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Zoning Desertification Risks by Using ICD and MICD Models in Niatak Region of Sistan, Iran

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Abstract: Desertification phenomenon threatens a considerable portion of the world and is developing rapidly. This has occurred more acutely in Iran. Thus, in this research, the current conditions, type and intensity of factors influencing desertification of Niatak Region of Sistan were investigated by using Iranian Classification of Desertification (ICD) and Modified Iranian Classification of Desertification (MICD). In ICD model, scores were given to the six influential factors in desertification of each working unit. Based on the results obtained from ICD model, the study area was divided into three classes (medium, high and very high) according to their desertification intensities. The medium, high and very high classes were about 2857.42, 1503.17 and 459.1 hectares, respectively. However, based on the results obtained from MICD model, the medium, high and very high classes desertification covers an area of about 1974.84 hectares (41%), 2385.71 hectares (49.5%) and 459.1 hectares 9.5% of the entire region, respectively.

Key words: Desertification, wind erosion, scoring, ICD, MICD, Niatak of Sistan.

Wind erosion has great intensity in desert regions and causes destruction of lands with more power compared to other regions. In development of wind erosion and its resulting destruction, several factors including intensity and duration of wind blow, physiochemical characteristics of soil, the region's topography, status of vegetation, etc. are involved. All these factors are interrelated and cumulatively they cause increased or decreased intensity of wind erosion and desertification in a region (Ahmadi *et al*., 2007). The effects of desertification phenomenon can be observed in any region with initiation of a number of destructive processes in the ecosystem. For evaluation, they can be described by several methods both quantitatively and quantitatively. According to studies conducted by International Fund for Agricultural Development (IFAD), desertification threatens 40% of the entire earth and each year it directly affects 12 million hectares land. This phenomenon causes loss of 42 billion dollars for the global economy each year and around 2 million inhabitants of the world are exposed to this phenomenon, causing migration of 5 million people from their homeland (Hosseini, 2008). Focus on desertification for a country like Iran, where 43 million hectares (25%) of its area is covered by desert, is an undeniable necessity. Out of this area of desert lands, six million hectares have a critical status and so far, only two million hectares of these lands have been contained. A major part of these regions are located in Sistan and Baluchistan Province. In Sistan region, due to incidence of recent meteorological and hydrological droughts, land use change, destruction of rangelands, withdrawal and transportation of sands off the lake floor and eventually conversion of sand hills in agricultural, rangeland and forest lands leading to desertification has reflected an extreme trend (UNEP, 2002). Several models have been presented for estimating the extent of desertification intensity based on the given ecological conditions for each region of the world. European Commission performed a comprehensive study in this regard and introduced a project called MEDALUS, which has eventually presented an ESAs model for preparation of desertification map in 1999 (Kosmas *et al*., 1999). Ladisa *et al*. (2002) examined the type and intensity of desertification of Bari region in Italy by using MEDALUS method. In this study, six indices including soil, climate, vegetation, land use, quality management and human pressure factors were considered and the final map of regional desertification was plotted by using geometrical mean of the all

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indices (Ladisa *et al*., 2002). Further, Lavado *et al*. (2009) used ESAs model to analyze the lands in southwestern Spain and concluded that the desertification maps which were produced based on this model were more realistic and more compatible with natural conditions. Gad and Lotfi (2008) used remote sensing and geographical information system to map the sensitive environmental regions of Egypt and concluded that the quality of Nile Valley soil was low. Further, 86.1% of the soil in entire Egypt was also placed in the low-quality class. Brunner *et al*. (2008) conducted WEPP model to investigate water erosion in Southern Uganda and concluded that the soil characteristics are affected by the region's topography that has an important effect on soil erosion process. Zhu *et al*. (2009) used GIS and fuzzy network and developed soil erosion map with a scale of 1:250000 for a region in China. In the above research, the region was classified into six groups. Li *et al*. (2009) investigated the effects of land use and surface cover changes on destruction of resources in watersheds of Qing Hai Lake in China (1997-2004). They concluded that this area was extremely vulnerable and sensitive to climate change and human interventions. According to them the trend of land destruction is ascending and the major factors are due to the human activities including increased population, over-grazing and wrong management. In another research, Singh (2009) evaluated the salinity and its relationship with desertification processes in India. Based on this study the problem of salinity extends across 6.73 million hectares of land and 30-84% of groundwater of northwestern India is salty and not suitable for irrigation of farming lands. Several studies have also been conducted in Iran. Ekhtesasi and Mohajeri (1995) introduced a zoning method for type and intensity of desertification in Iran (ICD) and investigated an area of about 10 million hectares in central Iran. Later Goia (2001) studied the Hossein Abad Mishmast Plain in Qom to present a regional model. They concluded that desertification is developing actively in this region and alkalinity and salinity under the influence of natural factors were the dominant desertification processes. Chamanpira *et al*. (2006) examined the desertification processes in Koohdasht Region by using ICD model. The most important factors in this region were destruction of water resources beside overuse of the aquifers. Zehtabian *et al*. (2006) analyzed the soils in Mahan Region (Kerman province) by using FAO-UNEP and ICD models, wherein they reported water erosion as the major influential factor. According to them about 32.31% of the region was in the medium and 66.78% in high desertification intensity classes. Ghasemi (2006) investigated the status of desertification in Sistan region by applying MEDALUS method considering water and soil factors. Later Fozuni (2007) studied the current status of desertification of Sistan Plain by using modified MEDALUS model and considering water and wind erosion factors. Based on the two-main selected criteria, the final map of the region suggested severe and very severe classes of desertification trend. Ahmadi *et al*. (2007) estimated and compared potential sedimentation due to water and wind erosion in Nematabad Bijar watershed by applying IRIFR.E.A and MPSIAC models. They concluded that IRIFR.E.A model had a suitable quantitative and qualitative accuracy and wind and water erosion were found to be effective in decreasing fertility of lands by about 22.6 and 77.4%, respectively. The total value of the sedimentation of the studied area was 9.7 t h^{-1} $year^{-1}$, where 2.2 and 7.5 t h^{-1} occurred through wind and water erosions per year, respectively.

