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Assessments of Environmental Sensitivity to Desertification in North Sinai, Egypt Using Remote Sensing and GIS Techniques

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Abstract— Desertification is a complex phenomenon which reduces the soil fertility involving ecological and economic processes that characterise the environment at different geographic scale. The MEDALUS model identifies regions that are environmentally sensitive area (ESAs). In this model, different types of ESAs to desertification can be analyzed in terms of various parameters such as landforms, soil, geology, vegetation, climate, and human actions. The studied area is located in the northern part of the Sinai Peninsula in arid and semi-arid region and third of its area is exposed to the threat of desertification with attention turning to the increasing area of deserts on Sinai, it is necessary to first identify areas liable to desertification before identifying mitigation and control measures. For this purpose it is necessary to prepare a desertification map as a guide for planners. In this study to evaluate the desertification condition regarding to local conditions of the study area, six indices of water, climate, soil, vegitation, management and wind erosion erosion were selected and assessment of desertification condition was conducted Based on these indices, weightening and MEDALUS model. The results showed that climate quality (CQI) with Description (Low quality), (VQI) with Description (Very low quality) and Management quality index (MQI) with Description (Moderate) have the highest effects. Soil quality index (SQI) (Moderate to High quality) have the lowest effect on the desertification process in the study area. Desertification Sensitivity Index (SDI) Almost Sensitive to Very sensitive areas (21-78%) of study area was located in the desertification.

Key words —Desertification, MEDALUS, GIS, Spatial analyst, Nourth Sinai.

1 INTRODUCTION

THIS Desertification is defined as a process of land degradation in arid, semi-arid and dry sub-humid areas, resulting from various factors, including climatic variations and human activities. Land degradation manifests itself through soil erosion, water scarcity, reduced agricultural productivity, loss of vegetation cover and biodiversity, drought and poverty (UNCCD, 2002) .

Desertification is a complex phenomenon which reduces the soil fertility involving ecological and economic processes that characterise the environment at different geographic scale. The most widely accepted definition of desertification is the one given by the United Nation Convention:. It defines desertification as 'land degradation in arid, semi arid and dry sub-humid areas resulting from various factors, including climatic variations and human activities'. The term desertification was generally associated to geo-physical conditions (e.g. soil, slope, vegetation cover) coupled with drought features and water availability but in Mediterranean land the study of the interaction of physical patterns with population dynamics is necessary to better delineate areas at risk. In fact, desertification impacts on the social, economic, and agricultural activities, and it is perceived as an ensemble of disasters affecting drylands, without a clear understanding of the involved processes (Fozooni L. et al, 2012).

The MEDALUS method (Kosmas et al. 1999) identifies regions that are an environmentally sensitive area (ESAs). In this model, different types of ESAs to desertification can be analyzed in terms of various parameters such as landforms, soil, geology, vegetation, climate and human actions. Each of these parameters is grouped into various uniform classes and weighting factor is assigned to each class.

Then four layers are evaluated soil quality, and management quality. After determined indices for each layer, the ESAs to desertification are defined by combining the four quality layer. All the data defining the four main layers are introduced in a regional geographical information system (GIS), and overlain in accordance with the developed algorithm which takes the geometric mean to compile maps of ESAs to desertification.

Different types of sensitivity to desertification were observed around The Mediterranean region. Most of highly sensitive areas in that region were primarily associated with low rain-

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fall, low vegetation cover, low resistance of vegetation to drought, steepness and high soil erosion(Gad and Lotfy, 2008; Hadeel et al., 2010).

The objectives of this work were to evaluate the environmental sensitivity to desertification in Nourth Sinai using the MEDALUS model and to identify ESAs in the studied area.

2. Material and Methods

2.1 Study Area

The studied area is located in the northern part of the Sinai Peninsula, and lies between longitudes 32° 30′ and 34°25′ east, and latitudes 30° 50′ and 31° 20′ North. The area has typically arid and semi-arid climatic conditions.

