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A GIS-based Model for Desertification Sensitivity Assessment Case study: Inland Sinai and Eastern Desert Wadies

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ABSTRACT

Desertification is one of the fundamental problems that threaten many arid and semi-arid areas. The Egyptian National Action Plan (NAP) to combat desertification divided the Egyptian territory into four agro-ecological zones. The Eastern desert and inland Sinai is one of the defined agro-ecological zones, where wadi plains represent potential sustainable areas. Wadi Al-Arish and Wadi Al-Asiouty were chosen to represent inland Sinai and eastern desert regions respectively.

The study aims at identifying the areas sensitive to land degradation in Inland Sinai and eastern desert of Egypt. Based on the MEDALUS approach and the characteristics of the study area, a regional model developed using GIS for computing and mapping the study area based on its sensitivity to desertification. The thematic layers of soils, vegetation, climate and management quality indices are the main inputs for estimating the Environmental Sensitivity to desertification. These layers were extracted and manipulated from, soil maps, satellite images, topographic maps, geologic maps and field survey. Spatial analyst function of Arc-GIS 9.3 software was used for overlaying the thematic layers, calculating the thematic indices and assessing the desertification index

The results show that 33.8% of Wadi Al-Asuity is characterized by a high sensitivity to desertification, while the low sensitive one exhibits only 19.4%. The moderately sensitive area occupies 28.6% of the wadi area. Wadi Al-Arish area shows more sensitivity, where 74% of its area is highly sensitive to desertification. The low sensitive areas to desertification represent 25% of the area. Land use must be adapted, on basis of the environmental sensitivity indices for desertification, in order to reduce or eliminate the risk of desertification and assure sustainable development.

Keywords: *GIS,* desertification sensitivity, *eastern desert, Sinai, satellite data.*

INTRODUCTION

UNEP (1994) defined desertification as: "land degradation in arid, semi-arid and dry subhumid zones arising from various factors, including climatic variation and human impact". Desertification is also defined as the consequence of important processes set, which are active in arid and semi-arid environment, where water is the main limiting factor of land use performance in the ecosystems (Batterbury and Warren, 2001). Land degradation can be defined, in this context, as the response of the environment, or part of it, to a change in one or more external factors (Batterbury and Warren, 2001). MEDLUS (EC. 1999) made a distinction between degradation processes in European Mediterranean environments and the more arid areas. Physical loss of soil by water erosion, and associated loss of soil nutrient status are identified as the dominant problems in the European Mediterranean region. However, wind erosion and salinization problems are most often in the southern Mediterranean coast (Glantz, 1977; Quintanilla, 1981; Zonn, 1981). Environmental systems are generally in a state of dynamic equilibrium with external driving forces. Small changes in the driving forces, such as climate or imposed land use tend to be accommodated partially by a small change in the equilibrium and partially by being absorbed or buffered by the system. Desertification of an area will proceed if certain land components are brought beyond specific threshold, where further change produces irreversible change (Tucker et al. 1991; Nicholson et al. 1998).

The environmental sensitivity of an area to desertification is a complex concept controlled by many different factors operating in association (Rubio, 1995; Thornes, 1995; UNEP, 1992; Basso et. al., 2000). An Environmental Sensitive Area (ESA) can be considered, in general, as a specific and delimited entity in which environmental and socio-economical factors are not balanced or not sustainable for that particular environment. Ferrara et al, 1999 postulated that the Mediterranean region is characterized by different sensitivity status to desertification for various reasons (i.e. low rainfall and extreme events due to low vegetation cover, low resistance of vegetation to drought, steep slopes and highly erodable parent material).

The MEDALUS method (**Kosmas et al. 1999**) identifies regions that are sensitive to desertification (ESAs). In this model, different types of ESAs can be analyzed in terms of various parameters such as landforms, soil, geology, vegetation, climate and management. 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, vegetation quality, climatic quality and management quality. After determining indices for each layer, the ESAs 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 degradation. Therefore, the objective of this study is to develop a GIS-based model for assessing desertification sensitivity in Inland Sinai and eastern desert of Egypt.