The aim of this research was to examine the current status of desertification, type and intensity of factors influencing desertification of Niatak Region of Sistan by applying Iranian Classification of Desertification (ICD) and Modified Iranian Classification of Desertification (MICD) models. In a research performed by the authors in 2012 on the same region, MEDALUS method had been used for analyzing the desertification status. Nevertheless, ICD and MICD models were used for further comparison.

Materials and Methods

The study area is located in the eastern part of Zabol City. Its distance from the city is around 13 km. This region has an area of 4819.6 hectares and average altitude of 470 m above the sea level and is located in 61° 33′ 36′′ and 61° 41′ 56′′ of eastern longitude, 30° 59′ 5′′ and 31° 7′ 23′′ of northern latitude of the Sistan Plain (Fig. 1). In terms of climate, Sistan Plain is dry during most of the months. The mean annual precipitation is about 62.84 mm and the mean temperature is 21.82°C. Given the high temperature of Sistan, level of evaporation off

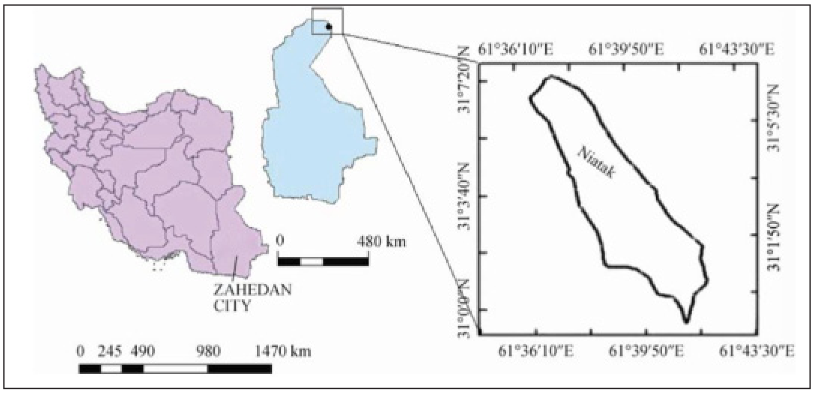

Fig. 1. The location of the Niatak region.

water surface reaches around 4700 mm per year, which is about 10 times more than the level of precipitation that caused extreme dryness in this region. Due to presence of fine-grained alluvial and river sediments the region is susceptible to erosion, where 120-day winds and dryness displace these particles easily and results in the development of sand hills with different shapes. The origin of the region's sediments goes back to Pleistocene deposits and new deposits, i.e. lake deposits of current dried Hamoun bed and delta deposits of Sistan Rivers (Fig. 2).

Table 1. Separation and signing of natural landscapes in the studied region

Row	Desert land escape			Signing
1	Lands with vegetation cover from forest and pasture	1- Lands with natural cover (P)	Nebkha-Clay Plain-Sand dune	P/R
			The coastal river has a seasonal forest cover	P/F
		2- Lands with planted vegetation (Ap)	Mulch lands	Ap/f
2	Lands without vegetation (B)		Sand dune	B/s
			River bed	B/r
			Barchan	B/b
			Clay plain	B/c
3	Agricultural lands (A)		Irrigated agricultural lands	A/I

In the current research, attempts were made to evaluate ICD and MICD methods. For this purpose, first the types of desert environments were determined and segregated. At this stage, basic studies were included in order to divide the study area into different classes based on their vegetational and natural features. These regions included forest, rangeland, cultivated and non-cultivated areas (Fig. 3; Table 1). As this region is lithologically uniform, the type of geomorphological profiles was considered as a basis of determining different working

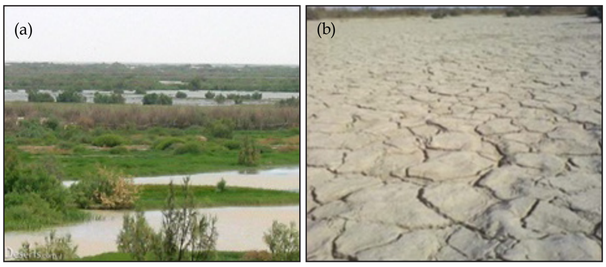

Fig. 2. Views of Hamoun Lake
(a. before the drought; b. after the drought).

