

Quantitative mapping of desertification risk using the modified MEDALUS model: a case study in the Mazayejan Plain, Southwest Iran

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ABSTRACT

This paper presents the Modified MEDALUS (MMEDALUS) approach, a quantitative assessment of desertification, in the case study area located in the Southern part of Iran. Six main factors of desertification including: soil, climate, plant cover, management, erosion state and ground water situation were considered for the model approach. Then several sub-factors determining the quality of each main factor were quantified according to their quality and weighted on a scale between 1.0 and 2.0. We used a Geographic Information System (GIS) software to analyze and prepare the spatial distribution of the factor layers. Subsequently, the final desertification hazard map was prepared by combining the different MEDALUS factors in Arc GIS 10.3 in order to define the final hazard classes on the basis of hazard scores based on the geometric mean of the main factors. The MEDALUS and MMEDALUS models show the “Desertification Potential” that in turn was validated with the current state of desertification observed in the field. The results show that the applied MMEDALUS approach yield significantly better results than the MEDALUS model in the study area. The results also show that the areas under severe and very severe hazard are the most extensive classes in the desertification map. Thus, we illustrate that most of the study area is sensitive to desertification. However, we highlight that management, climate and water table qualities were the most important indicators affecting the desertification processes, while soil quality seems to play a minor role in our study area.

KEYWORDS

desertification; assessment; MEDALUS; MMEDALUS

Received: 28 August 2019

Accepted: 21 September 2019

Published online: 20 December 2019

Zakerinejad, R., Masoudi, M. (2019): Quantitative mapping of desertification risk using the modified MEDALUS model: a case study in the Mazayejan Plain, Southwest Iran. *AUC Geographica* 54(2), 232–239
<https://doi.org/10.14712/23361980.2019.20>

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1. Introduction

Land degradation is a significant global environmental and socioeconomic problem (Taddese 2001; Miao et al. 2015). Drylands (arid, semi-arid, and dry sub-humid areas) cover approximately 40% of the Earth's surface (Deichmann et al. 2018) that are more sensitive to degradation (Zakerinejad et al. 2018). Desertification refers to land degradation caused by climate change and human activity in arid, semi-arid, and dry sub-humid areas (UNCCD 2014). In the early 1990s, desertification was defined as 'land degradation resulting from various factors, including climatic variations and human activities' (UNEP 1992). It is a prolonged type of land degradation which in space and time converts the productive ecosystem to a fragile one by two crucial factors, namely, climate and negative human activity. (Shoba, Ramakrishnan 2016). The character and intensity of desertification is closely related to environmental factors such as climate, soil characteristics, vegetation cover, and morphology. Desertification is also strongly linked to socio-economic factors, since human's behavior and their social and economic actions can greatly influence the evolution of numerous environmental characteristics. The United Nations Environmental Program (UNEP) estimates that 69% of the world's arid lands, excluding the very arid deserts, are under moderate to severe hazard of land degradation (Dregne 1991). This type of land degradation seriously threatens agriculture, natural resources and the environment (Lal 1998; Yang et al. 2003; Feng et al. 2010; Fleskens, Stringer 2014; Zakerinejad et al. 2018). Especially areas with arid and semi-arid climates are affected due to a lack of financial resources to cope with and mitigate the effects of soil erosion and desertification (Zakerinejad, Märker 2014; Zakerinejad, Märker 2015; Masoudi, Jokar 2017). Desertification was recognized as a severe problem already between the 1930s and 1960s in Iran. Iran having an arid to semi-arid climate with low precipitation and high evaporation rates compared to world averages shows a high vulnerability to land degradation and desertification. In the last decades over 20 per cent of the country is exposed to desertification. It has detrimental impacts on agricultural productivity and on ecological function (Zehtabian, Jafari 2002; Eliasson et al. 2003; Amiraslani, Dragovich 2009; Pan and Li 2013).

