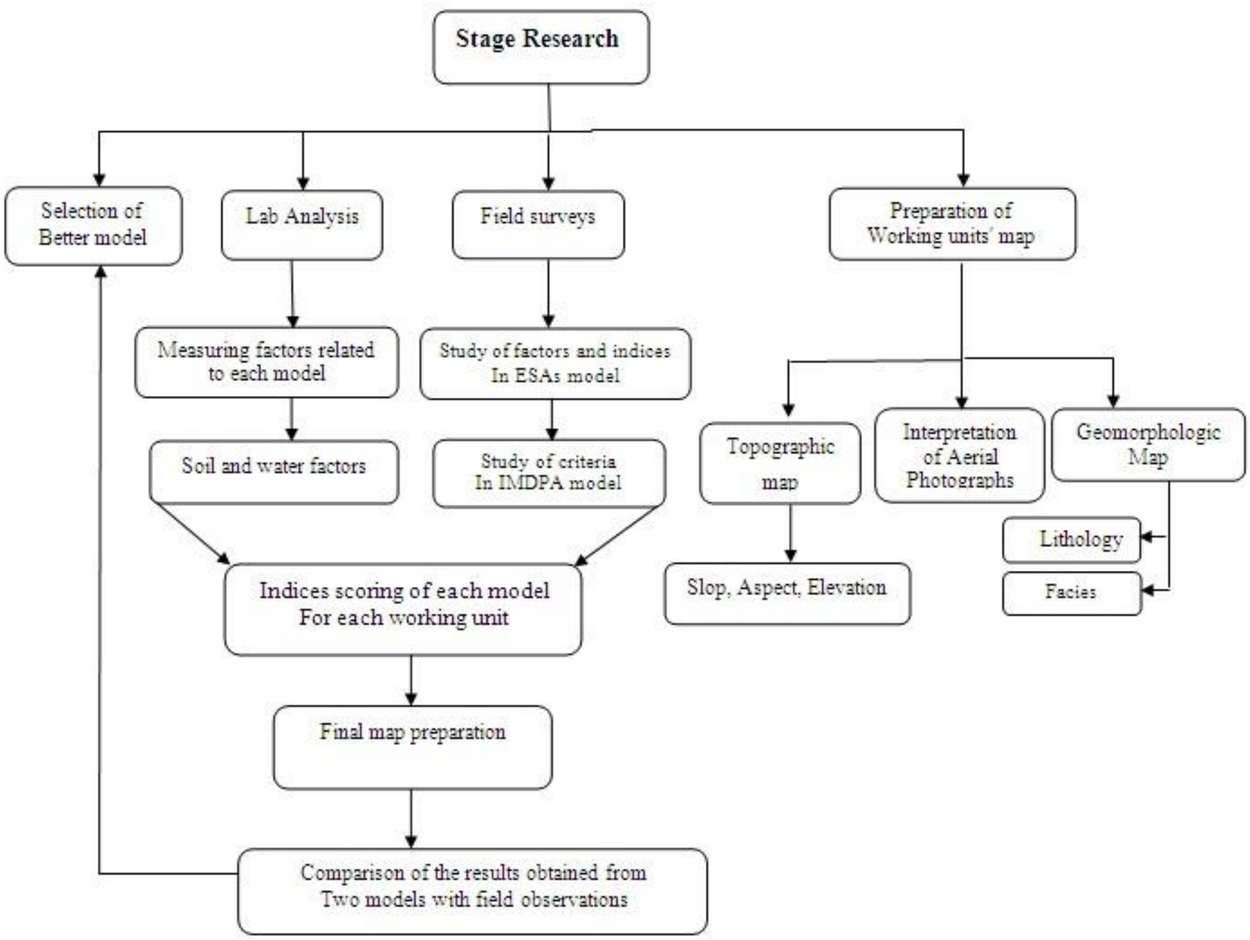

Fig. 1. Flowchart of the research stages for the study area.