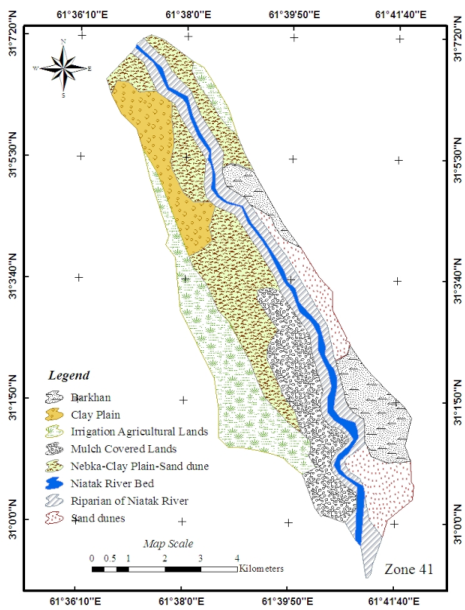

Fig. 3. The working unit map of the studied region
(Niatak of Sistan).

Table 2. The primary and secondary dominant factors influencing desertification in ICD model

Land degradation factors	Desertification class			
	Very high (7-10)	High (4-6.9)	Average (2-3.9)	Low (0-1.9)
Climate (C)	– Very dry climate with precipitation less than 70 mm (R) – The sequential droughts with severe impact on vegetation	– Dry climate with annual precipitation less than 250 millimeters and more than 70 millimeters – The period of drought is relatively high and its negative impact on vegetation is relatively high	– Semi-arid climate with annual precipitation more than 250 mm and less than 500 mm – The period of drought is limited and its effect on the reduction of vegetation is sensible	– Semi-humid climate with annual precipitation of over 500 millimeters – The drought period and its impact on reduction of plant production is subtle
Geomorphology (G)	– Mountainous and rocky areas with very steep slopes and extreme limitations for plant establishment with reduction of biomass (T) – Very sensitive lithological unit with severe restrictions on establishment of vegetation and biomass increase (g)	– Mountainous areas with a gradient of 40 to 100% and limit of rangeland topography – Lithology units are relatively sensitive and have a relatively high limit for establishment of vegetation	– Mountainous areas with a gradient between 20 and 40%, agricultural restrictions – The lithology unit is relatively sensitive and has a low limitation for the establishment of vegetation	– Flood plains with a slope of less than 20%, no restrictions on agricultural and forestry activities. – Unified and stable lithology unit for establishment of vegetation
Water and soil resources (Q)	– Lack of adequate soil moisture for plant establishment and lands covered with sand and active sand dunes (qt) – Highly saline water and heavy clay soil (ql)	– Young and undeveloped soils with limited moisture reserves, smooth hills and unstable sediments – Relatively salty surface with salty species, calcareous gypsum soils with medium moisture reserves	– Moderately developed soil with suitable moisture reserves – Moderately saline or calcareous soils with moderate moisture reserves	– Evolved soil with a very good moisture content – No limit for plant establishment – Soil resources are free of any qualitative restrictions for the establishment of the plant
Destruction of vegetation (P.D.)	– Irregular cutting down the shrubs and trees in presence or past (CU) – Irregular grazing and more than the capacity of the pastures at present (GR) – The agricultural pattern and even the regeneration of inappropriate vegetational cover and the relatively high production loss (PA)	– Poor habitat status – Invasive species 5 to 20% of plant composition) – Irregular and sensible cutting down the shrubs and trees – Overgrazing – A changing cropping pattern which is not in accordance with the conditions of the region	– Average habitat status – Invasive species 5 to 20% of plant composition – Cutting down the shrubs and trees is relatively more than annual production – Overgrazing is more than annual production – The cropping pattern is relatively consistent with the environmental conditions and potentials of the area and the production reduction is low	– Rangeland and forest areas with good and excellent condition – Deforestation effects are clear – Grazing is balanced or low – Cropping pattern and production management in accordance with the conditions and potentials of the region

Table 2. contd...

