Risk assessment of desertification using GIS in upper and lower reaches of Mond basin, Iran

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ABSTRACT

The present paper attempts to develop a new model by considering various indicators of different types of land degradation or desertification. These types include water erosion, soil salinity, vegetation degradation, and lowering of ground water table. The indicators can be used to find areas with higher rates of degradation which are called Potential Risk Areas (risky zones) in this paper, and can also be used to estimate the probability that degradation will increase in these areas. The Mond river basin, located in the southern part of Iran, has been selected as a test area to assess the risk and kind of desertification. For this purpose two sub basins of the Khormuj and Khane-Zenian & Siakh-Darengun have been chosen for detailed study as these two provide enough variation in climatic conditions like rainfall and topography. The different kinds of data gathered from records and published reports of the different governmental offices of Iran have been used for this purpose. The thresholds for the severity classes of indicators have been established and then the hazard map for each indicator of types of desertification has been prepared in a GIS. The risk maps of water erosion, soil salinization, lowering of water table, and vegetation degradation have been produced for both sub basins. Areas on the maps are assigned to risk classes on the basis of risk scores derived by considering the cumulative effects of all indicators overlying the area in the GIS. It was possible to distinguish the areas under 'actual risk' from areas under 'potential risk' of desertification types. Also areas under potential risk are classified to subclasses with different probability level to show a statistical picture of risk in future. The final map of risk of desertification is produced by overlaying all four maps of degradation types. Between the two basins the overall environmental condition in the Khormuj sub basin is worse. Results show that potential risk areas are much widespread than areas under actual risk in the upper reaches (of both sub basins) of Mond basin, indicating further threat of land degradation or desertification in the future. The percent of areas under actual risk are much more extensive in the lower reaches (Khormuj sub basin), indicating the higher degradation at present. It is hoped that this attempt using GIS will be found applicable for other regions of the world.

KEYWORDS

desertification; GIS; indicator; actual risk; potential risk

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1. Introduction

Drylands (arid, semi-arid and dry subhumid areas) are one example of a hotspot where land and populations are particularly vulnerable, both at present and into the future (Middleton et al. 2011). Drylands cover 41% of the planet's land area and are inhabited by more than 2 billion people (Middleton et al. 2011). Desertification (land degradation in drylands) has been ranked amongst the most urgent global environmental challenges (MA 2005). Indeed, land degradation will remain an important global issue for 21st century because of its impact on environment, and it effect on food security and the quality of life. Land degradation can be considered in terms of the loss of actual or potential productivity or utility as a result of natural or anthropogenic factors, it is the decline in land quality or reduction in its productivity (Zhang et al. 2014).

The United Nations Environmental Programme (UNEP) estimates 69% of the world's arid lands, excluding the very arid deserts, are under moderate to severe hazard of land degradation (Dregne 1991). The awareness about land degradation and desertification is not new. There are mentions of soil erosion dating back to classical times, and the subject was first brought to wide attention during the United States 'dust bowl' of the 1930s. In modern times, the human suffering caused by the drought in the West African Sahel zone during the 1970s led to the first UN Conference on Desertification in 1977. Since then, the problem has remained at the forefront of international discussions. In the early 1990s, desertification was defined as 'land degradation in arid, semi-arid and dry sub-humid areas resulting from various factors, including climatic variations and human activities' (UNEP 1992).

The alarming losses in economic revenues and agroecosystem services have revealed an acute need for monitoring of land degradation and analyses of its causes in order to advise decision makers on spatial targeting of land rehabilitation Measures (Dubovyk et al. 2013). Tracking trends in desertification, as well as land and soil degradation, and their links to different human and biophysical drivers is especially difficult (Eswaran et al. 2001), particularly if the information needs of stakeholders as diverse as policy makers, scientists, land managers and society at large are to be met (Vogt et al. 2011). The kind of authoritative and consensual assessments that are needed do not yet exist (UNCCD 2011). Within the coupled human-ecological system, it is necessary to identify critical variables that target both human and ecological system components. Monitoring needs to draw on indicators that measure both 'slow' and 'fast' human and biophysical variables (Reynolds et al. 2011).

Desertification involves a complex set of factors, interacting in space and time leading to a decrease in land productivity. It is closely related to many environmental factors such as climate, soil, vegetation cover, and morphology the character and intensity of which contribute to the evolution and characterization of different degradation levels (Masoudi and Amiri 2013; Barzani and Khairulmaini 2013; Masoudi 2014; Masoudi and Jokar 2015). Desertification is also strongly linked to socio-economic factors, since man's behavior and his social and economic actions can greatly influence the evolution of numerous environmental characteristics (Jafari and Bakhshandehmehr 2013).