MATERIALS AND METHODS

Study area

The Inland Sinai and the Eastern Desert of Egypt represent one of the four agro-ecological zones of Egypt. This zone is characterized by the hyper-arid conditions; with a mild winter and a hot summer. Two study sites were considered in the current study, Wadi Al-Arish representing Sinai Peninsula and wadi Al-Asiuty representing the eastern desert (Figure 1). The climatic condition of Wadi Al-Arish represents a typical arid climate with low rainfall. It has a high evapo-transpiration up to 5.5 mm day^{-1} in July (summer) and minimum of 1.9 mm day^{-1} in January (winter). The temperature varies from 30.6°C in July and 8.5 in winter. Relative humidity is higher in the summer than in the winter with maximum value of 75% in June and minimum of 66% in December. Concerning Wadi Qena, it represents a hyper-arid climate with almost no rain.

Figure 1. Location of study areas

METHODS

For the purpose of estimating the Environmental Sensitivity Index (DSI) to desertification, the Soil Quality Index (SQI), Vegetation Quality Index (VQI), Climate Quality Index (CQI) and Management Quality Index (MQI) were computed. Figure (2) demonstrates the main flow chart of concepts and studied steps performed. Weighting factors of each category of the considered parameters were used on basis of Kosmas et. al, (1999). The main input data for calculating sensitivity indices were driven from the results of field surveying, soil laboratory analyses, Landsat ETM^+ image classification, Digital Elevation Model (DEM), geological map (CONOCO, 1990) and climatic data.

An image processing system (i.e. ENVI 4.2) and a GIS system (i.e. Arc GIS 9.0) were the main tools for indices computations and ESA's mapping. Morphological description for 12 observation sites for each part of the study area, representing different landforms, was done using the FAO, 2006 guidelines Particle size distribution for the collected soil samples was carried out according to USDA, 2004 manual of laboratory analyses methods. The quality indices were calculated and employed in the GIS model for computing the Desertification Sensitivity Index (DSI). Based on the estimated values of DSI, the classes of desertification sensitivity in the area can be described as illustrated in Table (1).

Table1. Description of the classes of desertification sensitivity index (DSI)

Classes	DSI	Description
1	< 1.2	Areas in which critical factors are very low or not present, with a good balance between environmental and socio-economical factors
2	1.2 < DSI < 1.3	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 < DSI <1.4	Areas in which any change in the delicate balance between natural and human activity is likely to bring about desertification.
4	1.4 > DSI <1.6	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