Recently, several methods of desertification and land degradation assessment have been applied. The FAO/UNEP (1984) introduces the "Provisional Methodology for Assessment and Mapping of Desertification Hazard" which evaluates the main factors affecting desertification processes. This method was the first major approach that was developed to assess land degradation in arid and semi-arid regions. Some other important models are Global Assessment of Soil Degradation – GLASSOD (Oldeman et al. 1991),

Assessment of Soil Degradation – ASSOD (Van Lynden, Oldeman 1997) and LADA (Ponce Hernandez, Koohafkan 2004). Another model specifically developed for the Iranian conditions is the Iranian Model of Desertification Potential Assessment (IMDPA) proposed by the Iranian Forests and Rangeland Organization (Ahmadi 2007; Masoudi, Zakerinejad 2010). 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. In total 35 indicators are used by the model (Masoudi, Zakerinejad 2011). An alternative model especially developed and applied in several parts of the Mediterranean is the MEDALUS (Kosmas et al. 1999) which identifies regions that are environmentally sensitive to desertification processes. The model evaluates the main quality layers (factors) including soil, climate, vegetation, and management. After assessing these factors or quality layers, the Environmental Sensitivity Index (ESI) is defined by combining the four quality layers. ESI is a composite indicator that can be used to get insights into the factors causing desertification risk at a certain point in the landscape. Since the model was often applied in Mediterranean regions it is also appropriate to be applied in the Iranian conditions (arid and semiarid regions). So, all the data considering the MEDALUS (Modified MEDALUS) layers were prepared in a geographical information system (GIS), and overlay in accordance with the developed algorithm which took the geometric mean to compile maps of desertification intensity.

The main aim of this study is the assessment of the most important factors affecting desertification in the study area using the MMEDALUS model. Moreover, we compare the MMEDALUS model with the original model (MEDALUS) and evaluate both with the current state of desertification observed in the field. For this purpose, the Mazayejan (MZY) plain, located in Southern part of Iran, for which enough data were available has been chosen.

2. Materials and methods

2.1 Study area

The study area is located in the MZY plain, in the Fars province in the Southern parts of Iran (54°34' to 54°44' E and 27°59' to 28°5' N). The study area shown in Figure 1 is part of the Zagros Mountains. The Zagros mountain range from the north-west along the west to south-eastern parts of Iran. Its highest peak reaching nearly 5000 meters. The study area covers an ca 20,000 ha and is drained by the MZY river. According to the national topography map (1 : 25,000; Iranian Cartographic Center 1994) the elevation is ranging from 693 m a.s.l. to a maximum

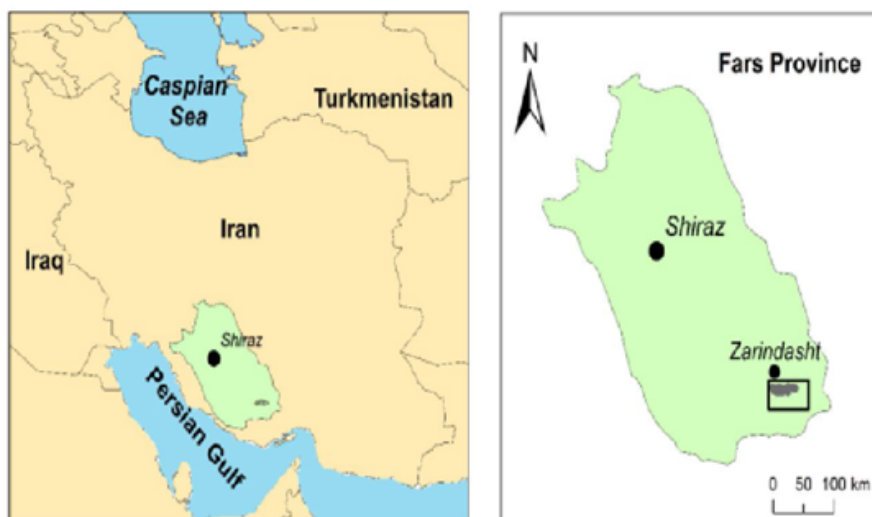


Fig. 1 Study area: MZY plain in Fars province Southwestern Iran.

altitude of 1,371 m a.s.l. The annual average rainfall is around 243 mm with a high inter-annual variability characterized by very dry summer months (June to September), followed by short period of heavy rainfall from December till March. Soil erosion as one of the most important types of land degradation and desertification is occurring frequently especially in the pediments of the mountain ranges of this area (Zakerinejad, Märker 2014; Zakerinejad, Märker 2015).

2.2 Methodology

Desertification is a complex phenomenon that leads to the reduction of land productivity (Sephehr et al. 2007). In order to assess the degree of desertification we applied the MEDALUS and MMEDALUS models. The key indicators of the MEDALUS model allow to identify the Environmental Sensitivity Areas (ESA). Generally, ESAs represent areas whose socio-economic and

ecological aspects are not sustainable for a particular landuse (Basso et al. 2004).