Iran lies within the arid and semi-arid climatic belt, and in such climatic conditions the desertification processes are known to progress more speedily and pervasively. Arid and semi-arid regions cover more than 85% Iran's land, of which desert areas account for 34 million ha (FRW (Forest, Range, and Watershed Management Organization) 2004). Compared to other countries in the Middle East, the present status of desertification in Iran is alarming as about 94% of arable lands and permanent pastures are estimated to be in the process of degradation (FAO 1994).

Different models for assessing desertification such as mathematical methods, remote sensing, parametric equations, direct observation and measurement have been developed. Recently, several methods of desertification and land degradation have been used. The FAO/UNEP (1984) introduces the "Provisional Methodology for Assessment and Mapping of Desertification Hazard" which evaluates the main parameters affecting desertification processes. This method was the first major exercise that was developed to assess land degradation in arid and semi-arid regions. In this method, the hazard of desertification is assessed on the basis of five maps using the sum of numerical values of indices for desertification status map (DS), desertification rate (DR), inherent risk (IR), domestic animal pressure (AP), population pressure (PP). Hazard desertification (HD) map was calculated as:

$$DH = DS + DR + IR + AP + PP$$

It determines its severity classes like slight, moderate, severe and very severe. To produce status, rate and risk of land degradation, main types of land degradation in arid and semi-arid climate are selected as: water and wind erosion, soil salinization and vegetation degradation (FAO/UNEP 1984).

The MEDALUS model (Kosmas et al. 1999) identifies regions that are environmentally sensitive areas (ESAs). It brings the results of the physical and socio-economic aspects of desertification to bear on the identification and use of desertification indicators at various geographical scales from the local to the European. In this method, different classes of ESAs to desertification can be evaluated using various data such as landforms, soil, geology, vegetation, climate, and human actions. Each of these data is classified into various classes and a weighting factor is considered to each class. Then four main quality layers including soil, climate, vegetation, and management are evaluated. After assessing indices for each quality layer, the Environmental sensitivity index (ESI) is defined by combining the four quality layers. ESI is a composite indicator that can be used to gain an understanding of factors causing desertification risk at a point. All the data considering the four main layers are prepared in a geographical information system (GIS), and were overlain in accordance with the developed algorithm which takes the geometric mean to compile maps of ESAs to desertification.

Some other important models are GLASSOD[1] (Oldeman et al. 1991), ASSOD[2] (Van Lynden and Oldeman 1997) and LADA (Ponce Hernandez and Koohafkan 2004). In both ASSOD and GLASSOD projects, local experts assessed the relative impact of a given amount of a certain type of degradation on the productivity of the soil. This kind of assessment seems to be more realistic in finding the degree of degradation because it is more related to its impact on soil productivity.

Project of LADA has been set up by FAO, UNEP-GEF and various other partners to assess Land Degradation in Dryland Areas (LADA), in which GLASSOD is one of the methodologies to be reviewed for its potential benefits to this project. This method is based on a sequence or framework of rule of different indicator to degradation referred as DPSIR (Driving forces, Pressures, State, Impacts and Responses). The DPSIR framework is an approach to environmental hazard, developed by the European Environmental Agency, for describing, monitoring and controlling of environmental problems (EEA 1999). The approach is based on the use of DPSIR indicators, which may be direct or indirect, ecological, technical, socioeconomic or cultural causes of environmental hazard. The hazard maps of DPSIR indicators processed in the hazard assessment models give a far better opportunity to distinguish the severity classes of environmental hazard (FAO 2002; Ponce Hernandez and Koohafkan 2004). The existing **Driving forces** (D) in nature and society produce **Pressures** (P) on the natural resource that result in the current **State** (S) of land resources, with a negative **Impact** (I) on society and the environment. This, in turn, may stimulate a **Response** (R) (EEA 1999). Driving forces include those activities that may (in) directly cause the problem. Pressure indicators include those activities that may (in) directly result in an increased pressure on the natural resource. State indicators reflect the conditions of the land as well as its resilience to resist changes. Impact indicators describe the effect and impacts of the increased or reduced pressure on the natural resource. Impact indicators or change indicators measure change in either positive or negative direction (degradation or improvement). Response indicators include those activities by the land users themselves to release the pressure from the land. In some instances environmental regulations may be necessary to effect proper control of land degradation (EEA 1999; Masoudi and Amiri 2015).