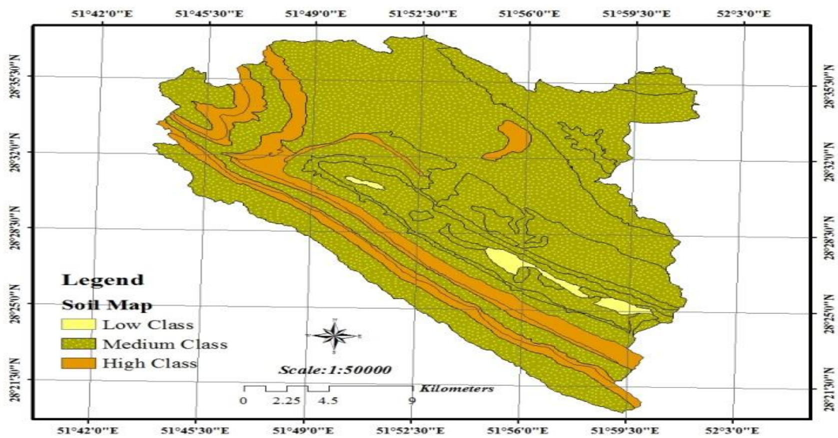

Fig. 2. Map of soil criteria by IMDPA model.

Soil criteria = (2.56 ×1.46×13.05× 1.95) 1/4 =2. 14 [8]

Table 1
Classification of desertification intensity (IMDPA).

Order	Numerical value	Class
1	0-1.5	Low
2	1.6-2.5	Medium
3	2.6-3.5	High
4	3.6-4	Very High

Table 2
Classes scores of the parameters used for the calculation of soil, water, climate, vegetation indices.

Index		Current conditions of desertification and scoring range			
		0-1.5 (low)	1.6-2.5 (medium)	2.6-3.5 (high)	3.6-4 (very high)
	Ec(dsm-1)	<5	5-8	9-16	>16
Soil	Soil depth (cm)	>80	50-80	20-50	<20
	Soil texture	SCL,SL,LS,CL	SiCL,SiL,SC	Si, C, SiC	S
	Subsoil gravel (%)	<15	15-35	35-75	>75
Water	Groundwater table decrease(cm/year)	0-10	10-20	20-30	30-50
	EC (µmhos/cm)	<250	250-750	750-2250	2250-5000
	CL (Mgr/liter)	<250	250-500	500-1500	1500-3000
	SAR	<10	10-26	26-32	>32
	Aridity Index(UTI)	180-150	150-120	120-90	0-90
Climate	Drought(year)	3-4	5-6	6-7	>7
	Annual Precipitation	>280	150-280	75-150	<75
	Cover Rehabilitation	No requirement for reclamation practices	Reclamation practices have been effective so far	Reclamation practices have been successfully conducted	Reclamation practices had not succeeded
Vegetation	Cover Efficiency	Equilibrium	Grazing slightly	Grazing more	Overgrazing

	grazing or less than capacity	more than production	Than capacity	
Cover condition (%)	85< Permanent canopy cover<100	15< Permanent canopy cover<30	5< Permanent canopy cover<15	Permanent canopy cover<5

Final result of water criteria assess: Water criterion with a weighted average of 1.39 is located in desertification low class. Electrical conductivity index with the weighted average of 1.68 is the most effective while two indices of the Chlorine and Sodium Adsorption Ratio, with weighted averages of 1.21 and 1.28, respectively, are the least effective in the desertification of the studied region. The layer of water criteria of the area is represented in figure 3. It is clear that the area is dominated by low class (approximately 64.59%).

Water criterion = (1.21× 1.68×1.51× 1.28) 1/4 =1.39 [9]

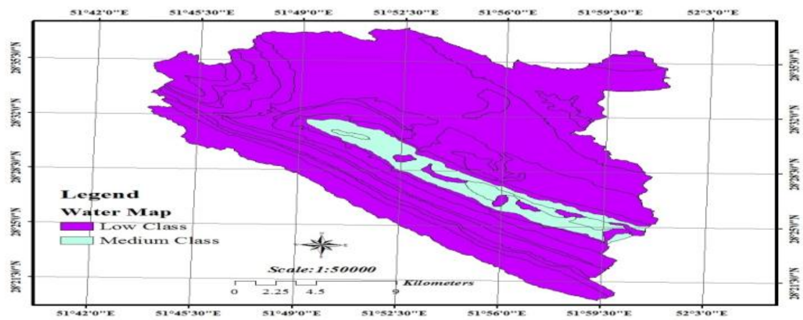

Fig. 3. Map of water criteria by IMDPA model.