Desertification Quality Index (DSI) = $(SQI * VQI * CQI*MQI)^{1/4}$

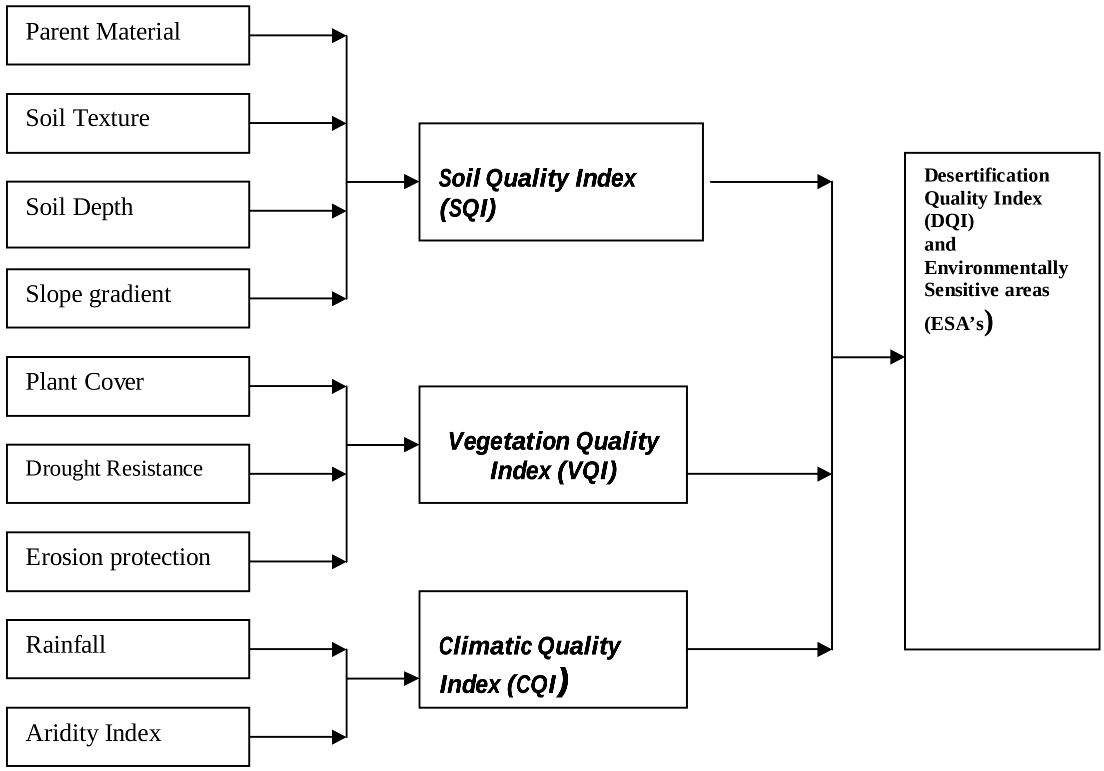


Figure 2. Flow chart of mapping Environmentally Sensitive Areas (ESA's)

RESULTS AND DISCUSSION

Soil Quality Index

Parent material

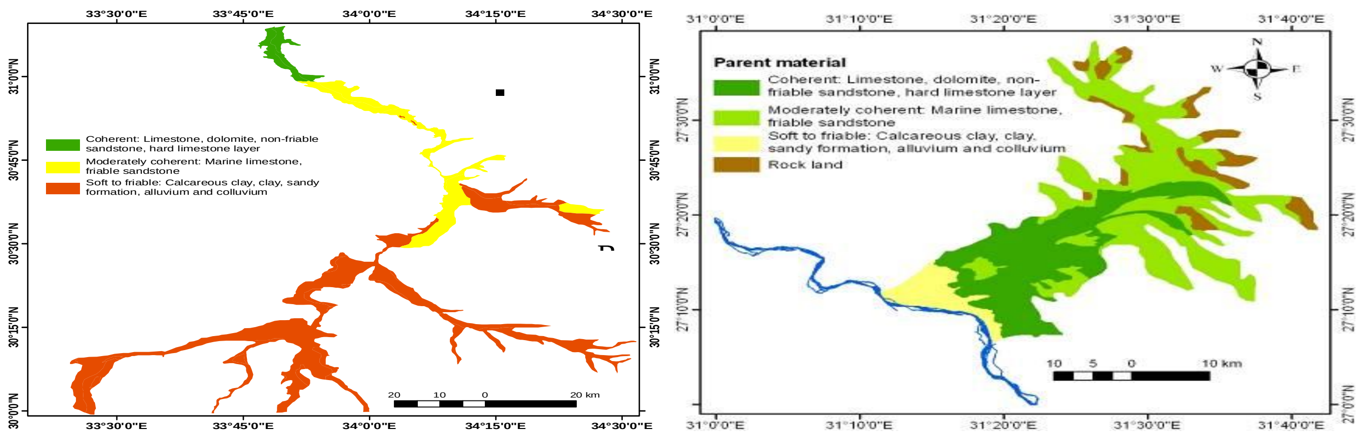
Parent material is considered very important factor for determining the susceptibility to desertification. (Table 2) and Figures (3 A and B) represent the types, scores and areas of the parent materials of the study areas.

It is found that the soil coherent parent material makes it less susceptible to desertification. Examples of coherent parent materials are Limestone, Dolomite, non-friable sandstone and hard limestone layer. The coherent parent material represents 5.33 % of Wadi Al-Arish and 34.1% of Al-Siuty. It dominates the northern part of Wadi Al-Arish and the western parts of Wadi Al-Asiuty.

