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Application of Methodology for Mapping Environmentally Sensitive Areas (ESAs) to Desertification in Dry Bed of Hamoun Wetland (Iran)

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AbstractSeveral models have been developed to estimate land degradation rate and evaluate desertification severity. This study attempts to apply the MEDALUS (Mediterranean Desertification and Land Use) model by considering existing conditions in the Hamoun wetland, located in south-eastern Iran. At first identification of the main factors affecting the desertification phenomenon was attempted, based on field survey. These factors include climate, soil, vegetation and management practices. Results showed that land management and extreme climate are the most important factors affecting the desertification process. In addition, in some land uses, lack of vegetation accelerates the prevalent wind intensity in the study area (known as "*the 120Rozeh"* (means 120 days and refers to the wind, with high speeds that blow from the North to the South during summer time) – the most famous Iranian winds) which continues its path without any barrier, and erodes the land surface. Results also indicated that the study area is mostly located in the critical desertification class. Based on the results, it is known that 14% of whole region (12,273 ha) is in the low-critical class, 48.2% (42,251 ha) in the medium-critical class, and 37.8% (33,134 ha) in the high-critical class.

Key words:*Desertification, MEDALUS model, Sistan region, Wind erosion*

1 INTRODUCTION

Desertification is the consequence of a set of important processes that are active in arid and semi-arid environments, where water is the main limiting factor of land use in ecosystems, and several factors may cause it, such as climate change and human activities. This problem can be seen not only in dry areas, but also in some parts of the semi-humid areas. Sand invasion and loss of quality and quantity of groundwater and reduction in soil fertility and increased susceptibility to land degradation are specific and dramatic consequences of desertification phenomena (Kosmas *et al.*, 1999). Mechanisms to explain desertification include changes in climate, human induced stress, herbivore and fire regime, but most studies agree that overgrazing by livestock has played a major role in desertification phenomena (Schlesinger *et al.*, 1990; Laycock, 1991; Fleischner, 1994; Archer *et al.*, 1995; Daily, 1995; van Auken, 2000). Plant cover amendment in degraded land can lead to considerable constructive change in the process of erosion. A revitalization of plant cover in damaged lands can enhance soil reclamation, improve the texture and structure of soil in the long run, as well as increase essential soil nutrients of nitrogen, phosphorus and potassium (Jafari *et al.*, 2004). Many arid and semi-arid types of grassland worldwide have experienced a shift in dominant vegetative composition from perennial grasses to shrubs and bare soil, a change coincidental with desertification

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(Daily, 1995; Jackson *et al.*, 2002; Scheffer *et al.*, 2001; van Auken, 2000). According to the definition proposed in the Rio Summit of UNCED (United Nations Conference on Environment and Development) in 1992, sustainable development incorporates economic, social and environmental spheres, once considered separate on a global scale (Benhayoun *et al.*, 1999). Desertification in north China is extremely serious due to poor climatic conditions, such as drought, severe wind erosion and long-term unsustainable human activities including over-grazing, extensive cutting, and over-reclamation (Wang, 2003; Yang *et al.*, 2005; Wang *et al.*, 2006).

Desertification is the result of complex interactions among various factors, including climate change and human activities (Thomas, 1997; UNCCD, 1994). In more than 100 countries, about 1 billion of the world's population of six billion is affected by desertification (Adger *et al.*, 2000). However, desertification dynamics can be accurately monitored and assessed via a combination of satellite observations and *in-situ* information (Collado *et al.*, 2002; Jabbar and Chen, 2006; Runnstrom, 2003; Yang *et al.*, 2007).

Despite the variety of methods of estimation, soil erosion from water and wind erosion have been proposed by researchers but, to date, no specific method for classification of desertification intensity based on the total desertification processes has been provided. Therefore, assessment of Regional Indicators should be considered for assessment of desertification processes. These Regional Indicators should be based on available international source materials, including remotely sensed images, topographic data (maps or DEM's (Digital Elevation Models)), climate, soils and geological data, at scales of 1:250,000 to 1,000,000) (Kosmas *et al.*, 1999). Regional Indicators may be used as a baseline for allocation of funds and expertise between countries and between regions within a country. Each Regional Indicator or group of associated indicators should be focused on a single process, e.g. wind erosion. In order to assess the desertification processes, various models have been proposed. The MEDALUS, which later in 1999 was named as ESA model, is the latest (Kosmas *et al.*, 1999).

The proposed methodology in this research is through the identification of Environmentally Sensitive Areas (ESAs) through a multi-factor approach based on both a general and a local knowledge of the environmental processes acting. In summary, this work focuses on the choice of appropriate indicators at the Sistan plain using ESAs model, to identify major factors affecting the dry bed of Hamoun wetland, in order to determine the desertification intensity.

2 STUDY AREAAND DATASETS

The dry bed of the Hamoun wetland of Sistan region located in the south-east of Iran extends between 61°32′30″ to 61°14′00″ E longitudes and 31°05′00″ to 31°27′00″ N latitudes, and covers an area of 876.58 km. Mean annual precipitation in Sistan is 62.84 mm, mean annual air temperature 21.82°C and mean annual evaporation rate is 4500 mm. The study area is covered by active dunes. This region geologically consists of Quaternary formations including clay and silt sediments. The study represents a medium relief, with high salinity and alkalinity, very deep but undeveloped soil with light texture and the slope ranging from 0.5% to 3% throughout critical regions. The soil moisture is classified as aridic regime (torric), based on the soil moisture regimes maps prepared at a scale of 1:2,500,000 and the weather station records of the study area. According to the meteorological records of the study area, the thermal regime of the region is hyperthermic. Based on morphological surveys of dug profiles in the region and analysis of laboratory results, the soils are classified in the two categories of entisols and aridisols.