Final result of vegetation cover criteria assess: Vegetation cover criterion with a weighted average of 2.39 is classified in desertification medium class. Analyzing the numerical value of three effective indices on vegetation cover degradation presents that cover efficiency index is the most effective factor in increasing desertification intensity. Figure 4 shows that most of the territory is characterized by medium class (approximately 100%).

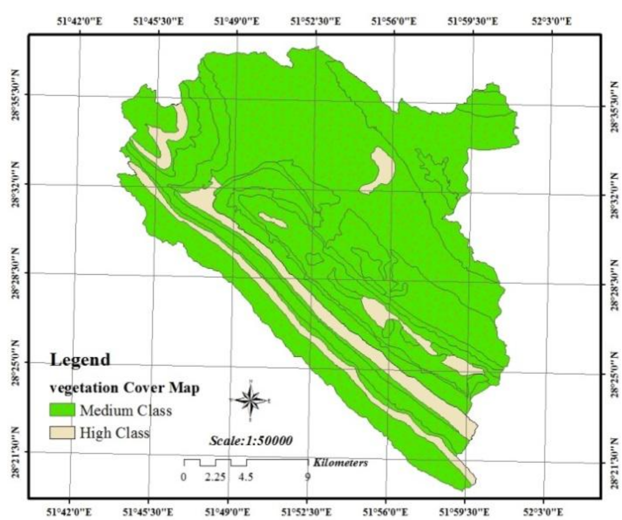

Fig. 4. Map of vegetation cover criteria by IMDPA model.

Vegetation cover criteria = (2.8 ×2.65×1.9) 1/3 =2.39 [10]

Final result of climate criteria assess: Climate criterion with a weighted average of 1.29 is classified in desertification low class. Annual precipitation index is located in medium class while two indices of the aridity and drought are classified in low classes. The layer of climate criteria of the area is represented in figure 5.

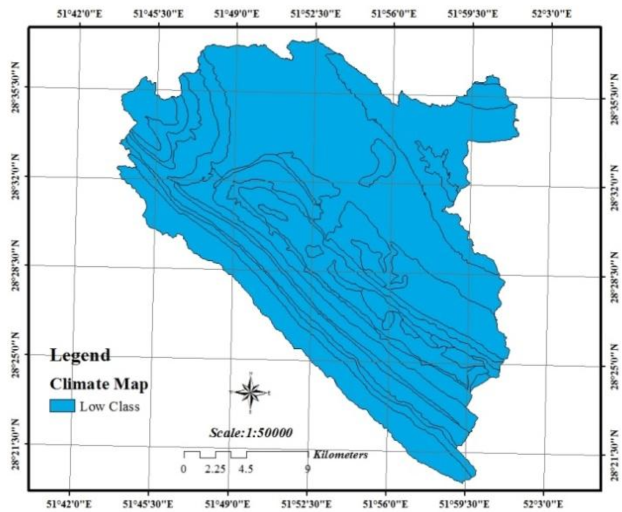

Fig. 5. Map of climate criteria by IMDPA model.

Climate criteria= (2.32× 1×1) 1/3 =1.29 [11]

Table 4 illustrates the general characteristics, classes and scores of the soil, water, vegetation covers and climate indices by IMDPA method.

Table 4
Geometric average of the quantitative values of soil, water, vegetation cover, climate criterion.

desertification intensity Class	current desertification status	Value	Index	
III	High	2.56	Soil texture	
I	low	1.46	Ec	Soil
III	High	3.05	Subsoil gravel (%)	
II	Medium	1.95	Soil depth	
I	low	1.21	CL (Mgr/liter)	
II	Medium	1.68	EC (µmhos/cm)	
II	Medium	1.51	Groundwater table decrease (cm/year)	Water
I	low	1.28	SAR	
III	High	2.8	Cover Efficiency	Vegetation covers
III	High	2.65	Cover Rehabilitation	
II	Medium	1.9	Cover Condition	
II	Medium	2.32	Annual Precipitation	
I	low	1	Aridity Index	Climate
I	low	1	Drought	