This type of parent material is the least susceptible to desertification and takes a score of 1.00 on the desertification sensitivity index. The Moderately coherent parent material, such as marine limestone and friable sandstone covers 20.71 percent of Wadi Al-Arish and 47.3% of Wadi Al-Asiuty This type of parent material is moderately susceptible to desertification and takes a score of 1.5 on the desertification sensitivity index. The soft to friable, such as Calcareous clay, clay, sandy formation, alluvium and colluvium covers 73.9. of Wadi Al-arish and 10.01 of Wadi Al-Asiuty. This type of parent material is the most susceptible to desertification and takes a score of 2.00 on the desertification sensitivity index.

Table 2. Types and occurrences of parent materials in Wadi al-Arish and Wadi Al-Asiuty areas

Parent material	Wadi Al-Arish		Wadi Al-Asiuty	
	Area (Km^2)	Area %	Area (Km^2)	Area %
Coherent: Limestone, dolomite, non-friable sandstone, hard limestone layer	62.11	5.33	302.90	34.10
Moderately coherent: Marine limestone, friable sandstone	241.40	20.71	424.00	47.73
Soft to friable: Calcareous clay, clay, sandy formation, alluvium and colluvium	862.06	73.96	88.95	10.01
Total	1165.57	100.00	72.48	8.16

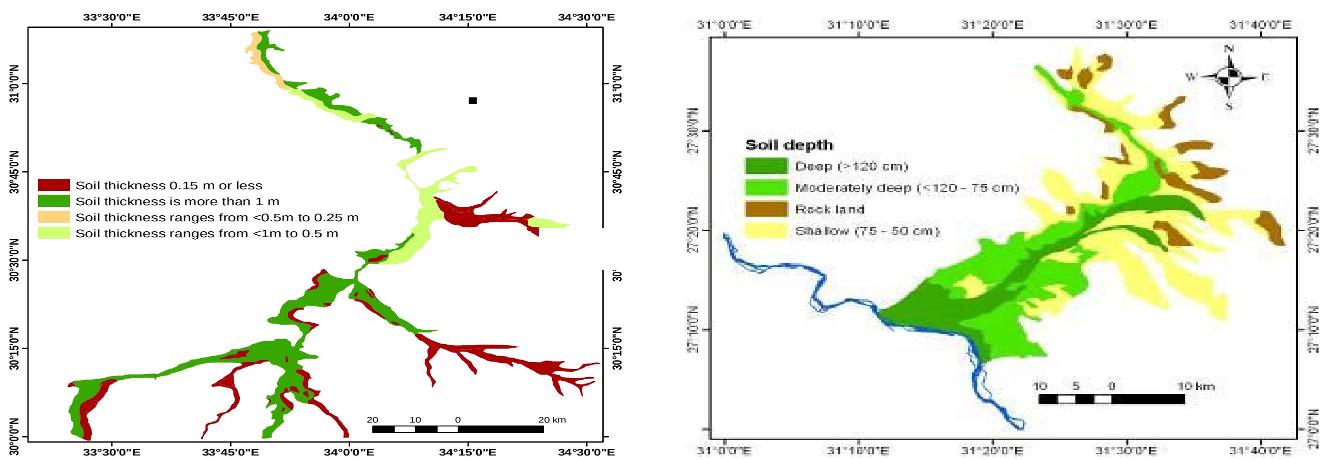


A B

Figure 3. Distribution of variable parent materials in (A)Wadi Al-Arish and (B) Al-Asiuty

Soil depth

Soil depth is very important factor for determining the susceptibility to desertification. The deeper the soil the less sensitive to desertification and vice versa. Figure (4 A and B) represents the soil depth in the study areas. The soil is divided to four classes according to its depth as (i.e. Very deep, Not deep, moderately deep and Very thin soil). The very thin soil is the most susceptible to desertification, and takes a score of 2.00 on the desertification sensitivity index.