Land degradation factors	Desertification class			
	Very high (7-10)	High (4-6.9)	Average (2-3.9)	Low (0-1.9)
Destruction of soil and land resources (W.D.)	– Converted forests and rangelands for farming purposes and with very severe urban development – Uncontrolled soil plowing	– Converted forests and rangelands for other purposes along with the reduction of biomass and natural production – Inappropriate soil plowing	– Land conversion and urban development compatible with needs – Fairly good crop rotation and plowing	– There are no traces of forest land conversion to other uses
Water resources destruction (W.I.)	– Reduced underground water level due to pumping and excessive water consumption (more than 20 centimeters per year (PU)) – Underground water reduction is very effective in reducing agricultural production – Methods in surface water usage and wrong irrigation which is inappropriate for environmental conditions (I)	– Relatively high reduction in underground water level (between 10 and 20 cm per year) – Reduced underground water levels have been effective in reducing rangeland and agricultural production – Irrigation methods and surface water control require control and revision	– Reduced underground water levels (below 10 cm per year) – Reducing underground water levels have been relatively effective in reducing pasture and agricultural production – Irrigation method and surface water control is relatively suitable, but still controls and revision are needed	– There is no reduction in underground water level – Surface water and underground water resources are well managed – Irrigation methods and are perfectly suited
Wind erosion and soil degradation	– The wind erosion effects are intense and are accompanied by active sand dunes	– High winding effects with semi-active sand dunes	– Low to moderate wind damage, the soil surface is stable	– No wind erosion effects
Possibility of desertification	– Desert greening is difficult with no economical ecological-economic justification – Desert greening operation was not successful	– Desert greening is possible through mechanical and biological operations at a great cost. – Desert greening operations have been relatively successful	– Desert greening is possible through mechanical and biological operations at a low cost – Desert greening operation has been successful	– With proper management, Desert greening takes place on its own – No desert greening operation is required

units. Therefore, beside field observations, unsupervised classification was also considered by applying ERDAS 9.1 on IRS.

ICD model analysis

In the first step, different types of desert environments were separated and determined. In the second stage, basic studies, field observation and scoring method were conducted to evaluate the factors influencing desertification. In the third stage, the estimation of the desertification intensity was considered based on two effective factors including the intensity of erosion - sedimentation and reversibility. Finally, based on the total sum of the estimated scores, the intensity of desertification was determined and categorized into different classes. According to this method, the factors influencing desertification were investigated. These are explained below:

Determination and separation of the desert environments: For this purpose, topography, geology, vegetational and natural landscape maps were considered in order to determine and recognize the deserts. So, these areas were identified on aerial photos. Then, homogenous units were separated by using stereoscope.

Determining the major and secondary factor in desertification: The next step was of assigning scores based on the expert comments and some criterion including management, vegetation

Table 3. Classification of intensity of desertification by ICD method

Symbols	Score	Severity of desertification
I	0-14.9	Very low
II	15-29.9	Low
III	30-44.9	Medium
IV	45-59.9	High
V	60-80	Very high

and wind erosion. Some other factors including soil texture, vegetational cover percentage, etc. were also evaluated through sampling and experiments. For soil evaluation, several profiles were excavated from different parts of the region. Later, considering the homogeneity of the soil texture across different working units, only two profiles excavated in each unit were transferred to the laboratory for experimental operations. To study the vegetational cover, Quadrat method was used where in a finite rectangular plot area was chosen in order to sample for plants or other features of a rangeland. Rectangular plot was used, as it covers more details because its length and its percentage of deviation is less than that of square or circle (Risser, 1984). The size of a plot also has a direct relationship with the type and extent of vegetational cover in a region. The plot area was decided to be twice as large as the largest plant and tree species in the region by considering the dominant plant species which included *Haloxylon*, *Tamarix* and *Atriplex*. Eventually, based on the preliminary studies done in the region, 10 plots were considered in each working unit to evaluate vegetation.

Estimation of desertification intensity of land: Based on the results obtained from the basic studies and field observations performed on working units, scores were given to the six most influential factors (three natural and three human) according to the experimental table (Table 2). As the form and intensity of erosion and reversibility of the ecosystem depends on more accurate estimation of desertification intensity of land, in addition to the primary and secondary human and environmental factors, scores were also given to these two factors. Thus, the total score was estimated for each working unit according to the scores from environmental (E), human factors (A) and desertification indices (I). Finally, based on the classifications related to the desertification intensity (Table 3), the classes of the desertification intensity were determined for each working unit.

Preparation of desertification map: After evaluating each of the desert landscapes (working units), suitable scores were assigned to each factor as detailed in Table 4 and then all units with same intensities were placed within certain ranges. Later smaller areas were distinguished and identified according to the type of the desert and environment besides primary and secondary factors influencing desertification.

MICD model analysis

In MICD model, effective wind erosion factors in Niatak region were investigated and eventually the desertification intensity map was developed. To evaluate the

Table 4. Wind erosion assessment indices in pastures and ruined forest lands (1:50000 scale)

Indicator type	Indices and scope of the score			
	Low (0-0.9)	Medium (1-1.9)	High (2-2.9)	Very high (3-4)
Reduction in the density of vegetation cover in some years, due to the climate change, plowing and removing the plants	Very low	Low	High	Very high
Stones larger than 2 mm in soil profile	Very high	High	Medium	Low
Formation of clay loam or salty and saturated layer on the soil surface	Very high	High	Medium	Low
Erosion and sedimentation class	Low	Medium	High	Very high
Forest management	Protective zone	Visible destructive effects	Great destruction	Severe destruction
Continuation of wind blowing at speeds above the threshold speed (6 meters per second at a height of 10 meters)	Less than 10 days a year	10-20 days a year	20-60 days a year	More than 60 days a year