Analysis of criteria and indices based on IMDPA model

Analysis of studied criteria in Dashteplang region showed that vegetation cover criterion with a weighted average of 2.39 is dominant criterion and has important role in desertification process while soil, water resources and climate criterion stands in next orders of desertification class. Among the indicators investigated, three indices subsoil gravel percentage, cover rehabilitation and soil texture with the weighted average of 3.05, 2.65 and 2.56, respectively, is the most effective while three indices of the aridity, drought duration and Chlorine , with weighted averages of 1, 1 and 1.21, respectively, are the least effective in the desertification of the region. The results showed that in the IMDPA method, over %99 of the study area is classified in moderate desertification class, and quantitative value of desertification intensity for whole the study area was obtained as DSI=1.74 on the basis of these four criteria that is indicative of average desertification intensity in the region and study area is located in a position that has the potential occurrence of severe desertification. The map of desertification status caused by IMDPA Model is represented in figure 6.

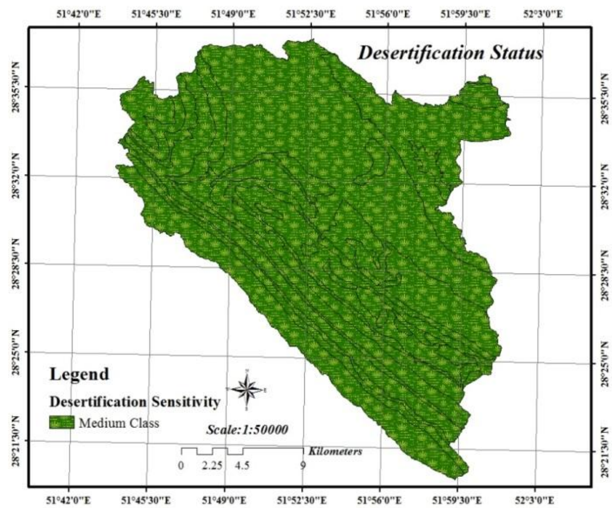

Fig. 6. Map of current desertification status caused by IMDPA Model.

3.2. Analysis of ESAs method

Result obtained of status of desertification assess by ESAs method are mentioned in the following:

Soil quality index: The results indicate that the areas of moderate soil quality index represent 74.72 % of the total area and the areas of low soil quality index represent 25.27 % of the total area. The moderate soil quality dominates the areas characterized by sandy texture, shallow depth and poor drainage. Figure 7 and table 5 represent the layer of soil quality index of the study area.

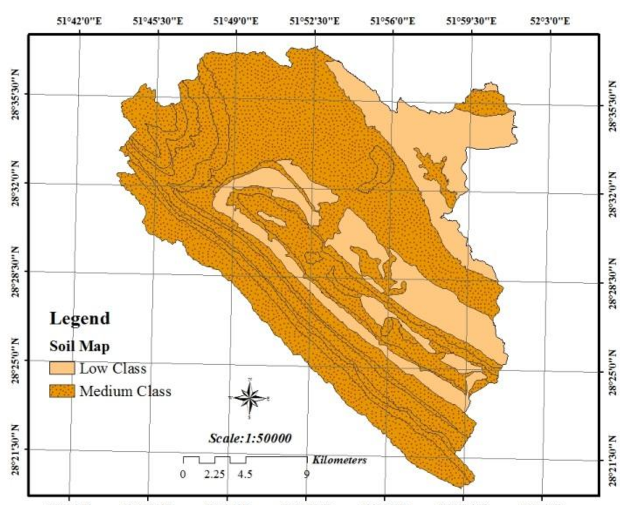

Fig. 7. Soil quality index (SQI) layer of the study area.

Table 5
Classes and scores of the soil parameters.

