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A case study of desertification hazard mapping using the MEDALUS (ESAs) methodology in southwest Iran

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Abstract

Understanding environmentally sensitive areas (ESAs) prone to desertification can lead to substantial gains in the efficiency of land use planning and partly avoid negative outcomes. The main objectives of this research were the monitoring and mapping of ESAs to desertification in the agro-ecosystem of the Khanmirza plain, Iran, during two time series (2000 and 2013). In the current study, an adjusted "Mediterranean desertification and land use (MEDALUS)" approach was applied to identify the most ESAs to desertification in the study area and monitorchanges inthe environmental sensitivity area indicator (ESAI)between 2000 and 2013 over the studied area.Fivemain thematic indicators have been evaluated including, Soil quality indicator (SQI), Management quality indicator (MQI), Climate quality indicator (CQI), Vegetation quality indicator (VQI), and Irrigation water quality indicator (IWQI). Results show that the areas affected by the critical desertification status covered approximately 7% of the farmlands and the meadowlands in this agro-ecosystem region in the year 2000. Likewise, in 2013, almost 24% of the study area was sensitive to and affected by desertification, giving a rate of increase of approximately 1.3% per year.More than half of the land used for agriculture has been moderately to severely degraded. The results also show that the central places intheregionwere affected by farmlands and meadowlands degradingto barrenlands due to mismanagement and a lack ofeffective planning withland and water resources. However, rehabilitation of irreversibly degraded land requires serious measures that aim torestore the capability of those areas and increase resistance to degradation through effective planning in water and land in the region.

1. Introduction

Anthropogenic activities have increasingly exerted large-scale influence on terrestrial ecological systems over the past century, primarily through agriculture. However, the impact of such changes on vital systems like water and land resources is hugely important **[9]** and **[4]**. Severe degradation is blamed for the annual disappearance of around 5–10 million ha of agricultural land as productionsystems**[8]**. The livelihood of millions of farmers living in dry zones around the world is threatened by degradation of arable farmland. Land degradation manifests itself in many forms; among them are soil erosion, increased sediment loading from bodies of water, loss of soil fertility, salinity, reduced ground cover, and the reduced carrying capacity of pastures. Consequently, desertification involves a complex set of factors **[3]**. The desertification phenomenon is the result of natural and anthropogenic processes, leading todegradation or loss of the land's productivity and complexity **[22]**. It is closely related to many environmental factors such as climate, soil, vegetation cover and natural resource management, all of which contribute to the evolution and characterization of different degradation levels **[2]**, **[19]**, **[20]**, and **[25]**. For instance, Sepehr et al. **[21]** found thatthe resilience of ecosystems to desertification issignificantly correlated to the inherent properties of that ecosystem. They also showed that the degree of an ecosystem's vulnerability to desertification is related to erodibility and erosivity potential and vegetation cover. Moreover, 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**[17]** and **[20]**.

Some researchers have presented several methods for evaluating the desertification process such as mathematical models, parametric equations, remote sensing, direct observation and measurement **[5]**, **[7]**, **[8]**,**[12]**, **[13]**, and **[16]**. However, some models, such as the standard "Mediterranean desertification and land use (MEDALUS)",arehighly flexible and allow updates according to local conditions and the availability of information **[6]** and **[10]**. The standard MEDALUS approach proposed by Kosmas et al. **[11]** identifies regions that are environmentally sensitive areas (ESAs). In general, the MEDALUS approach focuses on recognizing ESAs through multi-factor approaches. Recently, Bakr et al. **[1]** used this model by adding a new parameter, the irrigation water quality indicator (IWQI), and creating a new and up-to-date approach named the "adjusted MEDALUS" model. This approach assesses the main parameters affecting desertification processes and mainly calculates desertification hazards based on the scores considered for parameters affecting desertification. However, this model is fully flexible to variations of the local status of natural and social conditions in order to explain details of the study area with greater reliability.