3 MATERIALS AND METHODS

The MEDALUS model was used for calculating the ESA index to determine the situation and tendency of desertification in the Sistan region of Iran. The general methodology is fully described by Kosmas *et al.* (1999). In general, the ESA is a composite index that uses four quality indices which are in turn calculated from some individual parameters. The quality indices and their parameters are as follows: climate quality (annual rainfall and aridity); soil quality (texture, drainage conditions, gradient, parent material, depth and rock fragments); vegetation quality (fire risk, erosion protection, cover and drought resistance); and management quality (land use and management practices). The value of each parameter is divided into a number of classes, the thresholds of which have been determined empirically from extensive field work during the MEDALUS projects (Kosmas *et al.,* 2003). Each class is given a weighted index according to the importance of its role in land degradation processes from 1.0 (least) to 2.0 (worst). For example, the annual rainfall has three classes: >650, 650–280 and <280 mm, with weighted indices of 1.0, 1.5 and 2.0, respectively. Full details of the classes and weighted indices for each parameter are given in the relevant tables. The four quality indices are calculated from the algorithm Eq. (1):

$$\text{Quality\_x } ij = (\text{parameter\_1 } ij \times \text{parameter\_2 } ij \times \ldots \times \text{parameter\_n } ij)\ (1/n) \quad (1)$$

where i,j = rows and columns of a single elementary land unit of each parameter;

n = number of parameters used

In turn, the ESA index is calculated as per algorithm (2), thus:

$$\text{ES } ij = (\text{Quality\_1 } ij \times \text{Quality \_2 } ij \times \text{Quality \_3 } ij \times \text{Quality \_4 } ij)^{(1/4)} \quad (2)$$

where i,j = rows and columns of a single elementary land unit of each quality;

Quality_nij = values calculated from (3)

According to the value of the ESA index, each unit of land is classified into one of the following three categories based on its sensitivity to desertification:

- Critical: the area has already been subjected to high-intensity inappropriate use and is probably quite degraded.
- Fragile: the area is showing tangible results of a disturbance in the balance between natural and human activities and as a result there is evidence of desertification and degradation taking place.
- Potential: the area is at risk from desertification. If it is not properly managed, degradation will ensue.

Most studies confirm that the MEDALUS model evaluates the desertification rate accurately with acceptable results (Basso *et al.*, 2000; Rafiei, 2002, Kosmas *et al.*, 2003; Sepehr *et al.*, 2007; Lavado *et al.*, 2009). This model has some advantages over other models.

- The parameters of the model are readily available.
- The parameters are mapped as layers in ArcGIS9.2, IDRISI Kilimanjaro andERDAS IMAGINE 8.4, increasing speed and accuracy of data processing.
- In order to integrate the parameters related to each single index, the geometric mean of them was used instead of the arithmetic mean, because the geometric mean is more precise.

3.1 Soil quality indicators

Soil salinity/salinization is one of the main problems in arid zones leading to land desertification (UNEP (United Nations Environment Program), 1991). The geological formation of the dry bed of Hamoun wetland region comprises Quaternary sediments and lake deposits of thickness greater than 2000 m. No debris is observed from rock units and sediments prior to the Neogene and Quaternary periods. With respect to a sedimentary environment, the study area is known as the Hirmand River depositional environment. The stratigraphical units of the study area include new alluvial terraces of Niatak's river bed, lake deposits of the dry season Hamoun wetland, dunes, and sandy plains; all are sensitive to wind erosion. All lithological formations are either without continuity or with little continuity, fine texture and weak diagenesis, such that all of them provide an erodible sedimentary environment. Therefore, all the geological formations of the study area are susceptible to wind erosion. This is one of the causes that we expect to

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intensify the desertification process in the study area. On the basis of geomorphologic studies, the following classifications are distinguishable – four working units of piedmont plain, a type of paved piedmont plain and nine geomorphologic characteristics including a salt area with Nebka facies, degraded farmlands, river bed, flat floodplain, bare land, dry land with puffy surface, flat lands whit xerophyte and halophyte species, and bed plain of Saberi Lake.

The soil quality indicators for mapping ESAs can be related to: (1) water availability, and (2) erosion resistance. These qualities can be evaluated by using simple soil properties or characteristics given in regular soil survey reports such as texture, parent material, soil depth, slope angle, drainage, stoniness, etc. Table 1 contains the classes and assigns weighted indices for each of the six parameters used to assess soil quality.

- Soil texture is classified based on its sensitivity to desertification.
- Soil drainage condition is mainly used for assessing desertification risk due to salinization of flat areas located mainly in alluvial plains along the coastline or in depressions inside valleys. Three drainage classes are defined with respect to their effect on salinization.
- Soil depth is defined as the depth of the soil profile from the soil surface to the top of the regolith or unweathered parent material. Soil depth is classified in four classes.
- Slope gradient is classified in four classes according to the effect on soil erosion.
- Parent materials are classified based on their sensitivity to desertification.
- Rock fragments, as desert pavement that covers the soil surface, are classified in three classes according to their ability to preserve moisture content in soils and protect the soil particles from detachment by erosive blown winds.