Site no	Texture		Depth (cm)		Slope (%)		Parent material		Rock fragments (%)		Drainage condition	
	C	Sc	C	Sc	C	Sc	C	Sc	C	Sc	C	Sc
1	Si	1.2	100-75	1.2	>35	2	Co	1.7	< 20	1.3	I	1
2	SiL	1.2	100-75	1.2	>35	2	Sa	2	20-60	1.3	I	1
3	Si	1.2	100-75	1.2	18-35	2	Sa	1	< 20	2	I	2
4	Si	1	100-75	1.2	6-18	2	Sa	1.7	20-60	1.3	I	1
5	Si	1.2	100-75	1.2	>35	1.2	M	2	20-60	2	I	1.2
6	S	1.6	>100	1	<6	1	M	2	> 60	2	W	2
7	S	1.2	100-75	1	6-18	1.5	M	2	> 60	2	W	1.2

Where: C= Class, Sc= score, Si = silty, SiL = silty and Loamy, S=sandy, Co = conglomerates, Sa= sandstone, M = Marl, W= well drained, I= imperfectly.

Vegetation quality index: The plant cover (percentage), erosion protection, and drought resistance parameters were used for assessing the VQI. Figure 8 and table 6 represent the layer of vegetation quality index of the area. The data indicate that the areas with high vegetation quality index dominates the western parts of the region, it represents 28.22 % of the total area. The low vegetation index is due to the low density of plant cover.

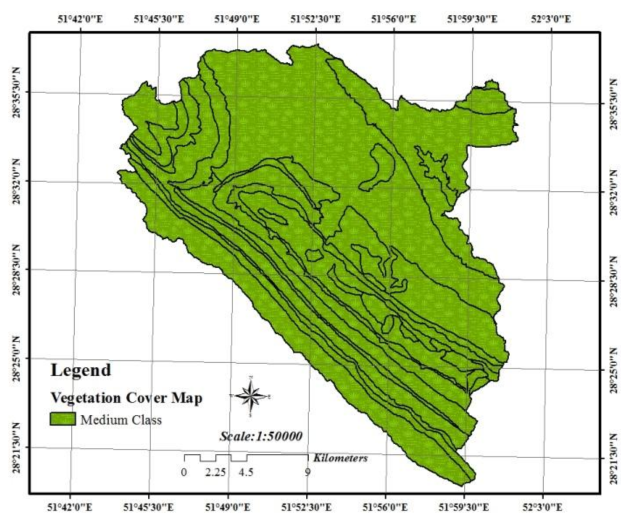

Fig. 8. Vegetation quality index (SQI) layer of the study area.

Table 6
Classes and scores of the vegetation parameters.

Site no	Plant cover		Drought resistance		Erosion protection		Fire risk	
	C	Sc	C	Sc	C	Sc	C	Sc
1	10-40	1.8	Aac and ag	2	Aac and ag	1	BL	2
2	10-40	1.8	Aac and ag	2	Aac and ag	1	BL	2
3	10-40	1.8	Aac and ag	2	Aac and ag	1	BL	2
4	10-40	1.8	Aac and ag	2	Aac and ag	1	Mm	2
5	10-40	1.8	Aac and ag	2	Aac and ag	1	Mm	2
6	10-40	1.8	Aac and ag	2	Aac and ag	1	BL	2
7	> 40	1.8	Aac and ag	2	Aac and ag	1	Mm	2

Where: C= Class, Sc= score, Aac and ag=Annual agricultural crops and annual grasslands, BL= Bare land, Mm=mixed Mediterranean.

Climate index: Climate quality index is assessed depend upon the amount of rainfall, aridity and slope aspect parameters. Table 6 represents the layer of climate quality index of the area. The amount of rainfall and aridity are the same in the region, but slope aspect and slope differ from place to another. The digital elevation model (DEM) of the study area was established and used for extracting the slope aspect. It is clear that the area is dominated by moderate climatic index. The layer of climatic quality index of the area is represented in figure 9 and table 7.