During winter, temperature degrees decrease, where the average high degree at noon Reaches 20 ^{o}c, while the low degree may average to about seven degrees in the early morning, but may drop to below zero degree in high inlands. In spring, the temperature degrees are changeable, where the average high degree may reach about 26 ^{o}c, and a low of about 13 ^{o}c, although the hot Khamasein wind waves may increase the temperature to above 40 ^{o}c. However, in summer, temperature degrees become moderate near the coast and increases as we move inward. The average high temperature degree may reach about 33 ^{o}c, while the low temperature degree may reach about 18 ^{o}c. Temperature degrees are almost equivalent in autumn and spring with a tendency to increase, with an average high degree of about 30 ^{o}c and an average low degree of about 15 ^{o}c. During times of hot waves of weather, temperature degrees rarely exceed 40 ^{o}c

The annual rainwater amounts falling over the peninsula, according to the meteorological data obtained from the weather forecasting stations in Sinai, are generally less than 200 mm in far northern zone at Rafah and El Arish, and are less than 20 mm in the lower south. The main geomorphologic units of North Sinai Peninsula are evaporites, coastal plains, sabkhas, dunes, alluvial fans, basins, wadis, alluvial plains, river terraces, and plateau (Mohamed, ,2014; Saleh et al.,2013) as shown in Fig.1.

The climatological conditions of the northern part of Sinai play an important role in shaping the study area and in controlling the ecology of the area. These conditions include extreme aridity, long hot rainless summer periods and mild winters in which storms rarely occur. The northern part of Sinai is also characterized by a so called El-Khamasin storms or sandstorms. These are violent winds which blow intermittently over a period of 50 days during February and March. Generally, the prevailing climatic conditions in the north Sinai include low rainfall, high temperatures, strong wind, high evaporation and low relative humidity. The temperatures in the north Sinai differ from one location to another according to its position from the Mediterranean Sea and the direction of winds (Hassan, 2002).

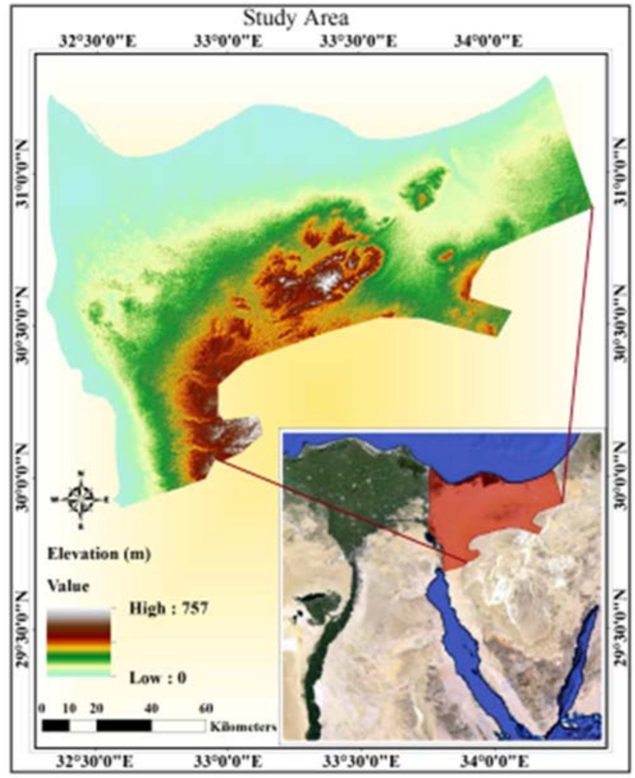

Fig.1 North Sinai and its topography.

2.2 The MEDALUS model

MEDALUS model identifies regions which are environmentally sensitive area (ESAs). In this model, different types of ESAs to desertification can be analyzed in terms of various parameters such as landforms, soil, geology, vegetation, climate, and human activities. Each of these parameters is grouped into various uniform classes and a weighting factor is assigned to each class. After that, four layers evaluated: soil quality, climate quality, vegetation quality, and management quality. After determining indices for each layer, the ESAs to desertification are defined by combining the four quality layers. All of the data defining the four main layers are introduced in a regional Geographical Information System (GIS), and overlaid in accordance with developed algorithm which takes the geometric mean to compile maps of ESAs to desertification (Kosmas et al.1999; Afifi et al.2010).