The data for this study such as the information on soils, climate and vegetation cover were collected in the field, from maps and from data available in the related reports published by the different departments of the Ministries of Jahade-Agriculture as well as by the Meteorological Organization of Iran. The MMEDALUS model is differing from the MEDALUS model since it considers two more factors, namely, the soil erosion state and the ground water situation (Table 1). Moreover, information about the organic matter, soil EC and evapotranspiration were integrated in the model. Furthermore, we adapted rainfall and their hazard scores for specific soil depth as shown in Table 1. Based on this method, 20 entities were identified in the study area. Each entity was considered as an individual study unit and the assessment of desertification was conducted for all of them.

Tab. 1 Classes and assigned weighing indices for the various parameters used for the assessment of soil quality (a), climate quality (b), vegetation quality (c), land management quality (d), erosion state quality (e), ground water state quality (f).

a. Soil quality index in the model

Slope (%)		Drainage		Soil Depth(cm)		EC (mmhos/cm)	
Description	Index	Description	Index	Description	Index	Description	Index
<6	1	well drained	1	>75	1	4>	1
6-18	1.2	imperfectly drained	1.2	75-30	1.2	4-8	1.2
18-35	1.5	Poorly drained	2	15-30	1.6	8-16	1.4
>35	2			<15	2	16-32	1.6
						32-64	1.8
						>64	2
Texture			Organic matter (%)			Stone fragment cover (%)	
Description	Index	Description	Index	Description	Index	Description	Index
L, SCL, SL	1	>3	1	>60	1		
LS, CL		2-3	1.2				
SC, SiL, SiCL	1.2	0.5-1	1.7	20-60	1.3		
Si, C, SiC	1.6	<0.5	2	<20	2		
S			2				

b. Climate quality index in the model

Rainfall (mm)		Aridity index (P/ETp)		Evapotranspiration (mm)	
Description	Index	Description	Index	Description	Index
>300	1	$AI \geq 1$	1	<1500	1
150–300	1.5	$0.1 < AI < 1$	1.5	1500–2000	1.5
<150	2	$AI \leq 0.1$	2	>2000	2

c. Vegetation quality index in the model

Fire risk		Erosion protection		Drought resistance		Plant cover	
Type of vegetation	Index	Vegetation types	Index	Types of vegetation	Index	Plant cover (%)	Index
bare land	1	gardens, evergreen rangelands	1	gardens, evergreen rangelands	1	>35	1
annual agricultural crops, cereals, grassland, shrubland	1.5	rangelands, permanent grasslands	1.3	rangelands, permanent grasslands	1.3	10–35	1
gardens, evergreen rangelands	2	annual agricultural crops, cereals, annual grasslands	1.6	annual agricultural crops, cereals, annual grasslands	1.6	<10	2
		bare land	2	bare land		2	

d. Management quality index in the model

Land use		Policy enforcement		Livestock pressure	
Type	Index	Degree of enforcement	Index	Livestock pressure	Index
agriculture lands	1	Complete: >75% of the area under protection	1	<1	1
good to moderate rangelands	1.3	Partial: 25–75% of the area under protection	1.5	1–2.5	1.5
poor rangelands	1.6	Incomplete: <25% of the area under protection	2	>2.5	2
bare land	2				

e. Erosion state quality index in the model

Water erosion		Wind erosion	
Description	Index	Description	Index
very low	1	very low	1
low	1.2	low	1.2
moderate	1.5	moderate	1.5
severe	1.7	severe	1.7
very severe	2	very severe	2

f. Ground water state quality index in the model

EC (mmhos/cm)		CL (mg/l)		SAR		Water Table Depth (cm)	
Description	Index	Description	Index	Description	Index	Description	Index
250>	1	250>	1	10	1	315>	1
250–750	1.2	250–500	1.2	10–18	1.3	285–315	1.5
750–2250	1.5	500–1500	1.5	18–26	1.6	285>	2
2250–5000	1.7	1500–3000	1.7	26	2		
5000<	2	3000<	2				

The MMEDALUS procedure in the first stage is based on six quality indicators (climate, soil, vegetation cover, management, erosion state and ground water situation). These six major layers were derived from the sub-indicator layers that reflect individual conditions attributed to a specific value according to Table 1. Subsequently, the six quality layers were combined to give a single desertification sensitivity layer (Environmentally Sensitive Index-ESI). Table 1 shows the indicators selected and the values attributed. These quality layer were then used in the GIS procedure to assess the final desertification intensity. A quantitative classification with values between 1.0 and 2.0 was used throughout the model for the indicators as well as for the final classification of desertification intensities. Value “1” was considered to areas of minor sensitivity, and value “2” was considered in areas with the major sensitivity. Values between 1 and 2 reflect a relative vulnerability.