The SQI (Soil Quality Index) is estimated from the weighted index assigned to each of the six parameters using Eq. (4):

SQI = (texture × parent material 8 rock × fragment depth × slope × drainage) $^{1/6}$ (4)

Table 1 Classes and assigned weighted indices for the various parameters used for assessment of soil quality.

Parameter	Class	Description	Index
Soil texture	1 2 3 4	L, SCL, SL, LS, CL SC, SiL, SiCL Si, C, SiC S	1 1.2 1.6 2

Parameter	Class	Description	Index
Drainage condition	1	Well drainage	1
	2	Imperfectly drainage	1.2
	3	Poorly drainage	2

Parameters	Class	Description	Index
Gradient (%)	1	<6	1
	2	6-18	1.2
	3	18-35	1.5
	4	35<	2

Parameters	Class	Description	Index
Rock fragments(%)	1	>60	1
	2	60-20	1.3
	3	20<	2

Class of soil quality	Description	Range
1	High quality	<1.13
2	Moderate quality	1.13-1.45
3	Low quality	1.46<

Parameter	Class	Description	Index
Soil depth (cm)	1	>75	1
	2	75-30	1.33
	3	30-15	1.66
	4	15>	2

Parameter	Class	Description	Index
Parent material	1 2 3	Shale, Schist basic, ultra basic conglomerates, unconsolidate Limestone, marble, granite, rhyolite, Ignimbrite, gneiss, siltstone, sandstone marl, pyroclastics	1 1.7 2

Parameter	Class	Description	Index
BGI index	1	<50	1
	2	50-75	1.1
	3	75-100	1.2
	4	100-125	1.4
	5	125-150	1.8
	6	>150	2

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3.2 Climate quality indicators

Climate quality is assessed using parameters that influence water availability to plants – rainfall, air temperature and aridity index. Table 2 contains the classes and the weighted indices assigned for each of the parameters. Recently, many studies have been conducted in an attempt to assess the relative roles that climate factors play in desertification and to reveal its causes (Reynolds and Stafford Smith, 2002; Archer, 2004; Wang *et al.,* 2005; Zheng *et al.,* 2006). However, the relative roles of climate change in desertification at the macro level are still unclear owing to a lack of consistent quantitative assessment methods and multi-scale studies.

- Annual rainfall (mm) is used to calculate the CQI (Climate Quality Index).
- BGI (Bagnouls-Gaussen aridity Index) Calculation of this index is straightforward since the data required can be easily obtained from common meteorological records. It is defined using Eq. (5):

$$BGI = \sum_{i=1}^{n} (2t_i - p_i)k_i \qquad (5)$$

where BGI is the Bagnouls-Gaussen aridity index, t is the mean monthly air temperature in °C, P_i is the total monthly precipitation in mm; and k_i represents the proportion of the month during which $2t_i - p_i > 0$. Based on the climatological data of the study area the Bagnouls-Gaussen aridity index is calculated at about 219.5 for this location.

The CQI (Climate Quality index) is calculated from the weighted index assigned to each of the parameters from Eq. (6):

$$CQI = (rainfall \times aridity)^{1/2} \qquad (6)$$

3.3 Vegetation quality indicators

The vegetation dynamic is very important in the process of desertification and can reflect the complex interactions between climate change and human activities (Hanafi and Jauffret, 2008). One of the factors under evaluation in the whole study area is the vegetation characteristics of the region; accordingly, the dominant type of vegetation includes xerophytes and halophytes and the common species are: *Alhage camelorum, Sasola dendroides,Haloxsilon salicornicum,Tamarix stircta,Tamarix aphylla*, and so on. The major part of the study area is the area prone to wind erosion due to insufficient vegetation cover, and in some of the geomorphologic facies wind erosion rate reaches its maximum level because speed reaches threshold velocity during dusty days. Some recent studies have selected the vegetation dynamic in desertification as an indicator to distinguish human-induced desertification from desertification induced by climate change. This is accomplished by comparing the potential or predicted vegetation cover with the actual cover (Evans and Geerken, 2004; Geerken and Ilaiwi, 2004; Herrmann *et al.*, 2005; Wessels *et al.*, 2008).

Vegetation quality is assessed in terms of: (1) fire risk and ability to recover; (2) erosion protection the vegetation affords to the soils; (3) drought resistance; and (4) plant cover.

Fire risk, erosion protection and drought resistance all depend on the type of vegetation cover.

Percentage cover was obtained from NDVI (Normalized Difference Vegetation Index) derived from a TM satellite image.

The VQI (Vegetation Quality Index) is assessed as the product of the mentioned vegetation characteristics (Table 3) related to sensitivity to desertification using Eq. (7):

$$VQI = (\text{fire risk} \times \text{erosion protection} \times \text{drought resistance} \times \text{vegetation cover})^{1/4} \qquad (7)$$

The VQI is divided into three classes defining the quality of vegetation with respect to desertification. The weighted index assigned to each parameter is also considered in the calculation of VQI.

Table 2 Classes and assigned weighted indices for the various parameters used for assessment of climate quality.

Parameter	Class	Description	Index
Rainfall (mm)	1	>650	1
	2	650-280	1.5
	3	<280	2

Class of climate quality index	Description	Range
1	High quality	<1.15
2	Moderate quality	1.15–1.81
3	Low quality	>1.81

Table 3 Classes and assigned weighted indices for the various parameters used for assessment of vegetation quality.