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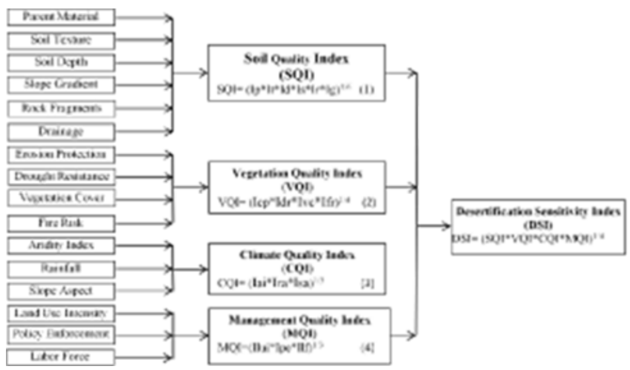

Where: (1) Ip= parent material, It= soil texture, Id= soil depth, Is= slope gradient, Ir= rock fragments, Ig=drainage; (2) Iep= erosion protection, Idr= drought resistance, Ivc= vegetation cover, Ifr= fire risk; (3) Iai= aridity index, Ira= rainfall, Isa= slope aspect, and (4) Ilui= land use intensity, Ipe=policy enforcement, Ilf= labor force.

Fig. 2: Adapted flow chart of the Mediterranean Des-

The required data for sensitivity evaluation were obtained from Spot 4 satellite images (acquired in 2011), geologic map, and soil maps. This is in addition to field observations and analyses of 25 surface (0-20 cm) representative soil samples. Each of the studied parameter was prepared as a thematic layer by using the ArcGIS 10.1 Software Package. Tables from 1 to 4 represent the classes and weighting indices of each parameter used in the assessment of the four quality indices (Elnaggar et al., 2013).

TABLE 1 CLASSES AND WEIGHTING INDICES OF PARAMETERS USED IN SOIL QUALITY ASSESSMENT.

Parameter	Class	Index	Description	Texture
Texture	1	1.00	Good	L, SCL, SL, LS, CL
	2	1.33	Moderate	SC, SiL SiCL
	3	1.66	Poor	Si, C, SiC
	4	2.00	Very Poor	s
Parameter	**Class**	**Index**	**Description**	**Parent Material**
Parent Material	1	1.00	Coherent	Limestone, dolomite, non-friable sandstone, hard limestone .layer
	2	1.66	Moderately	Marine limestone, friable
	3	2.00	Soft to friable	Calcareous clay, clay, sandy formation, alluvium and colluviums.
Parameter	**Class**	**Index**	**Description**	**Rock Fragments**
Rock Fragments	1	1.00	Very stony	> 60
	2	1.33	stony	20 - 60
	3	2.00	Slightly stony	<20
Parameter	**Class**	**Index**	**Description**	**Slope Gradient**
Slope Gradient	1	1.00	Very Gentle	< 6
	2	1.33	Moderately	6 - 18
	3	1.66	Steep	18 - 35
	4	2	Very steep	> 35
Parameter	**Class**	**Index**	**Description**	**Soil Depth**
Soil Depth	1	1.00	Deep	< 30
	2	1.33	Moderate	30 - 75
	3	1.66	Shallow	30 - 15
	4	2	Very shallow	< 15
Drainage	1	1.00	Good	Well drained
	2	1.33	Moderate	Imperfectly drained
	3	2	Poor	Poorly drained
Parameter	**Class**	**Range**	**Description**	
Soil quality index (SQI)	1	< 1.13	High quality	
	2	1.45	Moderate quality	
	3	> 1.46	Low quality	

TABLE 2 CLASSES AND WEIGHTING INDICES OF PARAMETERS USED IN VEGETATION QUALITY ASSESSMENT.

Parameter	Class	Index	Description	Fire Risk
Fire Risk	1	1.00	Low	Bare land, perennial ,agricultural crops annual agricultural crops ,(maize sunflower)
	2	1.33	Moderate	Annual agricultural crops
	3	1.66	High	Orchards
	4	2	Very High	Pine forests
Parameter	**Class**	**Index**	**Description**	**Erosion Protection**
Erosion Protection	1	1.00	Very High	Evergreen forests
	2	1.33	High	Pine forests, permanent ,grasslands evergreen perennial crops grasslands,
	3	1.66	Moderate	Deciduous forests
	4	1.80	Low	Deciduous perennial agricultural crops (almonds, orchards)
	5	2.00	Very Low	Annual agricultural crops ,((cereals annual grasslands, vines
Parameter	**Class**	**Index**	**Description**	**Drought Resistance**
Drought Resistance	1	1	Very High	Evergreen forests
	2	1.33	High	Conifers, deciduous, olives,
	3	1.66	Moderate	Perennial agricultural trees ,(vines almonds, orchards)
	4	1.8	Low	Perennial grasslands
	5	2.00	Very Low	Annual agricultural crops, annual grasslands
Parameter	**Class**	**Index**	**Description**	**Plant Cover %**
Plant Cover	1	1.00	High	> 40
	2	1.66	Low	10 - 40
	3	2.00	Very Low	< 10
Parameter	**Class**	**Range**	**Description**	
Vegetation quality index (VQI)	1	< 1.2	High quality	
	2	1.2-1.4	Moderate	
	3	1.4	Low quality	
	4	>1.6	Very low quality	