Qi et al. (2013) used two landscape evaluation approaches, an integrated model and an ecological analysis method, based on landscape elements and environmental quality, respectively, to describe desertification in the Heihe River Basin of northwestern China, by evaluating the current state of the local ecosystems and environment. In total, 32 typical environment factors were selected, classifying desertification in the region into four zones.

Sepehr and Zucca (2012) introduced technique for order preference by similarity to ideal solution (TOPSIS) method as a decision-making method for the selection and integration of desertification indicators. It is a multiple criteria method to identify solutions from a finite set. TOPSIS is an algorithm for determining the most preferable choices among the possible indicators that can be developed. The simulation case study presented is related to the selection of the best set of indicators to monitor land degradation by remote sensing in three different countries (Brazil, Mozambique and Portugal), within the framework defined by the DesertWatch Extension project.

In Iran, Ekhtesasi and Mohajeri (1995) introduced the ICD[3] model for the classification of desertification in Iran. One of the advantages of this method is its capability to identify the type of desert like natural and anthropogenic deserts. ICD was developed in four steps: separation of deserts types using land use and plant types, distinguishing of desertification causes including the major and minor causes, classification of desertification and preparation of desertification maps. The model classifies the severity of desertification to five classes: slight, low, moderate, severe and very severe.

A new model for assessing hazard of desertification, namely, Iranian Model of Desertification Potential Assessment (IMDPA) is developed by Forests and Rangelands Organization of Iran**.** This model considers nine criteria or aspects of desertification, namely, climate, geology-geomorphology, soil, vegetation cover, agriculture, water, erosion (including wind and water erosion), social-economics, technology of urban development for finding areas with higher hazard of degradation. Each criterion is evaluated by three or four indicators. Total numbers of indicators introduced for the model are thirty five (Masoudi and Zakeri Nejad 2011).

This paper attempts at evolving a model for assessing risk of land degradation in southern part of Iran. For this purpose the Mond river basin for which enough data were available for variability in climate and land degradation types has been chosen. It is

1 Global Assessment of Soil Degradation
2 Assessment of Soil Degradation
3 Iranian Classification Deserts

hoped that this attempt using GIS, which is the first attempt of its kind done on Southern Iran for land degradation, will be found applicable for other regions of the world. The present work has given the opportunity to compare the intensity of different types of land degradation related to the two sub basins of Khane-Zenian & Siakh-Darengun (upper reaches of Mond River) and Khormuj sub basin (lower reaches of Mond River) which differ in elevation, climate and status of degradation. The total area covered in the GIS analysis is 1,787,000 ha.

2. Study area

The Mond basin is bounded between Lat. 27°20′ and 29°55′ N and Long. 51°09′ and 54°45′ E, it lies in the southern part of Iran (Fig. 1), covering an area of nearly 47,835 km^2. The basin is divided to five main sub basins on the basis of hydrology and topography. These basins are: Qareh Aghaj, Mond Miyani, Firuzabad, Payab and Harm-Kariyan. This Mond basin was selected as study area for this research because of availability of more data for the two sub basins, namely, the Khane-Zenian & Siakh-Darengun sub basin (upper reaches of Mond River in Qareh Aghaj basin) and the Khormuj sub basin (lower reaches of Mond River in Payab basin). This study provided a good opportunity to compare desertification in these two sub basins that differ in their physiographic and climatic status. The Khormuj sub basin covers an area of nearly 264,803 ha and the Khane-Zenian & Siakh-Darengun sub basin covers an area of nearly 160,242 ha.

The population of the entire basin is estimated to be about 2 million of which nearly half is urban. The rural population is engaged mostly in agricultural activity and cattle raising. The main river is the Mond River that flows down the Southern Zagros to the Persian Gulf. The part of the Mond River in the upper reaches is called as the Qareh Aghaj River. The elevation varies between the see level in the Payab basin to 3185 m in Kharman Kuh in the Qareh Aghaj basin. The landscape units are mountains, hills, piedmont and plains. The climate is arid and semi-arid in most part of the basin with a mean annual rainfall range of 150–700 mm. The main period of precipitation is during winter (60% of total rainfall). The mean annual temperature measured at the Qantareh station in Payab is 26.1 °C and for the Band Bahman in Qareh Aghaj is 14.4 °C.