Parameter	Class	Description	Index
Fire risk (type of vegetation)	1	Pine forests	1
	2	Mediterranean macchia	1.3
	3	Annual agricultural crops (cereals, grasslands), deciduous oak, (mixed), mixed Mediterranean, macchia/evergreen forests	1.6
	4	Bare land, perennial agricultural crops, annual agricultural crops (maize, tobacco, sunflower)	2

Parameter	Class	Description	Index
Erosion protection	1	Mixed Mediterranean macchia/evergreen forests	1
	2	Mediterranean macchia, pine forests, permanent grasslands, evergreen perennial crops	1.3
	3	Deciduous forests	1.6
	4	Deciduous perennial agricultural crops (almonds, orchards)	1.8
	5	Annual agricultural crops (cereals), annual grasslands, vines	2

Parameter	Class	Description	Index
Drought resistance	1	Mixed Mediterranean macchia/evergreen forests, Mediterranean macchia	1
	2	Conifers, deciduous, olives	1.2
	3	Perennial agricultural trees (vines, almonds)	1.4
	4	Perennial grasslands	1.7
	5	Annual agricultural crops, annual grasslands	2

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Continue Table 3 Classes and assigned weighted indices for the various parameters used for assessment of vegetation quality.

Vegetation Quality Index	Description	Range
1	High quality	<1.3
2	Moderate quality	1.3 to 1.6
3	Low quality	>1.6

Parameter	Class	Description	Index
Cover percentage	1	>40	1
	2	40-10	1.8
	3	>10	2

3.4 Management quality or degree of human induced stress

Management quality is assessed in terms of: (1) main land use; and (2) management practices. Some types of land use (for example vineyards or cereal crops) inherently expose the soil to more risk of degradation because of the type of cultivation methods used. Management practices usually aim to mitigate the effects of degradation by attempting to control certain types of land use (e.g. grazing). The land uses of the study area were divided into the nine classes using high-resolution aerial photography delineation and interpretation, and the final land use map was completed by a field survey. Land uses are given as following geomorphological facies also (Table 4).

- Salt area with puffy surface (R3.2)
- Degraded farmlands (R2.1)
- Salt area with Nebka facies (R2.2)
- Saberi Lake bed plain (L1.1)
- Flat lands with xerophytes and halophytes species (L2.1)
- Dry land with puffy surface (L3.1)
- Floodplain with low relief (F1.1)
- Flat floodplain (F1.2)
- Flat floodplain (F1.3)

Distribution of the above facies in a land use map is shown in Fig. 1. In the following sections, for each land use type, the management practices are evaluated according to the recommendation described in the ESAs model, based on land use intensity information. In addition, the level of policy enforcement is also assessed. Finally, the MQI (Management Quality Index) is calculated.

Land use intensity

Four main land use classes including agricultural lands (cropland), pasture lands, natural areas and mining areas were divided into nine sub-classes of land use types or geomorphological facies. After land uses were delineated, an evaluation of land use intensity was carried out. The intensity of land use of a cropland is divided into three classes based on the frequency of irrigation, degree of mechanization in cultivation practices, application of fertilizers and agrochemicals and the types of plant varieties used.

The intensity of land use of a pasture land is defined by estimating the SSR (Sustainable Stocking Rate) and the ASR (Actual Stocking Rate) for the various types of land uses under grazing.

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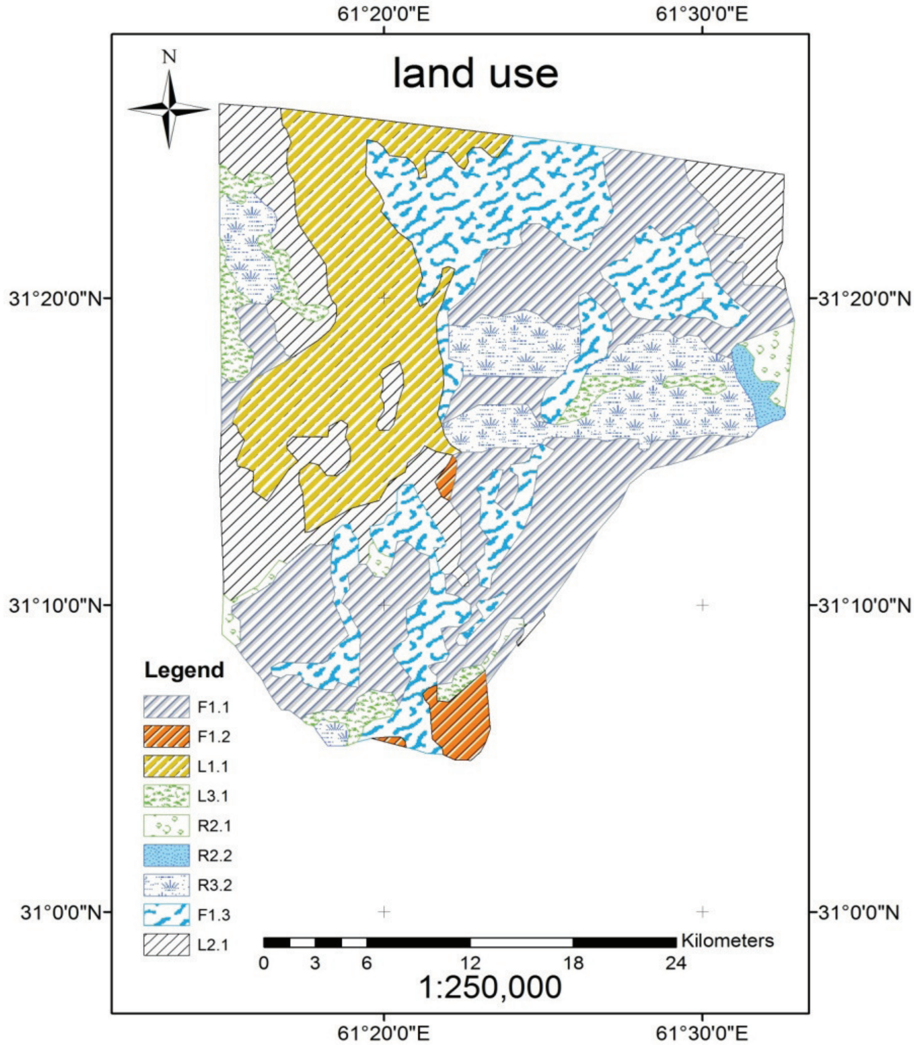