Due to the absence of reliable water resources, groundwater is the primary source of water supplyfor agricultural purposes in the Khanmirza agricultural plain in southwest Iran **[23]**. In recent years, excessive groundwater has been pumped to satisfy increasing water demands. Likewise, degradation poses a serious threat to land and water sustainability and local people's livelihoods. Groundwater resources in most shallow depressions have been completely withdrawn, consequently leaving severely salinized land behind which has led to severe degradation in this region. The emphasis of this study is on a dynamic system that reveals changes of desertification over 13 years (2000 to 2013). The specific objective was to identify ESAs to desertification in the study area using the adjusted MEDALUS method.

2. Description of the Study Area

The Khanmirza agricultural plain covers around 260 Km^2 and is located between 3474000 and 3501000latitude north and 498000 and 519000longitude east in the central mountainous region of Zagros-Iran (**Figure 1**). Based on synoptic weather station records, the annual average precipitation for this plain is 587 mm, 90% of which occurs between December and April **[14]**. In terms of climate quality status, the watershed is governed by the moderate Mediterranean climate and mainly covered by agricultural lands in the upstream of the north basin of the Karoon River **[15]**. The region is located in the central Zagros Mountains, a region of complex geography located at the intersection of large-scale atmospheric circulations **[26]**. This region is an agriculture and habitant pole of the Chaharmahal-Bakhtiari province and is faced with an extensive decrease in water level as well as a decrease in the quality of its groundwater**[24]**. During recent decades, the number of active wells has increased rapidly, for example, in 1987, there were approximately 300 wells in this plain; in 2013, there were more than 1000 tube wells, meaning around a three-fold increase over the past 26 years. The number of agricultural wells and the groundwater overdraft in the Khanmirza Plain has added to the excessive pressure on its confined aquifer, which has led to a reduction in land quality and consequently, has adversely affected the environment in such ways as increased levels of salt in groundwater resources and agricultural lands **[23]**. Hence, the study area faces land degradation and desertification due to both disregardfor potential land sensitivity and irrational exploitation of groundwater resources.

3. Materials and Methods

The MEDALUS method identifies regions that are environmentally sensitive areas. In particular, withthe adjusted MEDALUS approach different types of ESAs to desertification can be analyzed in terms of various parameters such as morphology, soil quality, geology, vegetation cover, climate, water quality, and human activities[1] and **[18]**. As shown in **Table 1** and **Table 2**, 20 data layers were considered for each period (2000 and 2013) in the current study and each of these parameters was grouped into various uniform classes and a weighting factor was assigned to each class. The main five the matic indicators were then evaluated, including the Soil quality indicator

(SQI), Management quality indicator (MQI), Climate quality indicator (CQI), Vegetation quality indicator (VQI), and Irrigation water quality indicator (IWQI). After determining all the layers (40 maps in the two periods) of each the matic indicator, the ESAs to desertification were defined by combining the five quality layers.