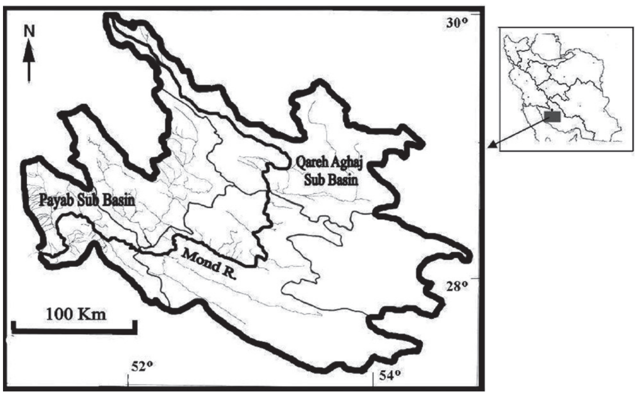

Fig. 1 Location map of Mond Basin in Iran.

3. Methods

1) Data gathering and processing for types of land degradation: The main types of land degradation in the two sub basins studied are: water erosion, wind erosion, soil salinization, lowering of ground water table and vegetation degradation. As the first step, the causes for each type of degradation have been identified. The data for this study have been gathered from the records and reports published by the different departments of the Ministries of Agriculture and Energy and the Meteorological Organization of Iran. The data obtained were of two typMasoudies: 1) numerical data and 2) thematic maps, but mainly in the map format (vector) with mostly semi-detailed scale (1 : 50,000 scale), useful for the GIS analysis. In all 18 maps have been digitized, 80 maps have been processed in the GIS. For example from a political boundary map of region after its digitizing in GIS, different socioeconomic maps were derived like density of population, percent of growth population, number of livestock and etc. The main types of data are on physiography (slope and land type), geology (rock formation), soil (depth, permeability, and erodibility factor), hydrology (water discharge), vegetation (density of vegetation cover and percentage of bare land) and climate (rainfall, evapotranspiration and temperature) and on some causes related to human activity such as over grazing, over pumping and density of population. These data especially thematic maps were verified to check quality of data with different way of verification in GIS like field observation and using topography maps. The data should not be old, because some data like vegetation cover or climate data change during time. Therefore in gathering of data this point took into consideration except those data that doesn’t change during a short time like geology map or its information.

2) Preparation of indicator hazard maps: In this research nine different indicators have been selected to achieve the best model for assessing the risk of water erosion, soil salinization and vegetation degradation in both the sub basins of the Mond Basin. Also eleven indicators for lowering of water table have been selected for assessing its risk. The status map of wind erosion has also been prepared. The recommendations like by the FAO and other scientists and also the statistical parameters of the present data for local conditions have been considered for producing

Tab. 1 The indicators used in the model of risk assessment for Desertification.

Type of Desertification	Indicators	Class limits and their ratings score				
		None (1)	Slight (2)	Moderate (3)	Severe (4)	Very severe (5)
a) soil salinization	1) Depth of water table (m)	>5	3–5	1–3	0.5–1	<0.5
	2) Soil texture	Coarse soils of mountains and hills	Coarse to medium and medium	Moderately fine	Fine	Very fine (clay texture)
	3) Slope (%)	30+	15–29	5–14	1–4	<1
	4) Quality of irrigation water Ec (μmhos/cm)	<250	250–749	750–2249	2250–4999	5000+
	5) Ground water quality Ec (μmhos/cm) SAR	 <250 <10	 250–749 10–17	 750–2249 18–25	 2250–4999 26–29	 5000+ 30+
	6)Efficacy of surface geology (ESG)*	<0.1	0.1–0.39	0.40–0.65	0.65–1	1+
	7) Climate	Sub humid and humid	Slightly semi-arid	Semi-arid	Arid	Very arid
	8) Dry index (P/ETP)	0.60+	0.40–0.59	0.20–0.39	0.05–0.19	<0.05
	9) Status of soil salinity EC (mmhos/cm) SAR	 <4 <8	 4–8 8–13	 8–16 13–30	 16–32 30–70	 >32 >70
b) water erosion	1)Soil erodibility	<0.1	0.1–0.19	0.2–0.34	0.35–0.49	≥0.5
	2) Soil depth (cm)	Very deep or ≥ 150 cm	Deep or 90–149 cm	Semi deep to deep or 50–89 cm	Shallow to semi deep or 10–49 cm	Very shallow to shallow or <10 cm
	3) Per cent slope	<2	2–4	5–14	15–29	≥30
	4) Intensity of rainfall**	<10	10–19	20–29	30–39	≥40
	5) Total rainfall (mm)	<50	50–199	200–399	400–599	600–1000
	6) Per cent bare ground	<20	20–39	40–59	60–79	≥80
	7) Per cent vegetation cover	≥70	50–69	25–49	10–24	<10
	8) Status of water erosion	Features of erosion insignificant	Sheet and rill erosion and occasional gully erosion visible	Sheet and rill erosion moderate and occasional gully erosion visible	Fairly high abundance of features of sheet, rill and gully erosion	Highly abundant sheet, rill and gully erosion (badlands)
	9) Erodibility of surface geology	Formations resistant against water erosion and thick alluvial deposits of plains.	Formations fairly resistant against water erosion	Formation with moderate resistance against water erosion	Formations with low resistance against water erosion	Formations susceptible to water erosion like salt domes associated with layers of marl, shale.