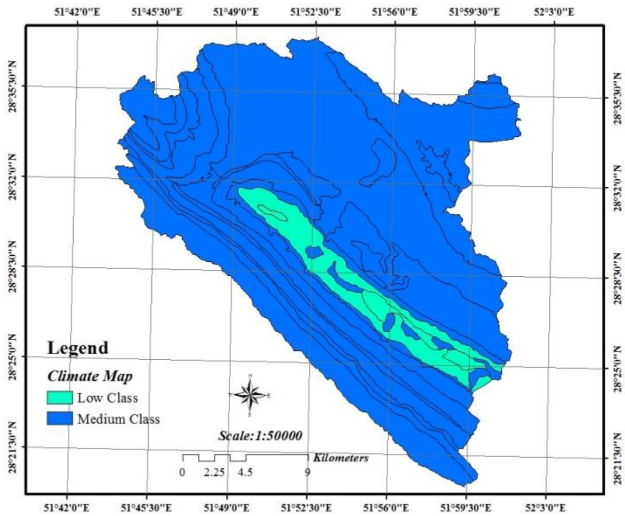

Fig. 9. Climate quality index (MQI) layer of study area.

Table 7
Classes and scores of the climate parameters

Site	rainfall		slope aspect		aridity	
no	C	Sc	C	Sc	C	Sc
1	280-650	2	SW& SE	1	75-100	2
2	280-650	2	NW & NE	1	75-100	2
3	280-650	2	SW& SE	1	75-100	2
4	280-650	2	NW & NE	1	75-100	2
5	280-650	2	NW & NE	1	75-100	2
6	280-650	2	SW& SE	2	75-100	2
7	280-650	2	SW& SE	2	75-100	2

Management index: The obtained data reveals that the areas of high quality management index are found in the center part of the region as it represents 4.5 % of the total area. The areas of moderate and low management quality represent 30.6% and 64.9 % of the total area, respectively. Figure 10 tables 8 represent the layer of management quality index of the area.

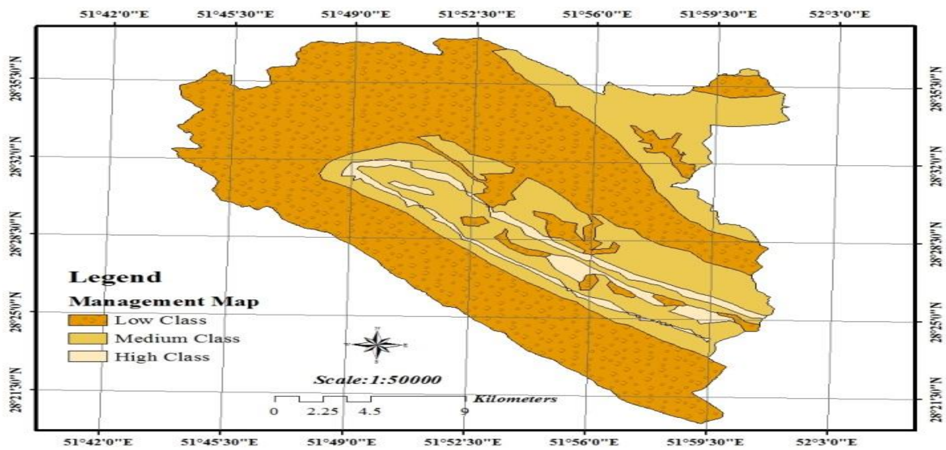

Fig. 10. Management quality index (MQI) layer of study area.

Table 8
Classes and scores of the management parameters.

Site no	land use type		Management policy	
	C	Sc	C	Sc
1	Ldr	1.6	>75	2
2	Dr	1.6	>75	2
3	Ldr	1.3	75 to 25	1.5
4	Dr	1.6	75 to 25	2
5	Ldr	1	75 to 25	1.5
6	Dr	1	75 to 25	1.5
7	AL	1.3	>75	1.5

Where: C= Class, Sc= score, Ldr = Less dense range, Dr = Dense range, BL= Bare land, AL = Agricultural lands.

Mapping environmentally sensitive areas (ESA's) to desertification

The results obtained by employing ESAs method reveals that the study area comprises of two sensitivity classes such as critical (C2) and critical (C3). It is seen that most of the area is under danger of critical. Table 9 shows the distribution of environmentally sensitive areas (ESA's) in Dashteplang region. It is clear that the critical (C2) sensitive areas for desertification in Dashteplang region are found in the center parts, where the soil quality, climatic quality and management quality are low; these areas represent 26.95 % of the study area. The areas of critical (C3) sensitive for desertification represent 73.04 % of the total area. Figure 11 represents map of current desertification status caused by ESAs Model.