A B

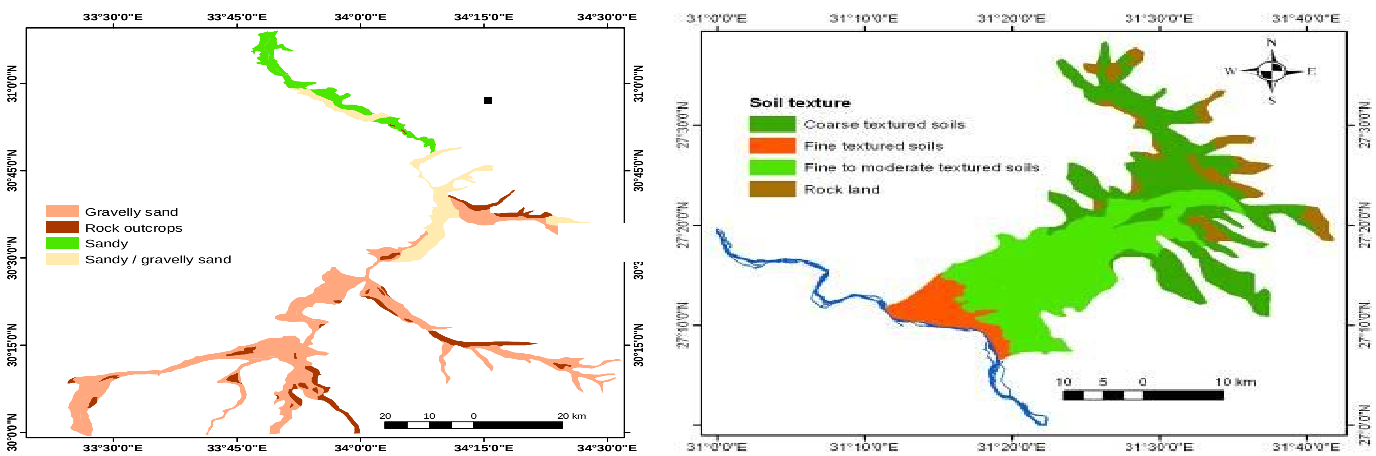
Figure 4. Categories of soil depths in (A) Wadi Al-Arish and (B) Al-Asiuty

Soil texture

Soil texture is very important factor for determining the susceptibility to desertification, Table (3) and Figure (5 A and B) represent the types, scores and areas of the soil texture the Wadi Al-Arish and Wadi Al-Asiuty areas respectively. The soil is divided to four classes according to its texture according to MEDLUS methodologies. The soils characterized as Not very light to average are the least susceptible to desertification, representing 21.29% of Wadi Al-Arish, while not found in Wadi Al-Asiuty. It takes a score of 1.00 on the desertification sensitivity index. The fine to average textured soils is moderately susceptible to desertification. Such soils exhibit 20.48% of Wadi Al-Arish and 42.07% of Wadi Al-Asiuty. The coarse textured soils are the most susceptible to desertification, covering 23.97% of Wadi Al-Arish and 39.76% of Wadi Al-Asiuty.

Table 3. Distribution of soil texture classes and assigned scores in Wadi Al-Arish

Type of soil texture	Score	Wadi Al-Arish		Wadi Al-Asiuty	
		Area Km^2	Area %	Area Km^2	Area %
Water bodies, Rockland or urban	0.00	2479.58	7.14	88.95	10.01
Not very light to average	1.00	7393.43	21.29	00.00	00.00
Fine to average	1.33	7111.32	20.48	373.74	42.07
Fine	1.66	9415.03	27.12	72.48	8.16
Coarse	2.00	8322.65	23.97	353.16	39.77
Total		**34722.01**	**100.00**	**888.33**	**100.00**



A B

Figure 5. Categories of soil texture in (A) Wadi Al-Arish and (B) Al-Asiuty

Surface slope

Soil surface slope is very important factor for determining the susceptibility to desertification, the higher the surface slope the more susceptible to desertification. The soil surface slope is divided to three classes as follow:

A - Gently slope; soil with surface slope of less than 6 percent which is the least susceptible to desertification.