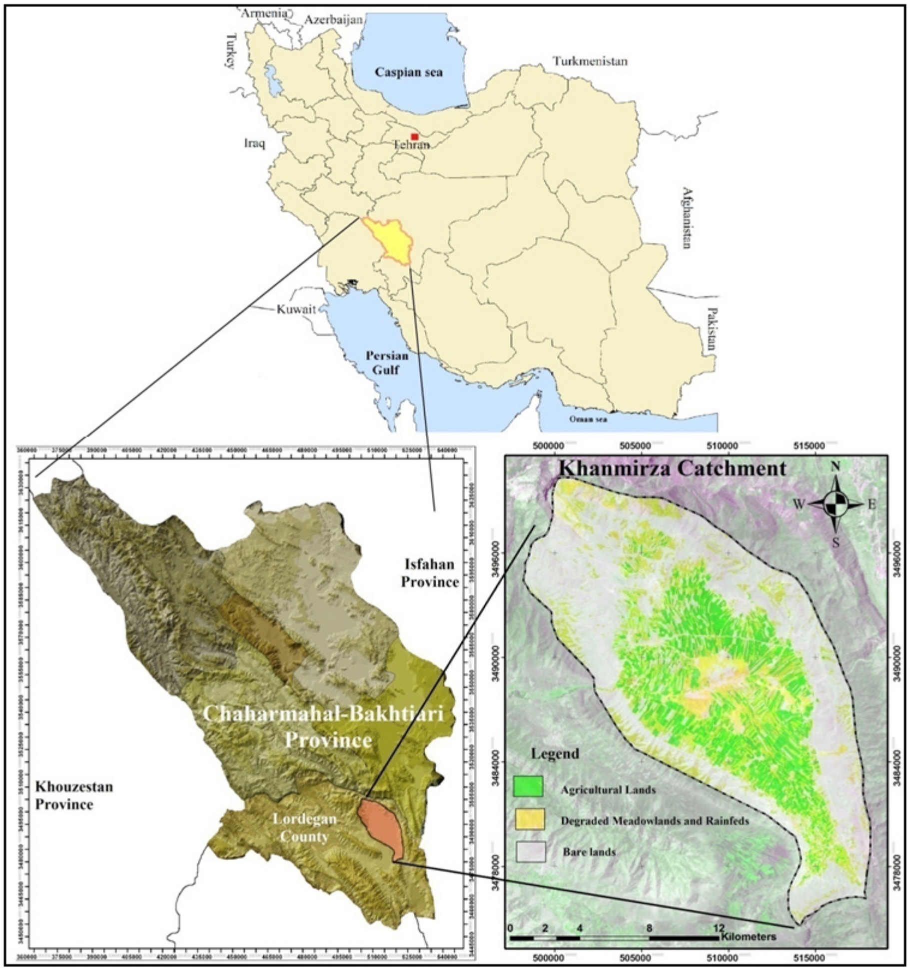

Figure 1: Location of the Khanmirza plain in Chaharmahal-Bakhtiari province in southwest Iran

The main indicators affecting the desertification process along with classes and the corresponding weights assigned for the agro-ecosystem of the Khanmirza plain are shown in **Table 1** and **Table 2**. All quality indicators with values ranging from "1 = best" to "2 = worst" have been applied throughout the model for individual indices as well as the final classification of the ESAIs. All data defining the five main layers are overlain in accordance with the algorithm developed for this purpose, which takes the geometric mean of the different weights of each individual parameter to compile maps of ESAs to desertification. All indicators were calculated as follows:

$$MQI = (\text{land use intensity} \times \text{policy enforcement})^{1/2}$$

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

$$CQI = (\text{rainfall} \times \text{aridity} \times \text{aspect})^{1/3}$$

$$IWQI = (ECw \times SAR \times Cl)^{1/3}$$

This approach is highly flexible and allows us to update data according to local conditions and the availability of information **[6]** and **[20]**. In this region, the sharp decline in groundwater levels led to land subsidence over the entire study area. Accordingly, as an important parameter in the study the area land subsidence layer was introduced to the SQI in the adjusted MEDALUS approach and calculated as:

$$SQI = (\text{rock fragment} \times \text{slope} \times \text{soil depth} \times \text{drainage status} \times \text{land subsidence} \times OM \times ECs \times pH)^{1/8}$$

Ultimately, the ESAI for the adjusted MEDALUS approach was calculated as:

$$ESAI = (SQI \times CQI \times IWQI \times VQI \times MQI)^{1/5}$$

Table 1: The main indicators affecting the desertification process along with classes and the corresponding weights assigned.

Index	Parameters	Class	Description	Weight	Data source
	Land use intensity	1	Low	1	Land use map
		2	Medium	1.5	
		3	High	2	
MQI		1	High degree of protection policies	1	Field study, land use map
	Policy	2	Moderate degree of protection policies	1.5	
		3	Low degree of protection policies	2	
		1	Gardens and orchards, evergreen rangelands	1	
	Erosion protection	2	Permanent grasslands and rangelands	1.4	Field observation, Land cover map
		3	Annual agricultural crops, cereals and annual grasslands	1.7	
		4	Bare land	2	
		1	>35%	1	
	Plant cover	2	10-35%	1.5	Land cover map
VQI		3	<10%	2	
		1	Bare land	1	
	Fire risk	2	Annual agricultural crops, cereals and annual grasslands	1.5	Field observation, Land cover map
		3	Gardens and orchards, evergreen rangelands	2	
		1	Gardens and orchards, evergreen rangelands	1	
	Drought resistance	2	Permanent grasslands and rangelands	1.4	Field observation, Land cover map
		3	Annual agricultural crops and annual grasslands	1..7	
		4	Bare land	2	
		1	NW-NE	1	Aspect map
		2	SW-SE	2	
	Aspect	1	AI>=1	1	
CQI		2	0.1<AI<1	1.5	
	Aridity	3	AI=<0.1	2	
		1	>600	1	
	Rainfall (mm)	2	300-600	1.5	
		3	<300	2	