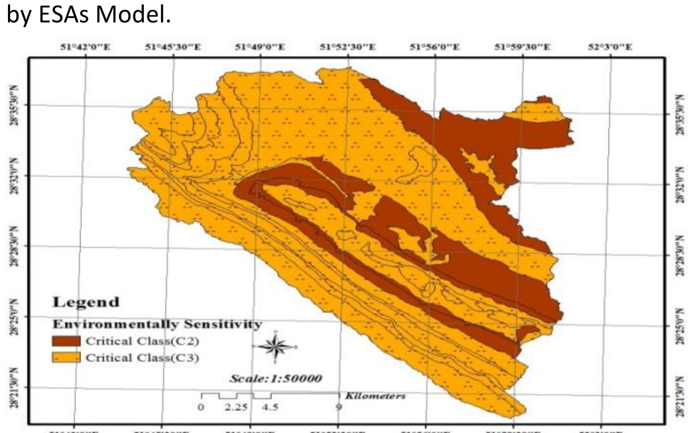

Fig. 11. Map of current desertification status caused by ESAs Model.

Table 9
Scores of the desertification sensitivity indices in study area.

Site no	Soil		Vegetation		Climate		Management		Desertification Sensitivity Index (DSI)	
	Score	Class	Score	Class	Score	Class	Score	Class	Score	Final Class
1	1.50	Low	1.64	High	1.68	Moderate	1.26	Moderate	1.51	Critical (C2)
2	1.63	Low	1.64	High	1.33	Moderate	1.14	High	1.42	Critical (C2)
3	1.56	Low	1.64	High	1.68	Moderate	1.55	Low	1.61	Critical (C3)
4	1.57	Low	1.47	High	1.33	Moderate	1.40	Moderate	1.44	Critical (C2)
5	1.61	Low	1.47	High	1.33	Moderate	1.55	Low	1.49	Critical (C2)
6	1.39	Moderate	1.64	High	1.68	Moderate	1.40	Moderate	1.52	Critical (C2)
7	1.60	Low	1.51	High	1.68	Moderate	1.00	High	1.42	Critical (C2)

4. Conclusions

Desertification is the consequence of important processes, which is active in arid and semi-arid ecosystems, where water is the original limiting factor in execution of land application [Kosmas, 1999]. In Iran, more than 85% of the country's 164.8 million ha are occupied by arid, semi-arid and hyper-arid regions with 34 million ha of desert. So, the major part of the country is susceptible to desertification. Although the government has performed many projects to combat desertification in recent years, it seems that they are not adequate due to the country's extensive arid regions (Sadeghi Ravesh, 2010). From the present study can be concluded that whole study area is affected by desertification phenomenon. This destructive phenomenon is caused by two natural and human factors. The human factors affecting desertification in the study region (cover efficiency) is in of control by human being. By noticing the evaluated factors, it is understandable that the human factor has the intensive effect on desertification throughout the study region. Very trivial percentage of vegetation, undesirable water quality, groundwater decline, and the sandy texture of soil and the trivial depth of soil that cause infiltration to become low, are the most important factors affecting desertification status in this region. By noticing reclamation practices conducted in the watershed area (mulching, Enclosure…), desertification severity in the study area has decreased in comparison with the past. In recent years, however, due to inaccurate management and over-utilization of natural resources in the region in particular, rapid decline of ground-water tables has caused a major area of agricultural lands to convert to barren lands or well drilling sites which in turn provides the background to desertification. Moreover, the climate changes in the recent years have tended to drought and anthropogenic factor shave also played a key role in intensifying desertification. Finally, it seems that the study region possesses potential of severe desertification occurrence. According to the results obtained from this research and the comparison of two methods employed with the region conditions, it is revealed that the IMDPA model and its studied indices is suitable for the study area and has acceptable performance that can be considered as a suitable technique for evaluating desertification status in the different regions of Iran. In contrast to other models in which desertification severity is determined on the basis of dominant criterion, in this method, intensities of all criteria under survey are considered and the current desertification status is characterized by noticing the entire criterion.

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