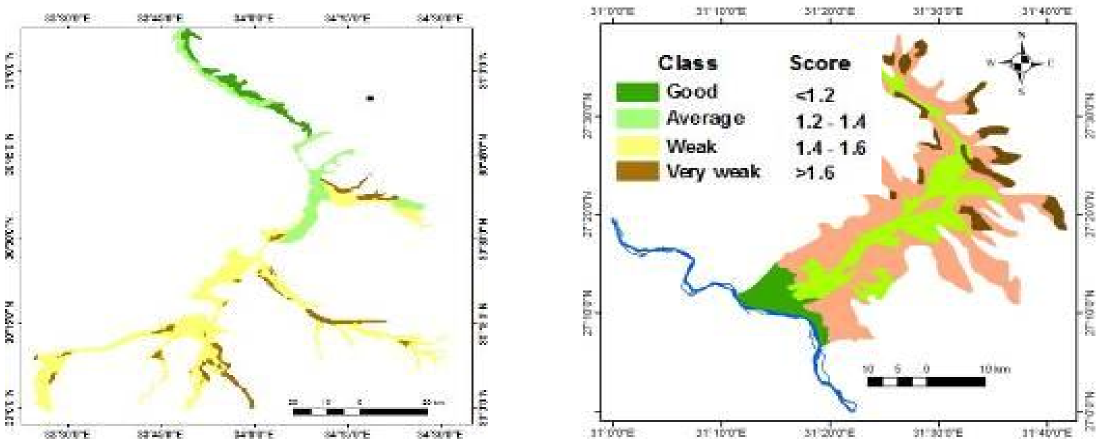
B - Gently undulating; soil with surface slope of between 6 and 18 percent which is moderately susceptible to desertification. It takes a score of 1.33 on the desertification sensitivity index.

C - Undulating texture; soil with surface slope between 19 and 35 percent which is the most susceptible to desertification. It takes a score of 1.66 on the desertification sensitivity index.

Soil Quality index

The soil quality index (SQI) was evaluated, based upon the parent material, soil depth, soil texture class and slope gradient. Figure (6 A and B) and table (4) represents the class, scores, description and areas of soil quality index of Wadi Al-Arish and Wadi Al-Asiuty areas.

The layer of soil quality index of the studied area, indicate that the areas of high soil quality index (value <1.13) is found in a small areas in both wadis it covers an area of 7.73% and 9.06% of the total area of Wadi Al-arish and Wadi Al-Asiuty respectively. The areas of moderate quality index (value = 1.13 – 1.45) represents 18.31 % and 28.1% of of Wadi Al-arish and Wadi Al-Asiuty respectively. The areas of low soil quality index (value >1.45) represents 73.96 % and 62.84 % of Wadi Al-arish and Wadi Al-Asiuty respectively. The low soil quality dominates the areas as they are characterized by sandy texture, shallow depth and poor drainage soils.



A B

Figure 6. Soil Quality Index of (A)Wadi Al-Arish and (B) Wadi Al-Asiuty

Table 4. Soil Quality Index of Wadi Al-Arish and Wadi Al-Asiuty

SQI	Wadi Al-Arish		Wadi Al-Asiuty	
	Area (Km^2)	Area %	Area (Km^2)	Area %
High quality	90.05	7.73	72.48	9.06
Moderate quality	213.46	18.31	224.60	28.10
Low quality	862.06	73.96	502.30	62.84
Total	1165.57	100.00	799.38	100.00

Vegetation Quality Index

Vegetation cover plays an important role in mitigating the effects of desertification and land degradation phenomena. The percentage of vegetation is a function of both man-made agriculture and natural vegetation coverage. The percentage of vegetation cover is a necessary input in a multi-criteria model to assess the vegetation quality index. In this research, vegetation cover percentage, erosion protection and drought resistance were used to assess the vegetation quality index.

Vegetation cover percentage

The research area shows variable soil characteristics, land suitability and geomorphologic properties, as well as potential of water availability. This indeed, is reflected in the percentage of vegetation cover which shows variable categories with main four categories

The areas were classified according to the following categories

- Vegetation cover >30%;
- Vegetation cover 30-10%;
- Vegetation cover < 10%;

Basically, the soil characteristics, water availability and morphological properties of the area constrain both variability and percentage of vegetation cover. The percentage of vegetation cover is a function of both land resistance and land protection. The higher the vegetation cover the higher the resistance and protection of the land for degradation and / or desertification. This layer is used as a key input in estimating the drought resistance and erosion protection indices.