The different quality layers are assessed using the following equations based on geometric means to integrate the individual sub-indicator maps.

$$\text{Soil Quality Index (SQI)} = (\text{texture} \times \text{electrical conductivity} \times \text{rock fragment} \times \text{depth} \times \text{slope} \times \text{drainage} \times \text{organic matter})^{1/7}$$

$$\text{Climate Quality Index (CQI)} = (\text{rainfall} \times \text{aridity} \times \text{evapotranspiration})^{1/3}$$

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

$$\text{Management Quality Index (MQI)} = (\text{land use} \times \text{policy enforcement} \times \text{livestock pressure})^{1/3}$$

$$\text{Erosion state Quality Index (EQI)} = (\text{water erosion} \times \text{wind erosion})^{1/2}$$

$$\text{Ground Water state Quality Index (WQI)} = (\text{CL} \times \text{EC} \times \text{SAR} \times \text{water table depth})^{1/4}$$

2.3 Description of ESI to desertification

Based on the data obtained from the applied methodology for defining the ESI map to assess desertification intensities in the MZJ plain, the various types and subtypes of ESI can be described as following in terms of land characteristics and management quality. According to their value, each of the six quality indices (MMEDALUS) were classified as high, moderate or low as shown in Tables 2. Finally, all six quality indices were combined to calculate a single index of desertification severity using the following equation:

$$\text{Final Equation} = (\text{SQI} \times \text{CQI} \times \text{VQI} \times \text{MQI} \times \text{EQI} \times \text{WQI})^{1/6}$$

The ranges of desertification intensity (ESI), for the four classes is illustrated in Table 3.

Tab. 2 Classification of six quality criteria used in the MMEDALUS Model and also the percent areas which belong to each class.

Kind of quality criteria	Class	Kind of quality	Range	Area (%)
Soil	1	High	<1.13	0
	2	Moderate	1.13 to 1.45	89.87
	3	Low	>1.45	10.13
Climate	1	High	<1.5	0
	2	Moderate	1.5	0
	3	Low	>1.5	100
Vegetation	1	High	1 to 1.13	0
	2	Moderate	1.13 to 1.38	0
	3	Low	1.38<	100
Management	1	High	1 to 1.25	0
	2	Moderate	1.26 to 1.50	19
	3	Low	>1.50	81
Erosion	1	High	1 to 1.25	43.68
	2	Moderate	1.26 to 1.50	34.72
	3	Low	>1.50	21.6
Ground Water	1	High	1.2>	0
	2	Moderate	1.–1.38	48.06
	3	Low	>1.38	51.94

Tab. 3 Classes of desertification intensity and corresponding range of indices (Sepehr et al. 2007).

Qualitative classes	Low	Moderate	Severe	Very severe
Quantitative classes	1–1.22	1.23–1.37	1.38–1.53	1.54–2

Note: In this research MEDALUS method (Masoudi and Zakerinejad 2010) was done based on its characteristics, too.

2.4 Testing the Models

In order to evaluate quantitatively the accuracy of the obtained maps (MEDALUS and MMEDALUS), the maps were compared to observed desertification intensities in the field (ground truth). The ground truth map was prepared based on agricultural production conditions. In this research we prepare the map of current state of desertification mapped based on the ratio between current production to potential production (FAO/UNEP 1984). A low ratio values reflect increasing desertification intensity. Finally the spatial distribution of the productivity ratio was compared to the MEDALUS and MMEDALUS results.

3. Results and discussions

We applied the two model approaches as described above to derive the spatial distribution of the desertification intensities. As shown in Table 2, most of the study area has moderate quality soils (89.87% of the area) in terms of desertification risk followed by low quality soils (10.13%). High quality soils were not documented in the area. Moreover, the majority of this area is characterized by low climate quality (100% of the area). This is mainly due to the relative low amount of precipitation occurring in the area and the high bioclimatic aridity index. All the different types of vegetation growing in the study area are characterized as low quality (100%). Additionally, the majority of this area is described by low land management quality (81%) especially in grazing areas. Most of the area shows a high erosion quality (43.68% of the area). Furthermore, the majority of this area is characterized by low ground water quality (51.94% of the area). The results also show that management, climate and ground water quality were the most important indicators affecting desertification process while soil quality seems to be less important in the study area (Figure 2).