Table 2: Adjusted SQI indicator along with parameters and the corresponding weights assigned

Index	Parameters	Class	Description	Weight	Data source
		1	<6	1	Slope map
	Slope (%)	2	Jun-18	1.4	
		3	18-35	1.7	
		4	>35	2	
		1	>60	1	
	Rock fragment (%)	2	60-20	1.5	Field observation
		3	<20	2	
		1	>75	1	
	Soil depth (cm)	2	30-75	1.4	Soil map
		3	15-30	1.7	
		4	<15	2	
		1	Well drained	1	
	Drainage status	2	Imperfectly drained	1.5	Field observation
		3	Poorly drained	2	
		1	Non-subsidence	1	
	Land subsidence	2	Low subsidence	1.5	Geomorphology map, Field observation
SQI		3	High subsidence	2	
		1	>3	1	
		2	2-Mar	1.2	
	Organic Matter (OM)	3	1-Feb	1.5	
		4	0.5-1	1.7	Lab analysis
		5	<0.5	2	
		1	<5	1	
	Electrical Conductivity soil (dS m^{-1})	2	May-16	1.2	
		3	16-34	1.5	Lab analysis
		4	34-64	1.7	
		5	>64	2	
	pH	1	<5.5	1	
		2	5.5-6.5	1.2	Lab analysis
		3	6.5-7.5	1.5	
		4	7.5-8.4	1.7	
		5	>8.4	2	

4. Results

Figure 2 shows the quality values and the distribution pattern of different indicators using the adjusted MEDALUS approach over the study area for 2000 and 2013. Generally, MQI refers to the quality of land management and planning by government agencies in collaboration with the local people. In the year 2000, the MQI results show that ~70% and ~20% of the Khanmirza plain was classified as high and low quality, respectively (**Table 3**). Furthermore, areas of high quality (37.53%) and areas affected by severe deterioration of management quality (27.28%) were mainly located in the north and central part of the region (**Figure 2**a and **Table 3**). In other words, almost 1374 ha (5.3%) of the total study area was highly sensitive to degradation in accordance with MQI in 2013.

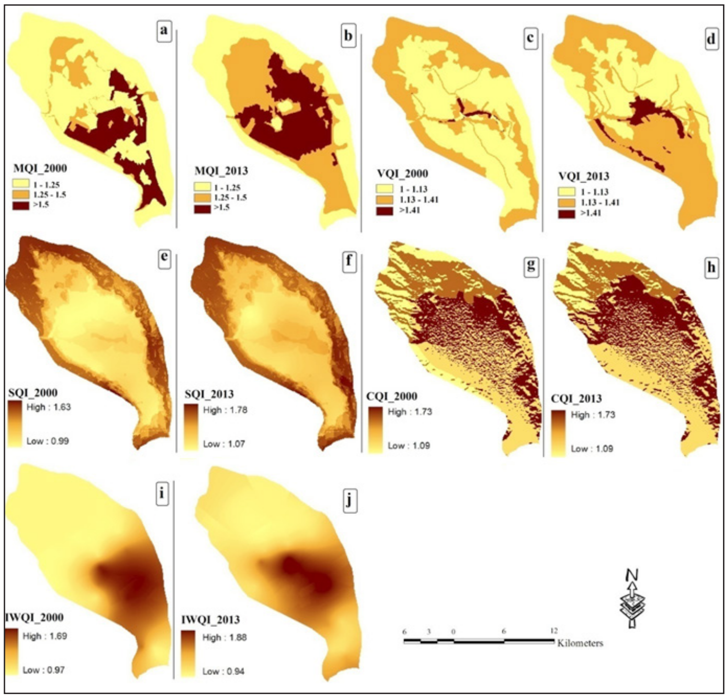

Figure 2: The spatial patterns of various quality indices for sensitivity areas to desertification