Fig. 1 Land use map based onaerial photography interpretation, satellite image classification and field surveys.

Table 4 Geomorphological facies obtained from classification of four land use classes.

Index	Geomorphological facies		Geomorphological sub-unit		Major geomorphological unit	
R2.1	Degraded farmlands	1-3-2	Covered plain	3-2	Plain	2
R2.2	Salt area with Nebka facies	2-3-2				
R3.2	Salt area with puffy surface	1-1-3	Clay plain	1-3	Playa	3
F1.1	Floodplain with low relief	2-1-3				
F1.2	Flat floodplain	3-1-3				
F1.3	Flat floodplain with *Tamarix sp.*	4-1-3				
L1.1	Saberi Lake bed plain	1-2-3	Deserts	2-3		
L2.1	Flat lands with xerophytes and halophyte spp.	2-2-3				
L3.1	Dry land with puffy surface	3-2-3				

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In natural areas such as forests, shrub land etc., the intensity of land use is defined by assessing the A (Actual) and the A/S (Actual to Sustainable) yield parameters; then the intensity of land use is classified into three classes based on the A/S ratio.

The intensity of land use for areas with mining activities is defined by evaluating the measures undertaken for soil erosion control such as terracing, vegetation cover, etc. Subsequently, the intensity of land use is classified into three classes based on the evaluated degree of land protection from erosion.

In areas undergoing active recreation such as skiing, rallies etc., the intensity of land use is evaluated by defining the A (Actual) and the A/P (Actual to Permitted) number of visitors per year, parameters; then the land use intensity is classified into three classes based on the A/P ratio.

Policy

The policies related to environmental protection are classified according to the degree in which they are enforced for each of land use. Information on the existing policies is collected and then the degree of implementation/ enforcement is evaluated. Three classes related to the policy on environmental protection are defined based on the information available in the model. The MQI is assessed as the product of land use intensity and the enforcement of policy for environmental protection using Eq. (8). Subsequently, the management quality is defined using information provided in the model. The MQI is calculated from the weighted index assigned to each parameter as follows:

$$MQI = (\text{land use intensity} \times \text{policy enforcement})^{½} \quad (8)$$

4 MATCHING THE RESULTS

The final step comprises the matching of the physio-environmental qualities (soil quality, climate quality, vegetation quality and management quality) for the definition of the various types of ESAs to desertification. The four derived indices are multiplied for the assessment of desertification in order to obtain the ESAI (ESAs Index) using Eq. (9):

$$ESAI = (SQI \times CQI \times VQI \times MQI)^{¼} \quad (9)$$

The ranges of ESAI for each type of ESA (as defined above), including the three subclasses in each type, are shown in Table 5. Each type of ESA is defined on a three-point scale, ranging from 2 (highest sensitivity) to 1 (lowest sensitivity), for better understanding and integration of the successive classes boundary limits. This methodology is then validated in the dry bed of the Hamoun wetland of Sistan plain (Iran), which will be considered as a target area for desertification studies within the framework of the EC research project (MEDALUS).

As shown in Fig. 2, the curves show some land uses classified as 'fragile' when each index is evaluated separately. The distribution of the values of sensitivity over the study region is clearly related to their general climatic characteristics and human induced stress, which plays a considerable role in desertification phenomena. Fig. 3 shows also that the majority of the study area is located in the C2 class and play a critical role in desertification process in these parts of the region.

The MEDALUS methodological framework to identify environmentally sensitive areas subject to land degradation, described in this paper, has been applied by several authors in different regions. Those research studies were frequently aimed to characterize desertification-sensitive areas under severe climate conditions due to the degree of drought. Core objectives of these studies focused on delineating (mapping) the areas sensitive to desertification or even to validate other models. Although the methodological framework was designed to be flexible enough for application to different regions and its results tested during the development of the MEDALUS EU funded project, little effort has been made subsequently into the evaluation and validation of the model results when applied to other locations. Apart from adapting the method to locally specific characteristics weighting assigned when calculating the ESA index, only very few of those studies used data gathered at field scale to validate their results (e.g. Basso *et al.*, 2000). Frequently, this validation method consisted of making a review of the values of the ESA index or the sensitivity classes obtained, and its distribution over the study areas, only based on the author's previous knowledge of the region's environmental characteristics. Especially when the environmental context of application of the model deviates from the one of the original MEDALUS participants' countries, we consider the methodological framework should imply an in-depth validation analysis, if possible, on true field data not used during the implementation of the model. Considering the difficulties of having sufficient data for validation at the regional scale, the use of public databases could be an appropriate approach.