The Bagnouls-Gaussen aridity index (BGI) was used for determining the aridity index from easily available meteorological data. BGI was calculated using the following equation:

$$\mathbf{BGI = \sum_{i=1}^{n} (2ti\_Pi) Ki}$$

Where: ti is the mean air temperature for month i in oC, Pi is the total

Precipitation for month i in mm and ki represents the proportion of the month during which 2ti - Pi >0.

TABLE 3 CLASSES AND WEIGHTING INDICES OF PARAMETERS USED IN CLIMATE QUALITY ASSESSMENT.

Parameter	Class	Index	Rainfall (mm)
Rainfall	1	1.00	> 650
	2	1.33	280 - 650
	3	2.00	< 280
Parameter	**Class**	**Index**	**BGI range**
Aridity	1	1.00	< 50
	2	1.10	50 - 75
	3	1.20	75 – 100
	4	1.40	100 - 125
	5	1.80	125 - 150
	6	2.00	> 150
Parameter	**Class**	**Index**	**Aspect**
Aspect	1	1.00	North
	2	2.00	South
Parameter	**Class**	**Range**	**Description**
Climate quality	1	< 1.15	High quality
	2	1.81	Moderate quality
	3	> 1.81	Low quality

TABLE 4: CLASSES AND WEIGHTING INDICES OF PARAMETERS USED IN MANAGEMENT QUALITY ASSESSMENT.

Parameter	Class	Index	Degree of Land use Intensity
Land use Intensity	1	1.00	Low Land use
	2	1.50	Moderate Land use
	3	2.00	High Land use
Parameter	**Class**	**Index**	**Degree of Policy Enforcement**
Policy Enforcement	1	1.00	Complete >75% of the area
	2	1.66	Partial 25-75% of the area
	3	200	Incomplete <25% of the area
Parameter	**Class**	**Index**	**Labor Force**
Labor Force	1	1.00	> 40
	2	1.33	30 – 40
	3	1.66	20 – 30
	4	2.00	< 20
Parameter	**Class**	**Range**	**Description**
Management quality index (MQI)	1	1.00 –1.25	High
	2	1.26 –1.50	Moderate
	3	> 1.50	Low

Quality indices were calculated and displayed as GIS ready maps from which class areas were calculated. Desertification Sensitivity Index (DSI) was calculated in the polygonal attribute tables linked with the geographic coverage using the spatial analyst tool in Arc GIS 10.1 software. Desertification Sensitivity Index (DSI) is calculated from the soil, vegetation, climate and management quality indices using the following equation:

$$\mathbf{DSI = (SQI * VQI * CQI * MQI)^{\wedge}(1/4)}$$

Environmentally sensitivity areas to desertification (ESAs) were assigned based on the estimated value of DSI as represented in Table 5.

TABLE 5 DESCRIPTION OF ENVIRONMENTALLY SENSITIVITY AREAS TO DESERTIFICATION (ESAS) BASED ON THE DSI VALUES.

Classes	DSI*	Description
1	< 1.2	Non-sensitive areas (Areas in which critical factors are very low or not present, with a good balance between environmental and socio-economical factors).
2	1.2 to < 1.3	Slightly sensitive areas (Areas threatened by desertification under significant climate change, if a particular combination of land use is implemented or where offsite impacts will produce severe problems).
3	1.3 to < 1.4	Moderately sensitive areas (Areas in which any change in the delicate balance between natural and human activity is likely to bring about desertification).
4	1.4 to < 1.6	Sensitive areas (Areas already highly degraded through past misuse, presenting a threat to the environment of the surrounding areas or with evident desertification processes).
5	> 1.6	Very sensitive areas to desertification.