Type of Desertification	Indicators	Class limits and their ratings score				
		None (1)	Slight (2)	Moderate (3)	Severe (4)	Very severe (5)
C) vegetation degradation	1) Potential of biomass production (kg/ha)	≥1000	650–999	350–649	100–349	<100
	2) Pressure of livestock***	≥5	1.5–5	1.0–1.5	0.5–1.0	<0.5
	3) vegetation cover (%)	≥70	50–69	25–49	10–24	<10
	4) Expansion of agricultural activity over lands suitable for natural resources	Natural resource lands (without any changes)	Irrigated lands with low limitations	Irrigated lands with limitations, or dry cultivation with low limitations	Dry cultivation with high limitations	Dry cultivation with very high limitations
	5) Rural Population Density (per sq. km)	<1	1–4	5–19	20–34	≥35
	6) Villages density (per sq. km)	0	0–0.02	0.02–0.06	0.06–0.09	≥0.09
	7) Climate	Sub humid and humid	Slightly semi-arid	Semi-arid	Arid	Very arid
	8) Coefficient variation (CV) of annual rainfall	<20	20–29	30–39	40–49	≥50
	9) Land suitability for vegetation cover	Very good	Good (suitable)	Medium	Low	Poor or very poor (Unsuitable soils)
d) lowering of ground water table	1) Over exploitation[#]	≥1.1	1 ≤ 1.1	0.9 ≤ 1	0.8 ≤ 0.9	<0.8
	2) Increased Consumption of ground water in the 10 years	< 1.10	1.1–1.32	1.33–1.65	1.66–1.99	≥2
	3) % Surface water consumption of total water consumption	≥75	50–74	25–49	10–24	<10
	4) Ratio of non-irrigated areas to irrigated areas	≥3	1.50–2.99	0.75–1.49	0.25–0.74	<0.25
	5) Average water consumption in irrigated areas (M^3/ha)	–	Other parts of plain	<10500	10500–16500	>16500
	6) Ratio of water exploitation from qanats[##] to that from wells	> 1	0.34–1	0.18–0.33	0.06–0.17	≤0.05
	7) Climate	Sub humid and humid	Slightly semi-arid	Semi-arid	Arid	Very arid
	8) Coefficient variation (CV) of annual rainfall	<20	20–29	30–39	40–49	≥50
	9) Annual rainfall, mm	≥1000	500–999	250–499	100–249	<100
	10) Influence of carbonate formations[###]	≥3	1.00–2.99	0.50–0.99	0.25–0.49	<0.25

Type of Desertification	Indicators	Class limits and their ratings score				
		None (1)	Slight (2)	Moderate (3)	Severe (4)	Very severe (5)
d) lowering of ground water table	11) Hydrogeology of plains	Coarse-grained texture, very thick alluvium, deep water table, excellent discharge	Medium to coarse-grained texture, thick alluvium, deep water table, good discharge	Relatively fine-grained texture, moderately thick alluvium, shallow water table, medium discharge	Fine-grained texture, thin alluvium, shallow water table, poor discharge	Fine to very fine-grained texture, very thin alluvium, shallow water table or no aquifer, very poor discharge

* ESG = ((2 × salt dome area) + (evaporates area) + (0.5 × area of formations with less evaporate material) / area of other formations

** Average of maximum for amount of rainfall in mm during 6 hours for period of 2 years

*** Pressure of livestock = potential of carrying capacity / actual density of livestock (Masoudi and Vahedi, 2014)

Over exploitation = Safe exploitation / actual extraction exploitation in MM^3 (million cube meter)

Qanat is a traditional form of freshwater extraction mostly in desert and arid areas to reflect and process water from upland area

R = extent of carbonate formations / extent of non-carbonate formations

hazardous thresholds of the indicators, revealing ‘none’ to ‘very severe’ hazardous conditions (ratings scores between 1 and 5) to assess the risk of these types of degradation (Table 1). The hazard maps have been prepared in the GIS for each indicator.