Table 5. Wind erosion assessment indices in agricultural lands with a scale of 1:50000

Indicator type	Indices and scope of the score			
	Low (0-0.9)	Medium (1-1.9)	High (2-2.9)	Very high (3-4)
Changes in cultivating patterns from trees or multi-yearly species to annual and sensitive species	The tendency of farmers to convert gardens to agricultural lands is low	Part of the gardens are converting into agricultural lands, but generally cultivated species are multi-yearly	The process of converting gardens to agricultural land is fast and the tendency to grow one-year species is increasing	A large part of agricultural land is dedicated to the cultivation of one-year species
Construction or removal of wind break around the fields	Farmers increase wind break around their fields	For various reasons, including the lack of water in some fields, the windbreaks are removed	Windbreaks are severely removed	There are no windbreaks in the fields
Soil structure changes	By increasing the clay amount, the agglomeration of the soil intensifies	By increasing the amount of harmful substances in the soil or the shortage of organic matter, the process of agglomeration decreases	By increasing the amount of harmful substances in the soil, the process of agglomeration decreases	Large amounts of soil lost their features due to the mismanagement
Shifting cultivation	Shifting cultivation is limited	Shifting cultivation is rising due to the water resources reduction, migration, etc.	Shifting cultivation is relatively fast for various reasons	Shifting cultivation is very fast for various reasons
Erosion and soil deposition of agricultural land	Low	Medium	High	Very high
Continuation of wind blowing at speeds above the threshold speed (6 m per second at a height of 10 m)	Less than 10	10-20	20-60	More than 60

Table 6. Wind erosion assessment indices in ragelands (natural deserts such as bare mountains, rock masses, bare hill moors, sand hills, cobblestone surfaces, deserts and all bare lands lacking vegetation) at a scale of 1:50000

Indicator type	Indices and scope of the score			
	Low (0-0.9)	Medium (1-1.9)	High (2-2.9)	Very high (3-4)
Stones larger than 2 mm in soil profile	Very high	High	Medium	Low
Formation of clay loam or salty and saturated layer on the soil surface	Very high	High	Medium	Low
Erosion and sedimentation class	Low	Medium	High	Very high
Soil resistance change	Low	Medium	High	Very high
Increased unstable salts in the soil or increased salt upper than the saturated limit in surface soil	Increased unstable salts in the soil in very low in surface soil	Increased unstable salts is low to moderate	Increased unstable salts is moderate	Increased unstable salts is high

desertification phenomenon by MICD method, first homogenous desert units were zoned. These units were the same as those already used in ICD model (Table 1 and Fig. 3). In this model, scoring indices differed according to the different land uses. Also, the desertification evaluation indices were also different in cultivated or rangelands (Tables 5 and 6). Finally the total value of the scores for each unit was determined with respect to the intensity of desertification and map of the area was developed.

Based on the above tables, the characteristics associated with each of the land uses were scored and the classes of desertification intensity were determined as depicted in Table 7.

Table 7. Classes of desertification intensity in MICD method

Signs	Score	Severity of desertification
I	0-5.6	Very low
II	5.6-11.2	Low
III	11.2-16.8	Medium
IV	16.8-22.4	High
V	22.4- 28	Very high

Table 8. The value of primary environmental factors (E) associated with ICD model in Niatak Region

Working unit	Main environmental factor (E)		
	Weather and climate (C)	Geomorphology (G)	Quantity and quality of water resources and soil (Q)
Irrigated agricultural lands	8.5	2	2.9
Mulch covered lands	8.5	2.5	6.5
River bed	8.5	2.75	2.75
Barchan	8.5	5.5	8.25
Sand dunes	8.5	4.75	8
Riverside of Niatak river	8.5	2	3.4
Clay plain	8.5	3.5	5
Nebkha-clay plain-sand dune	8.5	4.25	6.25

Results and Discussion

Determining the primary and secondary factors influencing desertification based on ICD model