*DSI= Desertification Sensitivity Index

TABLE 6 SOIL QUALITY INDEX (SQI), ITS PARAMETERS AND THEIR RELATED AREAS AND PERCENTAGES OF NORTH SINAI.

Parameter	Class	Index	Description	Area (km2)	%
Texture	1	1.00	Good	7010.7	6.24
	2	1.33	Moderate	0	0
	3	1.66	Poor	0	0
	4	2.00	Very Poor	7010.7	6.24
Parent Material	1	1.00	Coherent	7010.7	6.24
	2	1.66	Moderately	0	0
	3	2.00	Soft to friable	9376.3	8.34
Rock Fragments	1	1.00	Very stony	0	0
	2	1.33	stony	7010.7	6.24
	3	2.00	Slightly stony	9376.3	8.34
Slope Gradient	1	1.00	Very Gentle	9376.3	8.34
	2	1.33	Moderately steep	7010.7	6.24
	3	1.66	Steep	0	0
	4	2	Very steep	0	0
Soil Depth	1	1.00	Deep	9376.3	8.34
	2	1.33	Moderate	0	0
	3	1.66	Shallow	7010.7	6.24
	4	2	Very shallow	0	0
Drainage	1	1.00	Good	6912.4	6.16
	2	1.33	Moderate	1880.1	1.68
	3	2	Poor	7594.5	6.76
Soil quality index (SQI)	1	< 1.13	High quality	7010.7	6.24
	2	1.45	Moderate quality	6912.5	6.16
	3	> 1.46	Low quality	2463.9	2.2
Total				112343.5	100.0

3. RESULTS

Four layers were used to assess desertification sensitivity (DSI) and for mapping the environmentally sensitive areas (ESA, s) in the studied area, including soils, climatic, vegetation and management quality indexes. These layers were created in ageographic information system (GIS) using the spatial analyst tool. The Landsat ETM image of the studied area and the digital elevation + model were used to establish the main land type layer, this layer was used as a base map in the geographic information system.

3.1 Soil Quality Index:

Soil is an essential factor in evaluating the environmental sensitivity of an ecosystem, especially in the arid and semi-arid zones. Soil properties related to desertification phenomena include water storage and retention capacity and resistance to erosion. The soil quality index (SQI) was evaluated depending upon drainage condition, rock fragments (%) slope gradient (%), soil texture class, soil depth (cm) and parent material. Fig. 3 represents the layer of soil quality index of the study area. The results indicate that the areas of high soil quality index (value <1.13) represent 6.24 % of the total area (i.e. 7010.7 Km2), the areas of moderate quality index (value = 1.13 – 1.45) represents 6.16 % of the total area (i.e 6912.5Km2) and the areas of low soil quality index (value >1.45) represents 2.2 % of the total area (i.e 2463.9Km2).

The low soil quality dominates the areas characterized by sandy texture, shallow depth and poor drainage. Table 6 illustrates the general characteristics, classes and scores of the soil quality index.