The VQI maps reveal that the central districts of the study area fall into the critical class in the year 2013 (**Figure 2**d). According to **Table 3**, a considerable decline has occurred in the high classified area for VQI by about 5000 ha in 2013 compared with 2000. In this plain, the suspended sediment loads in the seasonal waterways were the result of processes of soil erosion and transport processes within the drainage basin areaforthe period in question. Likewise, severe depletion of groundwater has increased bare lands within most agriculture fields throughout the study area. Hence, SQIs are most marked with the confluence of bare lands and farmlands with a more than 15% slope in the marginal areas of the district in the years 2000 and 2013 (**Figure 2**e & f). However, the negative effects on soil quality led to soil loss by water and wind erosion and deterioration of physical and chemical properties of the soil in the region.

Table 3: The area coverage per quality indicatorfor the study area according to the adjusted MEDALUS approach

	Classification		2000		2013	
	Quality class	Ranging	ha	%	ha	%
MQI	High	1-1.25	18076.02	70.07	9680.99	37.53
	Moderate	1.25-1.5	2764.17	10.71	9077.48	35.19
	Low	>1.5	4954.76	19.20	7036.49	27.28
VQI	High	1-1.13	14885.94	57.70	9849.05	38.18
	Moderate	1.13-1.41	10621.26	41.17	14554.27	56.42
	Low	>1.41	254.64	0.98	1378.26	5.34
SQI	High	<1.13	8727.34	33.83	247.64	0.96
	Moderate	1.13-1.45	10360.26	40.16	13046.13	50.57
	Low	>1.45	4800.70	18.61	10594.53	41.07
CQI	High	<1.15	3770.66	14.61	2466.24	9.56
	Moderate	1.15-1.81	21965.09	85.15	23269.51	90.21
	Low	>1.81	-	-	-	-
IWQI	High	<1	11099.36	43.02	3982.66	15.44
	Moderate	1-1.41	7825.26	30.33	13803.06	53.51
	Low	>1	6870.34	26.63	8009.24	31.05

The results indicate an approximately two-fold decrease in soil quality from 4800 ha in 2000 to 10594 ha in 2013 (**Table 3**). From a water quality point-of-view, irrigation water quality is highest in the disturbed agro-ecosystem and is affected by agricultural activities. According to **Figure 2**i & j, the areas with high sensitivity are mostly centralized in the southeast and the central parts of the region. The exploitation of groundwater resources with high salinity for agricultural purposes for the long yearsled to the accumulation of salt content in the ground, reducing osmotic potential and soil fertility. According to **Table 3**, the water quality index dramatically decreased in 2013 compared with 2000 by 15.44 and 43.02 %, respectively. It seems the extreme land use sensitivity coupled with fluctuation in ground water resources resolved into an irreversible process of environmental degradation (desertification phenomenon) in the region.

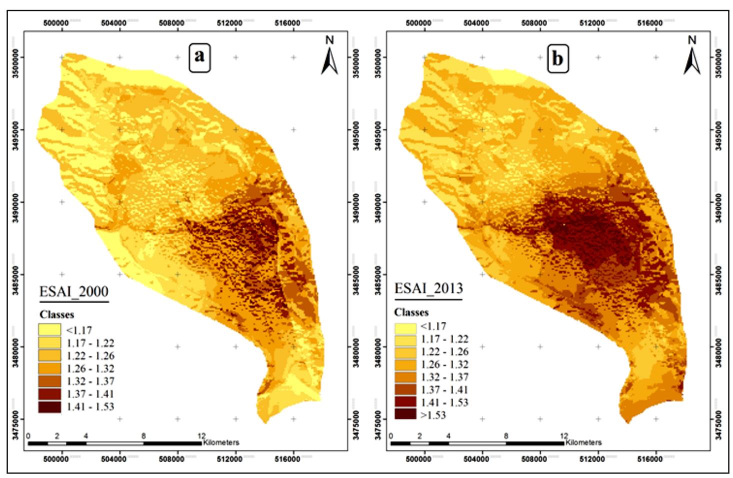

Figure 3: ESAI maps in the Khanmirza plain in 2000 and 2013.