Considering the results obtained from the base studies and field observations, scoring of the six factors (three environmental and three human factors) was done based on the experimental tables in ICD method (Tables 1 and 2). The main environmental factor (E) included three sub-factors of weather (Table 8), climate (C), geomorphology (G), quantity and quality of water resources and soil (Q) and each of these included sub-factors or sub-indices. The sub-factor of weather and climate consisted of two other factors as precipitation (R) and drought periodicity (DR). Geomorphology consisted of slope (T) and quality of water resources and soil (GL). Human factors (A) considered in this research involved three secondary factors (Table 9) including destruction of plant resources (PD), water resources (WI) and soil resources and lands (WD). The secondary factors of plant resources destruction consisted of plant removal and tree cutting (CU), over-grazing (GR) and wrong agricultural and forestation patterns (PA). The factors of water resource destruction consisted of pumping, groundwater level drop (PU) and faulty irrigation (I). The secondary factor of soil resource destruction consisted of wrong ploughing, long shifting cultivation (PI), irregular conversion of forests and rangelands to agricultural or unused lands and urban development (CH). Based on the conditions and studies conducted in the region, certain scores were given to each of them as detailed in the results (Hosseini, 2008; Ekhtesasi *et al*., 1995). Further, in the regions which were free from vegetation or any land use, human factor had no effect on desertification and for this reason scoring of human factors was not essential. Therefore, for keeping the balance in the scores, the score associated with environmental factors was multiplied by two considering the climate of the region studied. Problems such as low precipitation (59.6 mm), high evaporation (4475 mm) and persistence of drought periods were also considered. Drought in this region is of climatic, hydrologic, agricultural and eventually socioeconomic type. These factors were scored

Table 9. The quantitative value of environmental factors associated with ICD model in Niatak region

Working unit	Human factors (A)		
	Degradation of soil resources and lands (WD)	Destruction of water resources (WI)	Destruction of plant resources (PD)
Irrigated agricultural lands	6.75	8.75	7
Mulch covered lands	8.35	0	6.25
River bed	3.5	2	5.5
Barchan	0	0	0
Sand dunes	0	0	0
Riverside of Niatak river	4	1	7
Clay plain	0	0	0
Nebkha-clay plain-sand dune	8.25	0	8.25

Table 10. The quantitative value of factors associated with desertification indices (I), ICD model in Niatak region

Working unit	Desertification Indicators (I)	
	Possibility of desertification (AA)	Erosion and soil degradation (SE)
Irrigated agricultural lands	3.0	3.0
Mulch covered lands	5.0	5.0
River bed	3.0	4.5
Barchan	8.5	9.5
Sand dunes	7.0	8.5
Riverside of Niatak river	4.0	4.0
Clay plain	3.5	3.0
Nebkha- clay plain- sand dune	6.5	7.5

through an expert opinion. Considering the geomorphology factor, the studied region had no special topographic features with slight changes in the slope (less than 0.06%). Furthermore, severe mineral limitation for plant establishment were the feature of this region. Due to the special lithological structure including the small size of the sediments, it is not possible to utilize groundwater reservoirs. Water resources were primarily limited to the surface and near surface reservoirs (5-8 m). Furthermore, the soil in Niatak was young and undeveloped, which also contained sand and sediments, thereby causing plants to face many problems for establishment. Human activities such as; uncontrolled tree and shrubs cutting down for fuel supply, overgrazing due to lack of sufficient forage and unbalanced proportion of live-stock and rangeland. In Sistan region, recent droughts and drying of Hamoun Lake, caused serious problems for the microclimate of the region. Further, 120-day winds in Sistan, transported the sediments and the wind erosion led to conversion of major part of agricultural lands to regions with no land-use. In addition to the human and environmental factors, two factors such as forms and intensity of erosion as well as reversibility of ecosystem, can also be effective in more accurate estimation of the intensity of desertification of lands. For this purpose and based on the mentioned model, these two factors were used in the scoring (Table 10). In terms of desertification indices like possibility of reversibility and revival of the region, parts of the region have been developed as artificial *Haloxylon* forest. However, this project was not successful in some other parts and that has been taken into account in the scoring (Table 11). In terms of soil erosion and degradation, a major part of the region is a transit site for wind sediments, causing numerous problems for the residents and biome of the region. In this section, for calculating intensity of erosion in the region through scoring factors such as water erosion, wind erosion and increased salinity, the wind erosion, subfactors were removed from the relevant table. At the end, with total scores estimated from the environmental factors (E) and human factors (A), as well as desert indices of desertification (I), the total score for each working unit was determined. Eventually, by using the classification (Table 7), the class of

Table 11. The frequency distribution of intensity classes for the current status of desertification in Niatak region

Working unit	Desertification severity class	Area per hectare	Percentage of area relative to the whole area
Irrigated agricultural lands	III	882.57	18.3
Mulch covered lands	III	619.10	12.8
River bed	III	205.86	4.3
Barchan	V	459.10	9.5
Sand dunes	IV	439.51	9.1
Riverside of Niatak river	III	730.36	15.2
Clay plain	III	419.54	8.7
Nebkha- clay plain- sand dune	IV	1063.62	22.1
Total	-	4819.60	-

Table 12. Analysis of the processes, factors and intensity of desertification by ICD method in Niatak region

Working unit	Quantitative value of environmental factors	Quantitative value of human factors	Quantitative value of desertification indicators	Quantitative value of desertification	Display the current state of desertification
Irrigated agricultural lands	13.40	22.5	6.0	41.4	(III-A/I)/A-W.D(PU)
Mulch covered lands	17.50	14.5	10.0	42.0	(III-AP/F)E-C(DR)
River bed	14.00	11.0	7.5	32.5	(III-P/R)/E-C(DR)
Barchan	22.25	0.0	18.0	62.5	(V-B/b)/E-C(DR)
Sand dunes	21.35	0.0	15.5	58.0	(IV-B/S.D)/E-C(DR)
Riverside of Niatak river	13.90	11.0	8.0	32.9	(III-P/F)/E-C(DR)
Clay plain	17.00	0.0	6.5	40.5	(III-B/C)/E-C(DR)
Nebkha- clay plain-sand dune	19.75	16.5	14.5	49.5	(IV-P/R)/E-C(DR)

desertification intensity for each working unit was determined (Table 12).