3) Producing of risk maps for each type of land degradation: To project the effect of all the indicators the hazard maps for each type of land degradation were overlaid in the GIS using the following equations, giving proper weighting for each indicator. The attributes × 2 indicate their relative importance in assessing the severity of risk. On the other hand, the indicators that have less impact were given weighting (1):

Risk score for water erosion = ((Soil depth + Slope + Status of water erosion) × 2) + Erodibility of surface geology + Intensity of rainfall + Annual rainfall + Soil erodibility + Vegetation cover + Bare ground

Risk score for soil salinization = (Status of soil salinity × 2) + Efficacy of surface geology + Quality of irrigation water + Depth of water table + Ground water quality + Soil texture + Climate + Dry index + Slope

Risk score for vegetation degradation = ((Potential of biomass production + Vegetation cover + Rural population density + Pressure of livestock) × 2) + Expansion of agricultural activity over lands suitable for natural resources + Villages density + Climate + Coefficient variation (CV) of annual rainfall + Land suitability for vegetation cover

Risk score for lowering of ground water table = ((Annual rainfall + Hydrogeology of plains + Over evacuation + Increased consumption of ground water in the 10 years + Surface water consumption + Average water consumption in irrigated areas) × 2) + Ratio of non-irrigated areas to irrigated areas + Ratio of water evacuation from qanats to that from wells + Climate + Coefficient variation (CV) of annual rainfall + Influence of carbonate formations.

The risk score arrived at enabled to subdivide the severity classes of degradation types. Five such severity classes ranging from ‘none’ to ‘very severe’ were recognized (Table 2). The GIS analysis enabled the distinction of areas under ‘actual risk’ from areas under ‘potential risk’ of land degradation types. The actual risk areas show at present a state of degradation equal to or worse than the classes assigned for the risk. The present status of hazard is determined by considering the attributes of indicators 9, 8, 3 and 10 for soil salinization, water erosion, vegetation degradation and lowering of ground water table, respectively (Table 1).

Tab. 2 Severity classes in the Risk Maps and GIS models regarding the scores of polygons.

Risk type	Class limits and their score in the GIS				
	None	Slight	Moderate	Severe	Very severe
1) Water Erosion	12–18	18.1–30	30.1–42	42.1–54	54.1–60
2) Soil Salinization	10–15	15.1–25	25.1–35	35.1–45	45.1–50
3) Vegetation Degradation	13–19.5	19.6–32.5	32.6–45.5	45.6–58.5	58.6–65
4) Lowering of Ground Water Table	17–25.5	25.6–42.5	42.6–59.5	59.6–76.5	76.6–85

Areas under potential risk have been recognized using the following criteria:

(A) Potential risk area = areas where the risk class determined > present status of hazard.

The Potential risk areas include areas that, at present, show a state of degradation lower than the classes that are predicted by the risk analysis. For example, areas under 'moderate' potential risk have at present slight or no degradation but have moderate vulnerability towards worse conditions. For calculating the probability for potential risk, the risk scores have been converted to percentage. The potential risk classes were further divided into sub classes of severity in the risk maps, based on per cent probability of potential risk, thus giving a statistical picture of the risk. The following equation was used for this purpose:

(B) % Probability of Risk in Potential Risk Areas = $[(X-a)/b] \times 100$, where a is the least score (0% probability) for each type of land degradation in Table 2, b is the numeric difference between the highest and the least scores for each type of land degradation in Table 2, and X is the risk score in each polygon. Therefore, this equation tries to stretch the risk scores between 0 and 100. For example the equation for predicting of % risk of water erosion in each polygon is: $[(X-12)/48] \times 100$.

4) Producing of risk maps of land degradation or desertification: The final map of risk of land degradation is produced by overlaying all four maps of degradation types. To qualify the severity classes of desertification map, the maximum degree of risk among the four types of land degradation shown in each polygon was selected.