Vegetation drought resistance

Vegetation drought resistance is the layer that shows how much land and its vegetation cover is resistant to drought. There is a universal standard classification of the susceptibility of vegetated land to drought and therefore its resistance. The study areas, in reflection to the vegetation cover, shows three categories of drought resistance as follow:

1. Evergreen trees, bedrocks and bare soils; This category shows very high vegetation drought resistance index with value of 1.0

2. Shrubs; this category is moderately drought resistance index value of 1.66.
3. Very low vegetated land with vegetation drought resistance index value of 2.0

Vegetation erosion protection

Vegetation erosion protection is the layer that shows how much land and its vegetation cover is resistant to erosion. There is a universal standard classification of the susceptibility of vegetated land to erosion and therefore its resistance. This means that the higher the percentage of vegetation cover the higher the resistance of land to erosion.

The plant cover (%), erosion protection, and drought resistance parameters were used for assessing the vegetation quality index (VQI) as indicated in table (5) and Figure (7 A and B).

Table 5. Areas of different vegetation quality index classes

Class	VQI range	Oases	Area (km^2)	%
Good	<1.2	Wadi Al-Arish	122.26	10.49
		Wadi Al-Asiuty	143.32	16.13
Average	1.2-1.4	Wadi Al-Arish	507.88	43.57
		Wadi Al-Asiuty	302.90	34.10
Week	1.4-1.6	Wadi Al-Arish	448.12	38.45
		Wadi Al-Asiuty	353.16	39.76
Very week	>1.6	Wadi Al-Arish	87.32	7.49
		Wadi Al-Asiuty	88.95	10.01

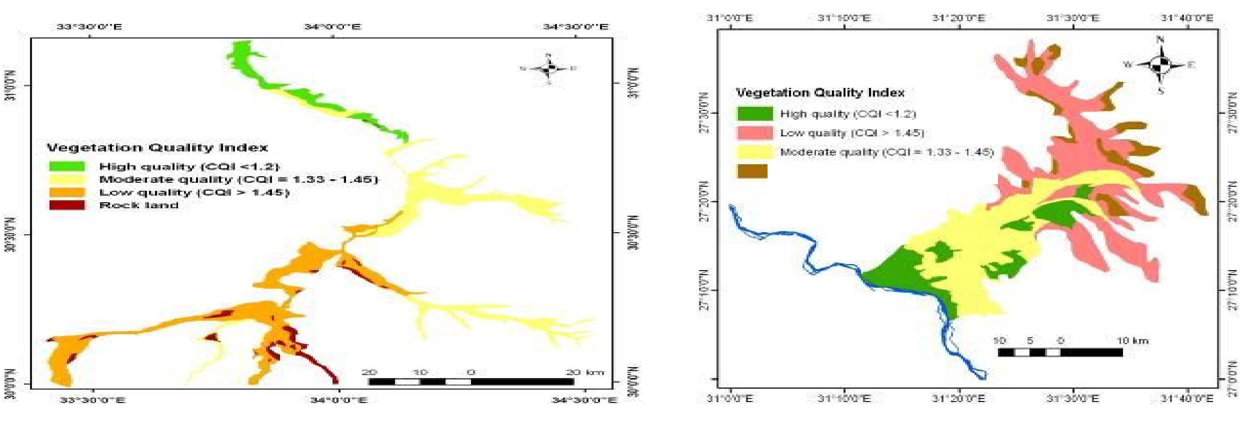


Figure 7. Vegetation quality index classes of (A) Wadi Al-Arish and (B) Wadi Al-Asiuty area

Climatic Quality Index

Climate quality index (CQI) is assessed on bases of the amount of rainfall, aridity and slope aspect parameters. The amount of rainfall and aridity are the same in the whole studied area, but the microclimate differ from a place to another due to variation in surface slope and slope aspect. The digital elevation model (DEM) of the depression was established and used for extracting the slope aspect. The climatic quality index layer of the area refer that it is characterized by a low (>1.80) climatic quality index.