As a result, it was found that the main desertification factor was environmental factor (drought, DR) and except agricultural lands, 81.7% of the entire region was affected by this factor (Table 12).

Eventually, according to the scores acquired in each working unit, the map of the desertification intensity was prepared for individual working units and later by combining units with same intensities, the final map of desertification intensity was developed (Fig. 4).

The results obtained from MICD model: The results obtained from MICD model are presented in Tables 13 to 15 along with Fig. 5.

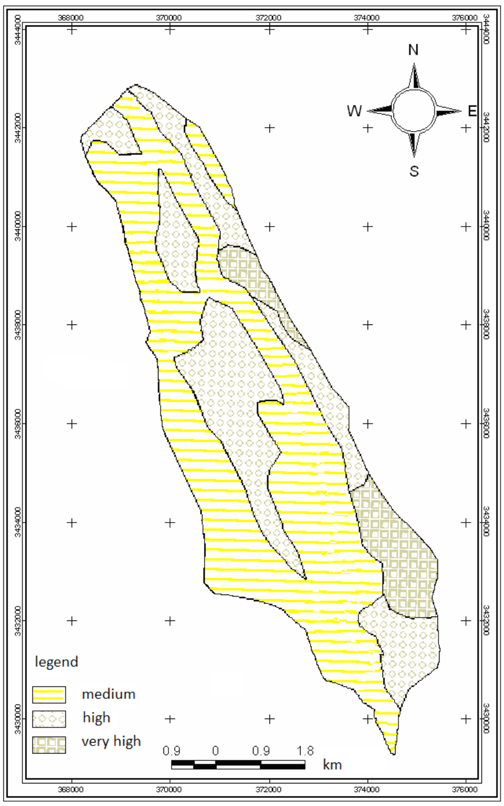

Fig. 4. The final map of the current status of desertification in Niatak Region by ICD method

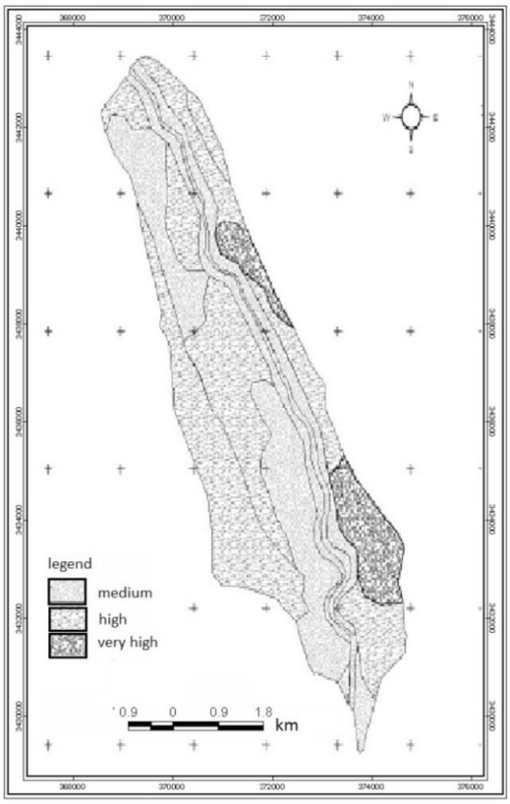

Fig. 5. The final map of the current status of desertification in Niatak Region by MICD method

Table 13. Evaluation of the desertification status in rangeland and ruined forest

Indicator type	Working unit			
	Riversides of Niatak river	Mulch covered lands	Nebkha-clay plain- sand dune	River bed
The possibility of reduction in the density of vegetational cover in some years due to climate change and plowing	3.00	3.00	3.50	3.00
Stones larger than 2 mm in soil profile	2.75	2.00	2.00	3.00
Formation of clay loam or saturated salt on the soil surface	1.75	1.00	2.75	1.75
The class of erosion and sedimentation	2.45	2.70	3.00	2.45
Forest management	2.00	3.50	3.25	3.00
Continuation of wind blowing at speeds faster than threshold speed	3.00	3.00	3.00	3.00
Sum of score	14.45	16.20	17.25	15.95
Potential status	Medium	Medium	High	Medium

Table 14. Evaluation of natural status of desertification resulting from wind erosion in lands with no use