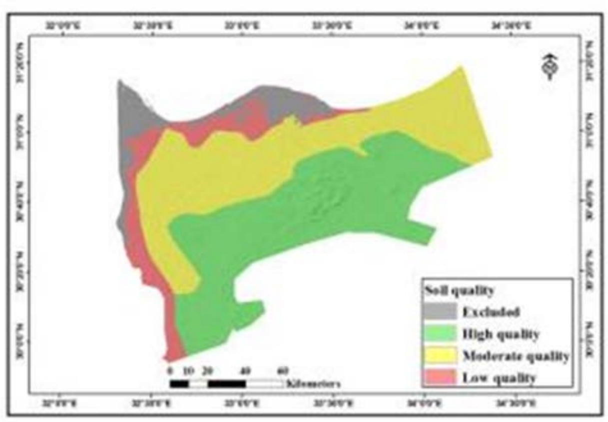

Fig.3 Soil quality index (SQI) related to desertification in North Sinai

3.2. Vegetation Quality Index:

Vegetation plays an important role in mitigating the effects of desertification and degradation phenomena. The plant cover (%), erosion protection, drought resistance and fire risk parameters were used for assessing the vegetation quality index (VQI). Fig. 4 represents the layer of vegetation quality index of the area. The data indicate that the areas of high vegetation quality (Value <1.20 it represents 0 % of the total area (i.e. 0 Km2), the moderate vegetation quality index (Value 1.2 – 1.4) dominates the northern east and western parts of the depression, it represents 0.28 % of the total area (i.e. 214.5 Km2). The low (Value 1.4) dominates the northern and north western parts of the depression, it represents 0.80 % of the total area (i.e. 621.9Km2) and very low vegetation index (Value >1.60) dominates the rest of the depression representing 18.35 % of the total area (i.e. 14111.6Km2) . The low vegetation index is due to the low density of plant cover. Table 7 illustrates the general characteristics, Vegetation quality index (VQI) parameters and their related areas and percentages of North Sinai.

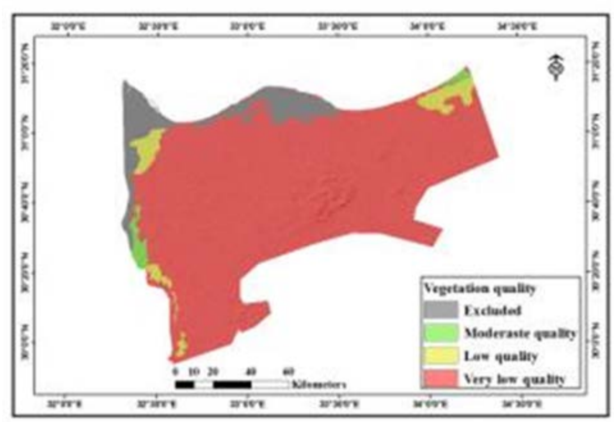

Fig. 4 Vegetation quality index (VQI) related to desertification in North Sinai

TABLE 7 VEGETATION QUALITY INDEX (VQI), ITS PARAMETERS AND THEIR RELATED AREAS AND PERCENTAGES OF NORTH SINAI

Parameter	Class		Description	Area (km2)	%
Fire Risk	1	1.00	Low	14750.1	19.18
	2	1.33	Moderate	300.5	0.4
	3	1.66	High	623.6	0.81
	4	2	Very High	0	0
Erosion Protection	1	1.00	Very High	0	0
	2	1.33	High	623.6136	0.81
	3	1.66	Moderate	0	0
	4	1.80	Low	0	0
	5	2.00	Very Low	15050.6	19.57
Drought Resistance	1	1	Very High	0	0
	2	1.33	High	0	0
	3	1.66	Moderate	623.6	0.81
	4	1.8	Low	0	0
	5	2.00	Very Low	15050. 6	19.57
Plant Cover	1	1.00	High	427.3	0.55
	2	1.66	Low	496.8	0.65
	3	2.00	Very Low	14023.9	18.23
Vegetation quality index (VQI)	1	< 1.2	High quality	0	0
	2	1.2-	Moderate	214. 5	0.28
	3	1.4	Low quality	621.9	0.80
	4	>1.6	Very low quality	14111.6	18.35
Total				76918.61	100

3.3. Climate Quality Index:

Climate quality index of the North Sinai was assessed based on three parameters, which are rainfall, aridity, and slope aspect. It is found that climate in the North Sinai is located under hyper-arid, where the mean annual precipitation is are less than 20 mm. The aridity index was greater than 150 according to the BGI range. Slope aspect was excluded from the calculations because the majority of the North Sinai is almost flat. According to these parameters, the climate quality index was fitted under one category, which is low quality. Climate quality has great influence on the vulnerability of soils to desertification due to its critical impact on the growing of vegetation and soil erosion.

3.4. Management Quality Index:

The crops, orchards and shrubs intensity layers were used with the policy enforcement data in the different land use type to assess the management quality index (MQI). The obtained data reveals that the areas of high quality management index are found in the south parts of the depression as it represents (0.92%) of the total area (i.e. 450.3267 Km2). The areas of moderate and low management quality represent (26.46 and 5.86%) of the total area respectively. The high values of the management quality index are due to the low intensity of the different land uses and the absence of the policy enforcement.