4. Results and discussion

The estimates done on the basis of observations on the current status of land degradation reflect only what has happened till date. Risk assessment, on the other hand, is based on modeling, calculations, predicting the potentially adverse situation that may arise in 10 or 50 years from now (Bridge et al. 2001). Most studies so far done in Iran like Feiznia et al. (2001) and in the world like method of USLE for water erosion or Metternicht and Zinck (1997) for soil salinity have based their estimation on the 'present status' of degradation. It should be also said that selection of such parameters which calculate the desertification hazard is more comprehensive than previous studies. Because nearly all effective factors have just been calculated (Masoudi and Amiri 2013; Barzani and Khairulmaini 2013; Masoudi 2014). There exists also confusion in the use of the term 'risk assessment' among many scientists (e.g. Norton et al. 2001; Van Der Knijff et al. 2000 and Filho et al. 2001) who actually estimated only the soil loss, using some of the models like USLE and not the risk. The different type degradation maps alone based on the present status of degradation are inadequate to predict areas under risk. It requires a comparison between the present status and data showing state of degradation in the past to find the rate of degradation. This is almost difficult in most of the cases because of unavailability of such data of the previous decades. The present model using different indicators of land degradation types has an edge to solve this problem since it finds the severity of degradation using cumulative effect of all indicators and then compares it with the present status of degradation.

In the present work, the risk assessment of desertification attempts to demarcate areas with greater probability of reaching the worst step of degradation like a change from moderate to severe state of soil

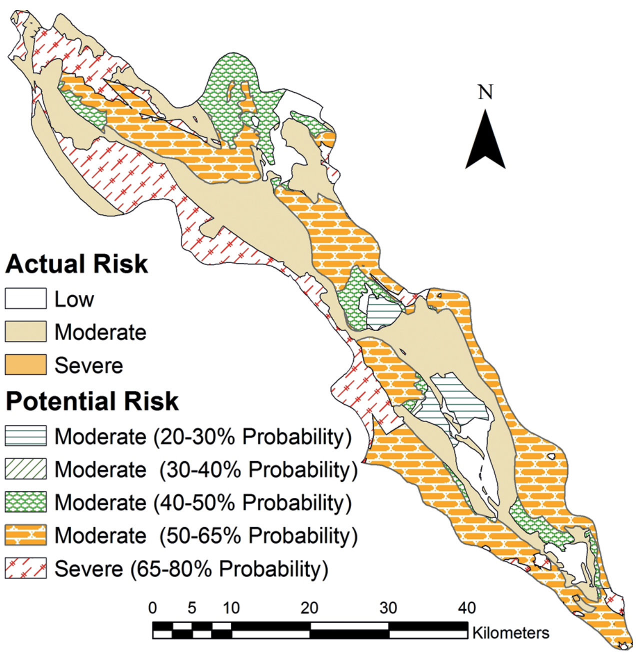

Fig. 2 Risk of water erosion in the Khane-Zenian & Siakh-Darengun sub basin.