According to the obtained results from employing the ESAs method, environmental factors are recognized as the main factor of land degradation for all the land use types of the dry bed of the Hamoun wetland region. In addition, the F1.1 land use is the most critical unit identified, with the maximum ESAI equal to 1.91, with respect to desertification classification of ESAs.

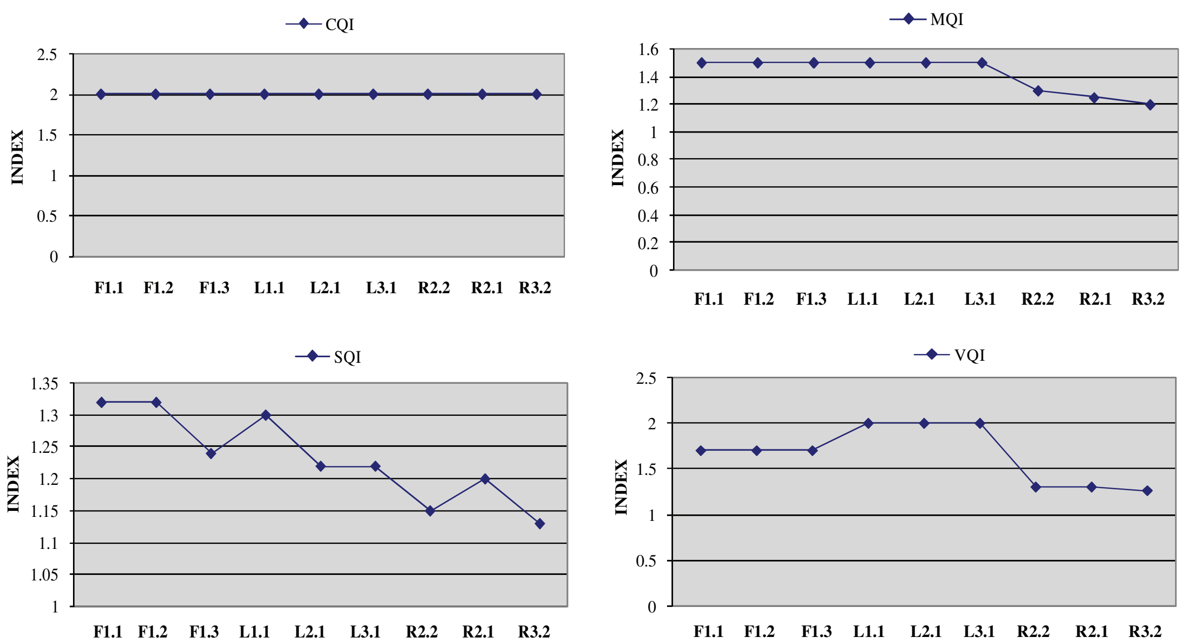

Fig. 2 Partial quality index values calculated for soil, climate, vegetation and management parameters and expressed as mean values of the main classes of sensitivity (higher values correspond to lower qualities).

Table 5 Class type and sub-type and their corresponding ESAIs limits.

Class type	Subtype	Range of ESA index	Area(ha)	Percent of area
Non-classified	N.C	–	–	–
Not affected	N.A	<1.17	–	–
Potential	P	1.17–1.22	–	–
Fragile	F1	1.23–1.26	–	–
Fragile	F2	1.27–1.32	–	–
Fragile	F3	1.33–1.37	–	–
Critical	C1	1.38–1.41	12273	14
Critical	C2	1.42–1.53	42251	48.2
Critical	C3	>1.53	33134	37.8

Finally, according to the field survey, comparison of the natural conditions of the region with expert opinion – based on a map prepared in Geographical Information System (GIS) – shows a good agreement between them. The slope factor indicated by obtaining the maximum score is one of the main factors in development of the desertification process. It is clear that flat land provides conditions for increasing the potential of desertification by allowing the acceleration of wind speed; the wind continues its path without any barrier. In addition, other soil factors including texture and lack of surface gravels and vegetation cover cause the region to be more sensitive to the desertification process.

5 CONCLUSION

Based on the data obtained from the applied methodology for defining ESAs to desertification in the Sistan plain, the various types and sub-types of ESAs can be described below in terms of land characteristics and management quality.

In Fig. 3 the map shows the distribution of sub-classes of sensitivity to degradation in the study area. The whole region belongs to the critical class of sensitivity (including three sub-classes of C_1, C_2 and C_3). Based on these results, we know that 14% of the whole region (12,273 ha) is in the low-critical class (C_1), 48.2% (42,251 ha) in the medium-critical class (C_2) and 37.8% (33,134 ha) in the high-critical class (C_3). Therefore, the medium-critical class (C_2) dominates in the study area and plays a critical role in the desertification process. The critical areas (C_1, C_2 and C_3) are very sensitive to degradation under any change to the delicate balance of climate and land use. Any change is likely to enhance reduction in biological potential with the result that this area will lose the remaining vegetative cover and be subjected to greater erosion rates.