Based on the above describe methodology different desertification maps (Figure 3) have been

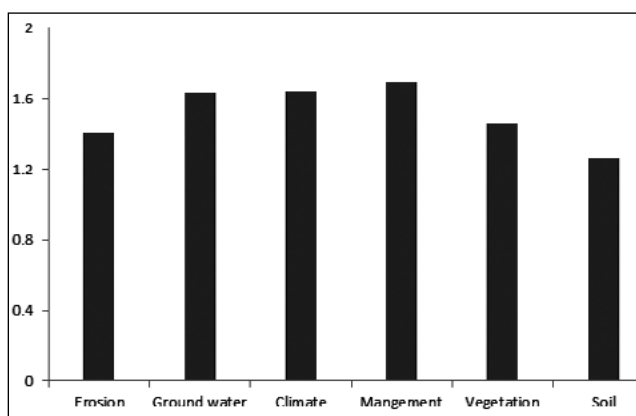


Fig. 2 Average of hazard degrees of main criteria used in the MMEDALUS Model.

produced for the MZY Plain. The current desertification map based on FAO/UNEP, 1984 is shown in the same figures for comparison. The desertification map derived with the MMEDALUS model shows that most of the territory is classified as severe and very severe desertification (84%) (Figure 4). These critical areas exist somehow all over the study area and coincide with areas of greater human activity or severely eroded soils and low ground water quality. These critical areas need management initiatives that can effectively promote a slow regeneration of the landscape as a measure to combat desertification.

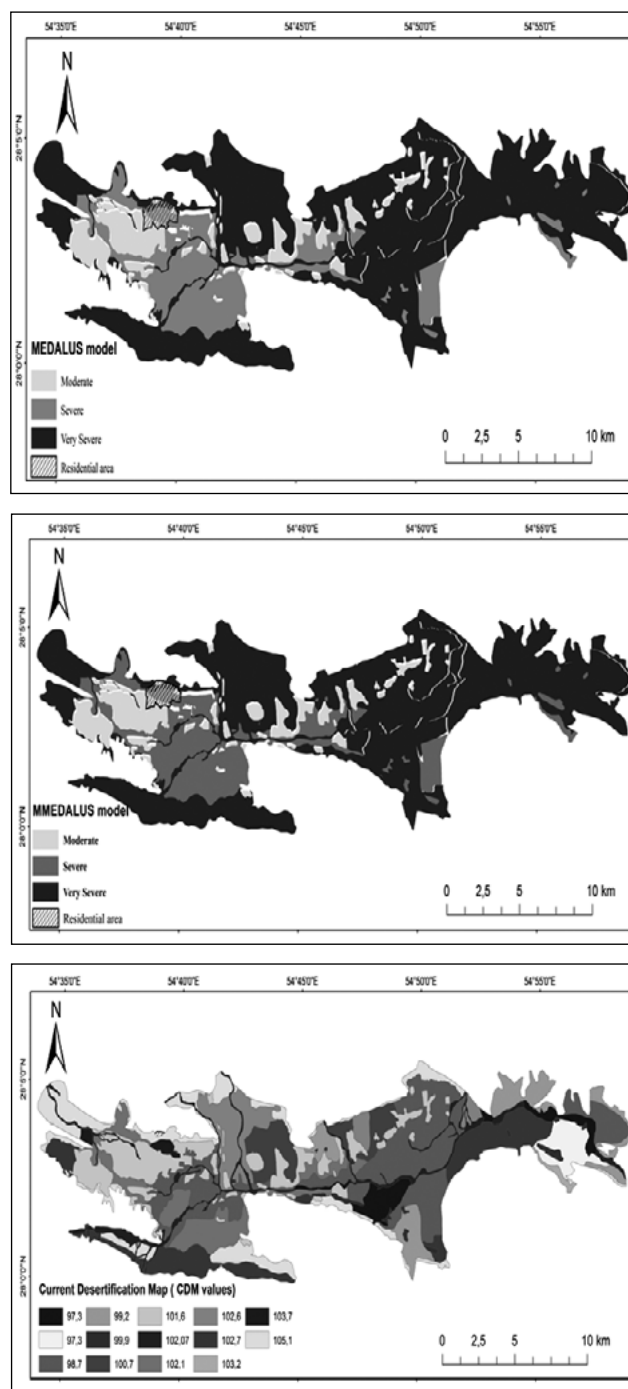


Fig. 3 Different desertification maps used for MEDALUS, MMEDALUS models and current desertification map.