The spatial distribution of ESAIs over the study area using the adjusted MEDALUS approach are displayed in **Figure 3**a & b.The final quality classifications of ESAs to desertification based on the adjusted MEDALUS approach in the study are presented in **Table 4**. As can be seen in these Figures, a remarkable deterioration of the environmental conditions in terms of vulnerability to desertification affected the agro-ecosystem of the Khanmirza plain inthe past 13 years. The results indicate that sensitivity to desertification in the year

2013 is higher than 2000, especially in the southern, southwestern, and central parts of the Khanmirza plain. In the year 2000, the ESAI was 58% and 7% in the region and were classified as fragile and critical ESAs, respectively (**Table 4**). According to **Table 4**, a relative decline by 63% in fragile areas and a considerable increase of approximately 24% have been seen in critical cases of the ESAs to desertification in 2013, givinga rate of increase of approximately 1.3 % per year.

Table 4: The quality classes of ESAs to desertification according to the adjusted MEDALUS approach in the Khanmirza agricultural plain.

Classification		2000		2013	
Quality class	**Ranging**	**ha**	**%**	**ha**	**%**
Non-affected	<1.17	4603.87	17.98	687.75	2.68
Potential	1.17-1.22	4222.77	16.49	2757.13	10.77
Low fragile	1.22-1.26	7648.52	29.88	4034.95	15.76
Moderate fragile	1.26-1.32	5140.68	20.08	7511.25	29.34
High fragile	1.32-1.37	2199.83	8.59	4476.83	17.48
Low critical	1.37-1.41	1096.84	4.28	2345.98	9.16
Moderate critical	1.41-1.53	682.96	2.66	3119.10	12.18
High critical	>1.53	-	-	668.62	2.61

Similarly, desertification of such lands stems from the mutual interaction between the vulnerable natural settings and anthropogenic activities. Consequently, wide areas of the region have in fact suffered negative impacts, including a sharp decline ingroundwater resources, land subsidence, and severe fragmentation of the agricultural landscape. It is clearly understandable that the current land and groundwater planning should thus be reinforced and focused on the introduction of measures to prevent and reduce land degradation in this sensitive region to desertification.

5. Conclusions

The emphasis of this study was on the dynamic investigation of environmental sensitive areas (ESAs) to desertification using the adjusted MEDALUS approach in the agro-ecosystem of the Khanmirza plain. However, outputs of the spatial patterns of quality indices such as WQI, VQI, SQI, CQI and IWQI were generated via various layers related to human and natural factors to create the final ESAI maps for the years 2000 and 2013.The adjusted MEDALUS approach reveals that the sensitivity areas to desertification within a critical status occupied only approximately 7% of the entire area in the year 2000, while an increasing trend leads to the land critical to desertification covering 24% of the region in 2013. As a result, a noticeable amount of farmland and meadowland have been degraded during the period of this study. It should be noted that the ESAI maps generated using the adjusted MEDALUS in this region depict the past and current status of desertification not the desertification potential.

Previous studies illustrate the complex relationships existing between representative naturaland human variables to land degradation **[17]**,**[18]**, and **[19]**. Authors have carried out an extensive study to identify which indicators would be most important to the desertification process in the region. Our field observations along with GPS sampling show that the findings of the adjusted MEDALUS are matched by the real conditions in the region. In spite of the wide field studies and the previous literature review, we compared our results with Taghipour et al. **[14]** and Motiee et al. **[23]** who conducted their research in the same region. They classified TM images using remote sensing techniques and depicted the central parts of the region affected by severe land use changes (irrigation land converted to bare lands) in their research. Our results have also shown that the areas affected by desertification were mainly in the central parts of the study area. In agreement with Bakr et al. **[1]**, the distribution of ESAI is closely related with the relationship between the parameters that were used to build the index. The IWQI and the parameters that were added to the SQI play an important role in increasing the sensitivity to desertification, especially in the central parts of the region. Thus, applying integrated irrigation management and enhancing irrigated land management will greatly combat the desertification process. Various layers containing either the static conditions (e.g. soil, climate, geology variables) or the dynamic factors (e.g. land cover and irrigation quality variables) have been used in the current research, allowing us to find the real status of desertification and land degradation in the region. However, the rate of spread of desertification should be restrained using effective land use planning and appropriate policies in the management of agricultural water resources in the Khanmirza plain to combat desertification.

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