Indicator type	Working unit		
	Barchan	Sand dunes	Clay plain
Stones larger than 2 mm in soil profile	3.50	3.50	1.0
Formation of clay loam or saturated salt on the soil surface	3.75	3.50	1.0
The class of erosion and sedimentation	3.65	3.20	2.1
Change in soil resistance to turbulence	4.10	3.75	1.5
Increase in the amount of unstable salts or increase in the amount of salts above the saturated level in the soil surface	3.75	3.50	1.2
Sum of score	18.80	17.45	6.8
Potential status	High	High	Low

Table 15. Evaluation of the natural status of desertification resulting from wind erosion in lands with agricultural land use

Indicator type	Working unit
	Agricultural lands
Changes in cultivating patterns from tree species or perennial crops to annual and sensitive species	3.5
The status of the construction or removal of wind barriers around the fields	3.2
Soil structure changes	2.9
Land release	3.2
Erosion and soil deposition of agricultural land	2.8
Continuation of wind blowing at speeds faster than threshold speed	3.0
Sum of score	18.7
Severity of desertification	High

Based on the results obtained from ICD model, the studied region was divided into three classes in terms of desertification intensity (medium, high and very high). The area of medium, high and very high classes was 2857.42, 1503.17 and 459.1 hectares, respectively, accounting for 59.3, 31.2 and 9.5% of the entire area of the region (4819.6), respectively (Table 16). Investigation of the results obtained from MICD model also indicated that the studied region consists of three classes of medium, high and very high. The lands with medium desertification cover an area of around 1974.84 hectares (41% of the entire region), the lands with class of high desertification 2385.71 hectares (around 49.5% of the entire region) and finally, the severe class covers 459.1 hectares (around 9.5% of the entire region). One of the reasons which reduced the desertification process in the region was the effect of protective activities performed in

Table 16. The status of desertification in Niatak region based on ICD and MICD models

MICD model results			ICD model results		
Percentage of desertification	Desertification rate per hectare	Desertification severity classification	Percentage of desertification	Desertification rate per hectare	Desertification severity classification
41.0	1974.84	Medium	59.3	2857.42	Medium
49.5	2385.71	High	31.2	1503.17	High
9.5	459.10	Very high	9.5	459.10	Very high

Niatak including mulching, transplanting and irrigation.

Conclusion

Based on the investigations performed in the present study, ICD model has reached desirable results in evaluation of the type and intensity of influential factors in desertification in comparison with FAO-UNEP and MEDALUS models.

- The model is relatively comprehensive and step-by-step and thus reduction of expert error in this method is more sensible in comparison with the other models.
- This model is compatible with local biome conditions and could be easily used in evaluation and separation of the type of desert environments.
- Through this model, one could prepare the map of different desert environments and desertification intensity.

This model, however, has some disadvantages. For example, some of the factors examined in this model were estimated and valued only qualitatively, which reduced accuracy of the scoring. Further, the range of scores across different classes of the model was very wide. These two factors led to disagreement among the researchers while evaluating the factors. In addition, as human factor had no effect on desertification of the regions free from any vegetation, the score associated with environmental factors was multiplied by two, which doubled the effect of environmental factors and this may lead to an error in the conclusions. Insufficient attention to wind erosion and its improper scoring is another disadvantage of this model. Accordingly, MICD model, which has a greater emphasis on wind erosion, was considered. In MICD method, the difference in the evaluation indicators is based on their use which has increased its accuracy compared to other indicators. A disadvantage of this method is the use different number of investigated indices across different land uses. For this reason, in this method, the range of scores will be different for classification of desertification intensity in each land use. It should be noted that in models related to erosion and water sedimentation, one could ensure accuracy of the obtained results through comparing observed statistics with those obtained from the model. For this reason, the accuracy of the results obtained from the presented models is not absolute. The only way for evaluation is to compare the results obtained from the model and giving due consideration to the conditions governing the region's biome. Thus, based on the results obtained, it was found that all the models used in this paper were suitable for estimation of the desertification intensity in Niatak Region in Sistan to a certain extent.

Major part of desertification and destruction in the studied region is due to the hydrological drought, rather than meteorological drought. As Hamoun lake is fed by Hirmand river and a major part of its watershed is located in Afghanistan, construction of Kajaki and Arghandab dams along with numerous barriers in Afghanistan prevents entrance of water of Hirmand river to the lake which caused hydrological drought in Sistan region. Further, 120-day winds with a speed higher than the threshold speed of erosion (more than 6 m/s) have significantly increased soil destruction, wind erosion, development of drought and thermal tensions. A huge part of Niatak region consists of wind erosion phases depicting harvesting, transport and sedimentation areas. Presence of phases such as clay plains with parabola-shaped surfaces, Nebkha, as well as sand zones and hills within a distance close to each other reveals the severe status of wind erosion and desertification potentials in the region. For this reason, the results of evaluation of desertification potentials in the region indicate the existence of higher classes of desertification. In the past, the studied region has been a corridor for extreme winds with dust and posed numerous environmental constraints for the people living in the region. However, in recent years some activities (such as mulching, transplanting and irrigation) have been performed in order to combat desertification effects and maintain the environment favorable for inhabitation.

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