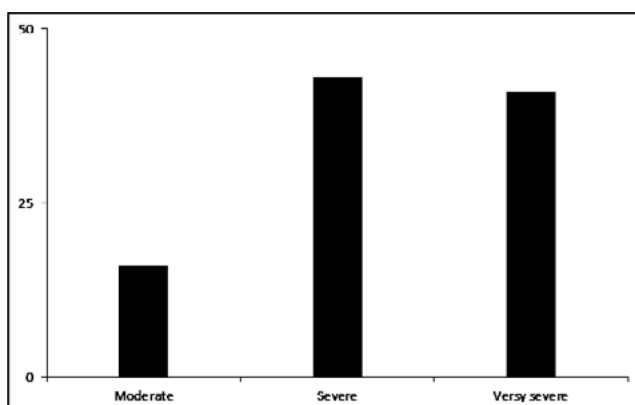


Fig. 4 Percent areas under hazard classes of desertification in the MZY Plain using MMEDALUS model.

In order to compare the different desertification maps with the agricultural productivity ratio (current desertification map), we use a correlation matrix. As illustrated in Table 4, there is an inverse correlation between current desertification map and the risk of desertification detected by MMEDALUS (0.05 level). It means by decreasing the ratio of current production to potential production the risk of desertification is increasing. While, there is no correlation between the reduction of production and the risk of desertification by MEDALUS in the study area. The 'ratio of current production to potential production' has been used to describe the current state of land degradation in the different models of land degradation or desertification assessment such as FAO/UNEP, GLASSOD and ASSOD. In both ASSOD and GLASSOD models, local experts assess 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. In other words, the estimates of ASSOD consider that a given amount of soil erosion is a more serious problem on poor and shallow soil than on a deep and fertile soil.

The developed model (MMEDALUS) attempts to assess and identify the factors affecting desertification. The results indicate the the MMEDALUS model outperforms the MEDALUS model in the study area. Results also revealed that the main reason for the better performance of the MMEDALUS assessment was to define a suitable criteria framework (e.g. adding ground water and erosion criteria). The result agree with other findings such as published by Sepehr et al. (2007) and Jafari, Bakhshandehmehr (2013).

4. Conclusion

In this study, MEDALUS and MMEDALUS models were mapped in the MZJ area. This MEDALUS model approach was adjusted to develop a regional model that could be adapted to the south and south west of Iran. The results obtained show that most of the area can be classified as having severe and very severe desertification susceptibility in accordance with the ground truth map of agricultural productivity ratio. Especially the MMEDALUS model shows a good accuracy with the ground truth map and hence, outperforms the MEDALUS model. The results also show that management, climate and ground water quality were the most important indicators affecting desertification process while soil quality seems to be less important indicators. The current state of the environmental conditions is caused by the arid climate, unproper management and also by the deterioration of the ground water. This highlights that particularly human activities play an important role in accelerating desertification process in the study area. The improvement of the MEDALUS approach by taking into account the groundwater and soil erosion state (MMEDALUS) generally allows for a better assessment of the desertification status of a landscape. However, in future studies we will focused on the integration of data related to water and soil salinity. In addition, considering some quantitative map of soil erosion may be useful for a further improvement of desertification modelling.

Finally, the limitation of desertification research assessment and monitoring in several developing countries (e.g., southeast of Iran, Iraq, Afghanistan, etc.) is the absence of historical data, including climatic, pedological (soil salinity, organic matter) information. Therefore applying simple models driven mainly by remote sensing data and available regional and national data is crucial to evaluate desertification on small spatial scales especially in remote areas.

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Tab. 4 Correlation matrix between current desertification map and MMEDALUS and MEDALUS maps.

		MEDALUS	MMEDALUS
Ratio of current production to potential production	Pearson Correlation	-.029	-.185*
	Sig. (2-tailed)	.671	.033

* Correlation is significant at the 0.05 level.

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