TABLE 8 MANAGEMENT QUALITY INDEX (MQI) ITS PARAMETERS AND THEIR RELATED AREAS AND PERCENTAGES OF NORTH SNAI

Parameter	Class	Index	Description	Area (km^2)	%
Land use Intensity	1	1.00	Low Land use	29.1	0.06
	2	1.50	Moderate Land use	11.8	0.02
	3	2.00	High Land use	0	0
Policy Enforcement	1	1.00	Complete Partial	4241.2	8.63
	2	1.66	Partial protection	9254.5	18.82
	3	200	Incomplete protection	2891.3	5.88
Labor Force	1	1.00	> 40	0	0
	2	1.33	30 – 40	0	0
	3	1.66	20 – 30	3786.1	7.70
	4	2.00	< 20	12600.9	25.64
Management quality index (MQI)	1	1.00 –1.25	High	450.3267	0.92
	2	1.26 –1.50	Moderate	13004.7	26.46
	3	> 1.50	Low	2882.4	5.86
Total				49152.3267	100

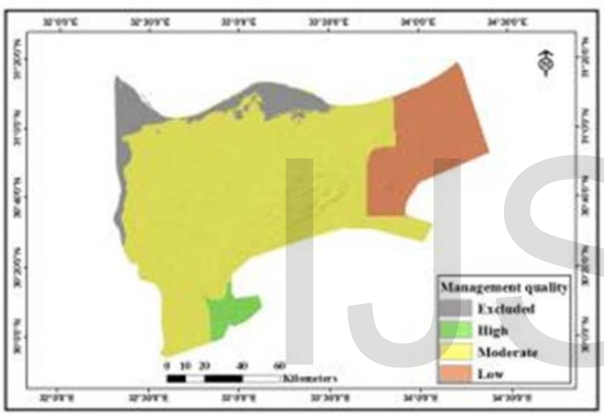

Fig. 5 Management quality index (MQI) in North Sinai

3.5. Environmental Sensitivity Areas in the North Sinai:

Based on the results of the above mentioned quality indices, soils in the North Sinai were fitted into two environmental sensitivity classes to desertification as represented in Table 9. These classes are sensitive and very sensitive areas as illustrated in Fig. 6. Sensitive areas represent about (21.23%) of North Sinai. However, very sensitive areas represented only about (78.77%) of the area.

TABLE 9. ENVIRONMENTAL SENSITIVITY AREAS (ESAS) AND THEIR RELATIVE PERCENTAGES IN NORTH SINAI

Class	DSI*	Description	Area (km^2)	%
1	< 1.2	Non-sensitive areas	0	0.00
2	1.2 to < 1.3	Slightly sensitive areas	0	0.00
3	1.3 to < 1.4	Moderately sensitive areas	0	0.00
4	1.4 to < 1.6	Sensitive areas	3165.3	21.23
5	> 1.6	Very sensitive areas	11740.8	78.76
Total			14906.1	100.00

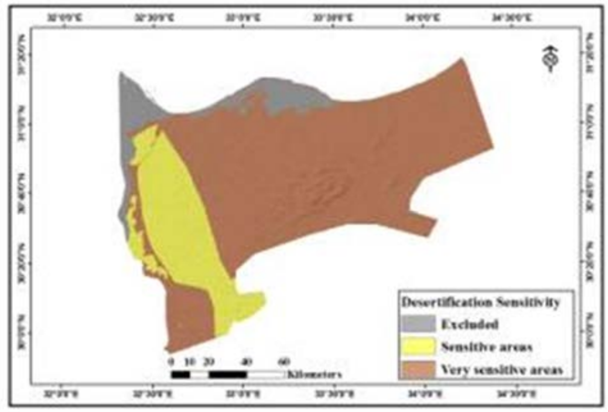

Fig. 6 Environmental sensitivity areas (ESAs) to desertification in North Sinai

CONCLUSION

It could be concluded that the Mediterranean Desertification and Land Use (MEDALUS) model could provide a valuable quantitative assessment of environmental sensitivity to desertification. It also could support decision makers with important information that could help in protecting and sustaining natural resources. In this model environmental sensitivity to desertification was evaluated based on four important quality indices (soil, vegetation, climate and management) that have great impact on that phenomenon.

Remote sensing and GIS techniques are very helpful to collect, store, manage, retrieve, analyze, and output the huge amounts of geospatial data and field observations.

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