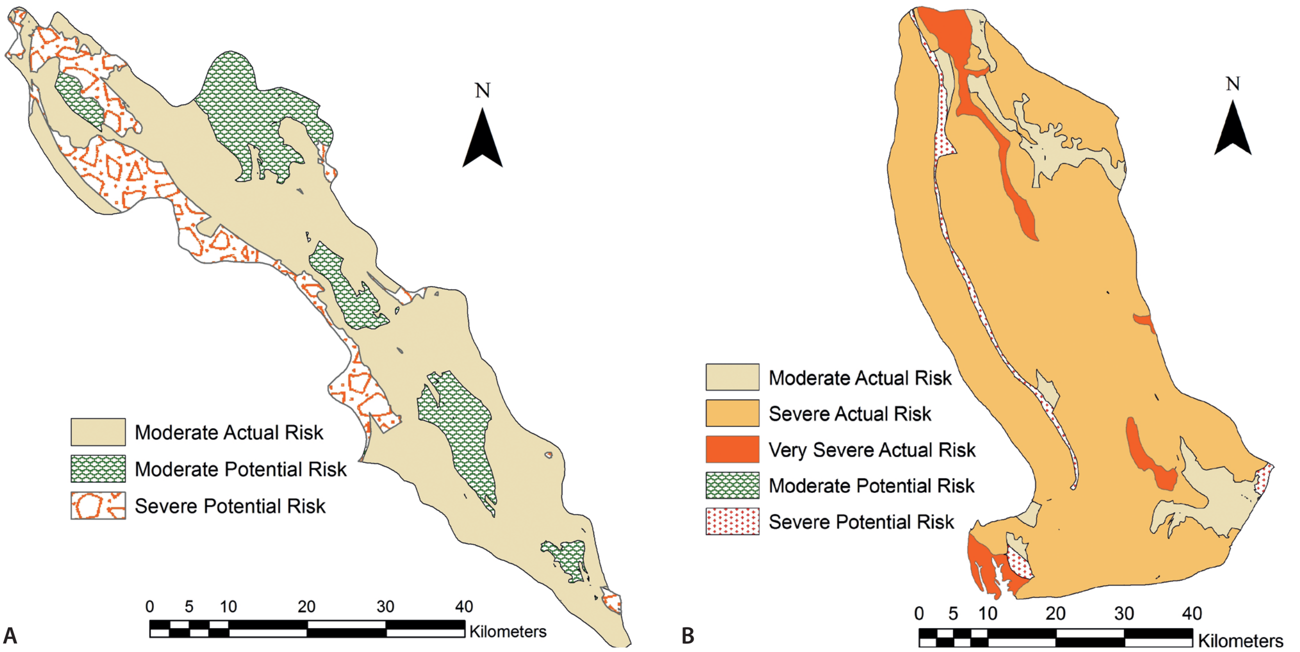

Fig. 3 Risk of desertification in the study area: (a) Khane-Zenian & Siakh-Darengun sub basin; (b) Khormuj sub basin.

salinization or other types of degradation and also measure the probability (risk) of this adverse change (Masoudi et al. 2005; Masoudi et al. 2006; Masoudi et al. 2007; Masoudi 2014). This kind of classification using two categories of 'actual risk' and 'potential risk' and its subclasses based on per cent probability in the risk maps is the first attempt of its kind for defining areas with higher risk of degradation. Preparing such risk maps may prove to be useful for regional planners, and policy makers for agricultural and environmental strategies, not only in the semi-arid and arid conditions of Southern Iran but also in other countries facing similar problem. The model can be made applicable for other countries only after little modification of some of the indicators, based on the local conditions. The risk map of water erosion is one example of this kind of methodology for assessing risk of land degradation types (Fig. 2).

To prepare the severity classes of desertification maps, the four types of desertification were overlaid in GIS. Once again from the desertification risk maps (Fig. 3) the areas under actual risk and areas under potential risk were identified. Those under actual risk have been further divided into the moderate and the severe risk classes but both define those areas in which the present state of degradation is moderate or severe for any one type of degradation. From the Fig. 3, it is concluded that in both sub basins areas under actual risk are more widespread compared to areas under potential risk. Among severity classes a greater proportion (63%) of land is under 'moderate risk' in the Khane-Zenian & Siakh-Darengun sub basin while the in the Khormuj it is 88% under 'severe and very severe risk'. This implies the obvious that the conditions in the Khormuj sub basin with arid climate are worse compared to the Khane-Zenian & Siakh-Darengun sub basin, with semi-arid climate. On the other hand, the vulnerable potential risk areas under the threat are more extensive in the Khane-Zenian & Siakh-Darengun (37%) compared to the Khormuj (3%). These results indicate that the already degraded lands with worse condition are lesser in the Khane-Zenian & Siakh-Darengun sub basin and therefore they need more attention for protection against future degradation. Also GIS analysis shows the main type of desertification in the plains and high lands of both sub basins is the vegetation degradation. This reflects the overall impacts of climatic and anthropogenic causes and soil degradation on the vegetation cover.

5. Conclusions

The Mond Basin model is the first attempt of its kind for defining the risk of desertification and can be made applicable for other areas in Iran and elsewhere. The main results of the present paper are:

1. The hazard maps of different indicators processed in the risk assessment model give a far better opportunity to distinguish the severity classes of risk of desertification. Creating some new indicators for the first time for this assessment was another achievement of the present work. Some of the new indicators are: ratio of non-irrigated areas to irrigated areas, 'Efficacy of surface geology' (ESG) and 'influence of carbonate formations'. To identify the severity classes of such indicators, the local statistical conditions of data have also been considered.

2. The model based on the statistical parameters helps to identify the areas under actual and potential risk and their sub classes based on per cent probability.

3. Areas under actual risk are widespread in both the sub basins especially in the Khormuj sub basin, indicating the more severe land degradation at present. The potential risk areas in the Khane-Zenian & Siakh-Darengun sub basin are more widespread compared to the Khormuj, indicating further threat of land degradation in future. Areas under potential risk will be the areas needing immediate attention for remedial measures for reclamation and conservation for each type of degradation.

4. Considering both actual and potential risk areas it is concluded that the areas under severe risk are dominant in the Khormuj while those under moderate risk have a greater spread in the Khane-Zenian & Siakh-Darengun. This shows between the two basins the overall environmental condition in the Khormuj sub basin is worse.

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