Desertification sensitivity index

The three previous layers were used together to assess the environmentally sensitive areas (ESA's) to desertification, on bases of the calculated desertification sensitivity index (DSI). Table (6) presents the classes, scores, description and areas of the Environmentally Sensitive Areas to desertification in the study areas. Figure (8 A and B) show the distribution of environmentally sensitive areas (ESA's), it is clear that the sensitive areas for desertification in the area are found in the southern part of Wadi Al-Arish and the eastern part of Wadi Al-Siuty, whereas vegetation quality are low; these areas represent 73.96 and 42.00 % of Wadi Al-Arish and Wadi Qena respectively. The areas of low to moderate sensitivity for desertification exhibit an area of 17.31 and 19.37 % of Wadi Al-Arish and Wadi Al-Asiuty respectively.

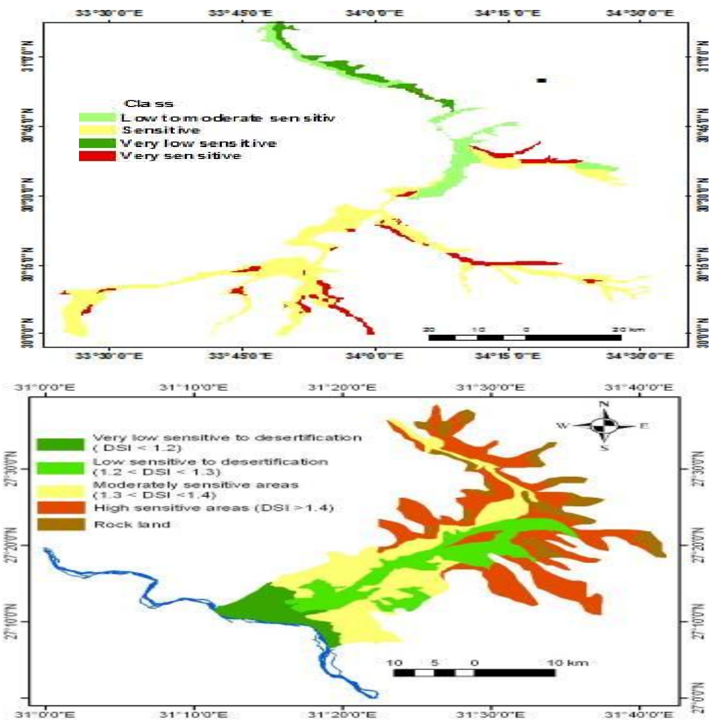


Figure 8. Environmentally Sensitive Areas to desertification in (A) Wadi Al-Arish and (B) Wadi Al-Asiuty

Table 6. Occurrence of Environmentally Sensitive Areas (ESA's), based on DSI values

Soil index	Wadi Al-Arish		Wadi Al-Asiuty	
	Area (km^2)	Area (%)	Area (km^2)	Area (%)
Non affected areas or very low sensitive areas to desertification	90.05	7.73	88.95	10.01
Low to medium sensitive areas to desertification	213.46	17.31	172.08	19.37
Medium sensitive areas to desertification	0	0	254.19	28.61
Sensitive areas to desertification	708.7	60.8	72.48	8.16
Very sensitive areas to desertification	153.36	13.16	300.64	33.84
Total	**1165.57**	**100**	**888.33**	**100.00**

CONCLUSION AND RECOMMENDATION

It can be concluded that the assessment of desertification sensitivity is rather important to plane sustainable development in highly potential desert areas as wadis and plains. Achieved information is essential to improve the employment of natural resources. The merely quantitative aspect of desertification sensitivity demonstrates a clearer image of the risk state, thus, reliable priority actions can be planned. Remote sensing, in addition to thematic maps, may supply valuable information concerning the soil and vegetation quality at the general scale. However, for more detailed scales, conventional field observation would be essential..

The Geographic Information System (GIS) is a valuable tool to store, retrieve and manipulate the huge amount of data needed to compute and map different quality indices to desertification

The Egyptian territory is susceptible to very high-to-high desertification sensitivity, however the Nile Valley is moderately sensitive because of its vegetation cover. Action measures are essential for the sustainable agricultural projects located in the desert oases, wadis and interference zone.

It can be recommended that mathematical modeling should be developed for the operational monitoring of different elements contributing in desertification sensitivity. Multi scale mapping of ESA's are needed to point out the risk magnitude and causes of degradation in problematic areas.

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