Sub-type C_3: in sub-type C_3, the area with a very low slope (dominant slope <0.5%), silt and sandy loam textured, deep and very low drained soils formed mainly on flat floodplain, the desertification trend is more critical. Climatological conditions intensify desertification in this sub-type, because the climate is mainly characterized as semi-arid, in few cases as dry sub-humid, with rainfall around 62.84 mm, and dry bio-climatic index (Bagnouls-Gaussen aridity index – BGI – >150). The existing dominant vegetation is mainly xerophyte and halophytes species such as *Alhage camelorum, Sasola dendroides,Haloxsilon salicornicum, Tamarix stircta,Tamarix aphylla,* with very high fire risk, but with high potential to protect the soil from erosion and high drought resistance. These types of vegetation cover usually less than 10% of the surface soil in the study area. These areas are intensely used for grazing purposes and assumed as very high policy for environmental protection.

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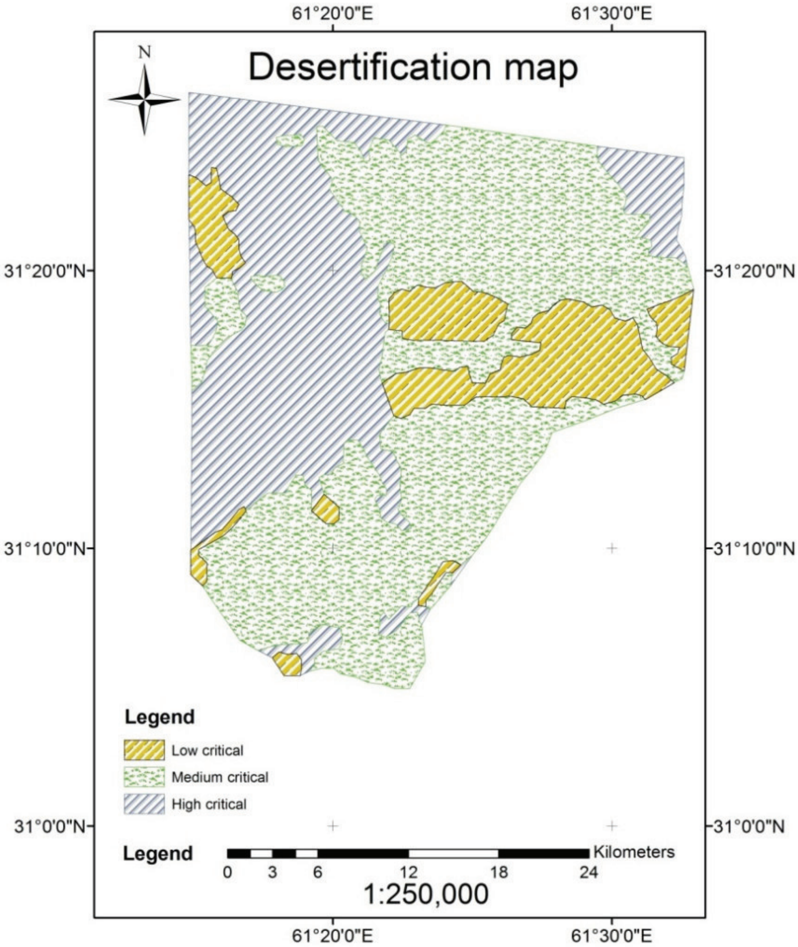

Fig. 3 A typical map of the three sensitivity classes, obtained by partitioning the ESA index.

Subtype C_2:areas with very low steepness (dominant slope<2%), loam textured, deep and very low drained soils formed mainly on cropland. The climate is mainly characterized as semi-arid, in some cases as dry sub-humid, with annual rainfall about 62.84 mm, and dry bio-climatic index BGI (greater than 150). The dominant vegetation is mainly grasses characterized by high fire risk and less subject to erosion protection, very high resistance to drought. The plant cover usually is greater than 20%, or in some cases appears to be around 20–25%. These areas are mainly under very high land use intensity and very high policy for environmental protection.

Subtype C_1: areas with very low gradient (dominant slope <3%), loam textured, deep and low drained soils formed on area of river bed. The climate is characterized mainly as dry sub-humid, in some cases as semi-arid, with rainfall around 62.84 mm, and mainly very dry bio-climatic index (BGI >150). The dominant vegetation is xerophytes and halophytes such as *Alhage camelorum,Sasola dendroides,Haloxsilon salicornicum*, having high fire risk, moderate erosion protection, high resistance to drought, and the plant cover is usually greater than 40%. These areas are mainly under moderate land use intensity and partial policy for environmental protection.

As Table 6 shows, the various types of ESAs sensitive to desertification are clearly related to the degree of soil erosion. The maps of ESAs and the degree of erosion were independently compiled.

Fig. 3 shows that the sensitivity of the various sub-types of ESAs to erosion decreases in the following order:

Critical-C_3>critical-C_2>critical-C_1

Therefore, the highest management practices are required for mitigation of desertification in environmentally sensitive areas in order to protect the soils from wind erosion. Potential ESAs to desertification may require either protection from erosion or from salinization owing to the shallow groundwater table.

According to studies conducted in this region and the results obtained, ESAs method should be applied in other climatic regions of Iran in order to determine the advantages and disadvantages of this method. By comparing the obtained results in this study with those of research projects in different parts of the world (Sepehr *et al.,* 2007 – in the south of Iran –, Zehtabian and Rafii Emem, 2003 – in the Varamin plain of Iran), it can be concluded that, unlike other methods, the ESAs method applied in this study has higher precision. The elements (input data) of this method are simpler than other methods, and the majority of data are readily available from basic studies of vegetation, climate, soil and land capability conducted by governmental organizations such as the local Natural Resources and Watershed Management Organization. On the basis of field surveys, the regions were placed in a low-critical sub-class. This implies that the desertification trend can be minimized by performing biological and mechanical measures. Otherwise, the regional situation will become more critical because of the adverse climatic conditions governing the region. As the desertification map indicates, those regions that lie in the high-critical sub-class are mostly occupied by migrated and active sand dunes. This is a critical sign of desertification in the study area. To prevent the study area from further desertification it is necessary to develop source-finding studies of sand dunes in source area, which is supposed to be the sub-type of C3, C2 and C1 using wind-breaks or reafforestation. In order to decrease the migration of sand dunes, implementation of sand stabilization projects is recommended.

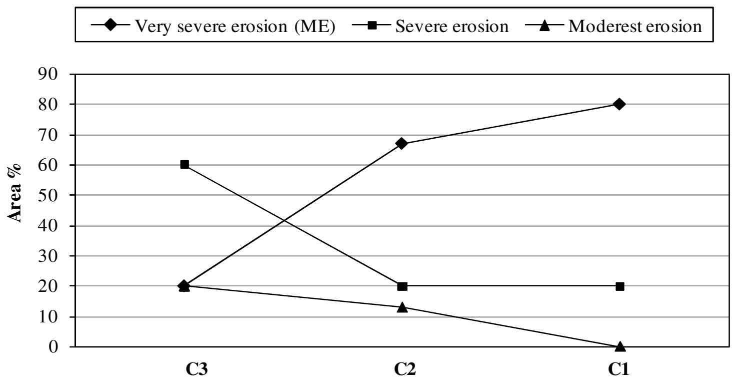

Fig. 4 The area percentage oferosion rate in different types of environmentally sensitive areas in the dry bed of the Hamoun wetland.

Table 6 The erosion distribution classes in various types of ESAs on the dry bed of the Hamoun wetland.

ESAs	No erosion (NE)	Slight erosion (WE)	Moderate erosion (ME)	Severe erosion (SE)	Very severe erosion (VSE)	Total
Critical-C3	0	0	20	58.4	21.6	100
Critical-C2	0	0	12.4	20.1	67.5	100
Critical-C1	0	0	0	20	80	100

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کاربرد روش ESAs جهت تهیه نقشه شدت بیابان‌زایی در بخشی از بستر خشک تالاب هامون (ایران)

سیّدهدایت پروری، احمد پهلوانروی، علیرضا مقدم نیا، عبدالحمید دهواری و داوود پروری

چکیده بیابان‌زایی فرایندی است که موجب تخریب و انهدام اکوسیستم‌های طبیعی گردیده و سبب کاهش تولید بیولوژیک در حد ظهور تخریب خاک می‌شود. مدل‌های چندی جهت برآورد میزان تخریب و ارزیابی شدت بیابان‌زایی ارائه شده است. در این تحقیق سعی شده تا با توجه به شرایط حاکم بر منطقه مدلی را انتخاب کنیم که با شرایط منطقه سازگار باشد. این مدل تحت عنوان MEDALUS می‌باشد. در این روش به جای میانگین حسابی از میانگین هندسی داده‌ها استفاده می‌شود. تحقیقات به عمل آمده در مناطق مختلف نشان داد که میانگین هندسی نتیجه را بهتر ارائه می‌دهد، لذا در این تحقیق سعی شده ابتدا بر اساس بازدیدهای میدانی عوامل اصلی موثر بر فرایند بیابان‌زایی شناسایی شود. این عوامل شامل: اقلیم، خاک، پوشش گیاهی، ژئومورفولوژی، فرسایش بادی، عوامل مدیریتی و سنگ شناسی می‌باشند. با توجه به نتایج به دست آمده از این تحقیق مشخص شد که از این میان عامل اقلیم، مدیریت کاربری اراضی و فرسایش بادی با کسب بیشترین میزان امتیاز به عنوان مهم‌ترین عامل پیشرفت فرایند بیابان‌زایی می‌باشند. هم‌چنین در برخی از کاربری‌های اراضی عدم وجود پوشش گیاهی باعث شده تا بادهای شدید منطقه سیستان که به عنوان معروف‌ترین بادهای ایران به حساب می‌آیند، بدون هیچ مانعی مسیر خود را پیموده و سطح زمین را مورد فرسایش قرار می‌دهد. هم‌چنین نتایج نشان می‌دهد منطقه مورد مطالعه در طبقه بیابان‌زایی بحرانی قرار دارد. با توجه به نتایج مشخص می‌شود که از کل منطقه حدوداً ۱۴ درصد، معادل ۱۲۲۷۳ هکتار در زیر طبقه بحرانی کم، ۴۸/۲ درصد، معادل ۴۲۲۵۱ هکتار در زیر طبقه بحرانی متوسط و ۳۷/۸ درصد، معادل ۳۳۱۳۴ هکتار در زیر طبقه بحرانی شدیدقرار دارد.

کلمات کلیدی: بیابانزدایی، مدل مدالوس، منطقه سیستان، فرسایش بادی

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