



## ASSESSMENT AND SPATIAL ANALYSIS OF SENSITIVITY TO DESERTIFICATION IN WADI EL NATRUN, NORTHWESTERN EGYPT USING MEDLAUS MODEL

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### ABSTRACT

Desertification processes reduce the productivity of soil and as a result affect food stocks. The main objective of this study is integrating remote sensing data and a geographic information system (GIS) to evaluate the environmental sensitivity to desertification in Wadi El Natrun, Egypt based on the Mediterranean Desertification and Land Use (MEDALUS) approach. The collected soil data; from description of represented soil profiles and analysis of soil samples, in addition to climate, plant cover, and management data were considered for assessing the sensitivity of desertification. The obtained results showed that 10.4 % of Wadi El Natrun area is considered as a severe sensitive area to desertification owing to alkalinity and salinity, while the moderate sensitive class occupies approximately 10.93 % of the study area. The low sensitive area exhibits 76.3 %. This area is described by high soil quality because the study area is one of the new development areas which is not affected by the factors of desertification.

**Keywords:** Desertification, MEDALUS, Wadi El-Natrun, GIS, Remote sensing

### INTRODUCTION

Land degradation is a global environmental issue, given the various negative impact for socio-economic and ecological implications. According to

the United Nations Convention to Combat Desertification (UNCCD), Land degradation leads to reduced production capacity in addition to soil erosion, physical /chemical /biological /economic land deterioration, and long-term loss (or degradation) of vegetation. When a severe deterioration in drought areas called the process of desertification i.e. arid, dry sub-humid and, semi-arid areas (UNCCD, 1994).

Desertification affects about one billion populations in about one hundred countries (Adger et al 2000). It is mainly as a result of an important set of processes, which are active in arid and a semi-arid environment, where the amount of water is the main determining factor for land use performance in the ecosystems (Gad and Shalaby, 2010). The interaction and interference between several factors such as land cover, climate, physical human activities and change in natural and land use caused in the increase of desertification phenomenon (Thomas, 1997 and UNCCD, 2000). Human is one of the most factors which resulted in an increase of the phenomenon of desertification (Herrmann and Hutchinson, 2005). In the last decades, several methods and approaches have been advanced to classify areas of land degradation such as spectral biophysical indicators (Lamchin et al 2016). To characterize the desertification process in an easy and a comprehensive way, specific indicators can be used by taking into consideration qualitative and quantitative methods (Lamqadem et al 2018 and Gad, 2020). The MEDALUS model has been used

in different Mediterranean regions at local, national, and regional scales. **Kosmas et al (1999)** developed the MEDALUS methodology for identifying the most areas which are sensitive to desertification at different scales (**Luca and Sofia, 2011**). Four indicators have been used in the MEDALUS model to assess the desertification index which are vegetation quality, climate quality, management quality, and soil quality. Many researches used the MEDALUS model to assess the desertification in the Mediterranean region with precise satisfactory results (**Basso et al 2000 and Eun et al 2019**).

Wadi El Natrun has always been confined as a possible area for reclamation because of its good location and has groundwater appropriate to irrigation. The source of this water is the streams of the Nile River, due to its closeness and low level (**El-Maghraby, 1990**). Wadi El Natrun is considered one of the most important depressions in the Western Desert of Egypt, which is famous for its reclaiming new lands. Agriculture in Wadi El Natrun depended on groundwater with spraying and drip method, field crops and orchards have been cultivated in the newly reclaimed land. Thus, the existence of irrigation water as ground water of suitable quality, the existence of natural freshwater springs and availability of water in the sandy layers above the shallow water table southwest of the Depression are the main reasons for the importance of Wadi El-Natrun (**Abd El-Ghani et al 2015**).

The main objective of the current work is to employ geospatial analyses for assessing and mapping the environmentally sensitive areas (ESAs) to desertification in the area of Wadi El Natrun, North West Coast of Egypt using the MEDALUS multi-factor approach based on both general and local knowledge of the environmental processes acting.

## MATERIALS AND METHODS

### Study Area and satellite data

The study area includes Wadi El Natrun area and the surrounding desert fringes. It is located in Beheira Governorate at about 110 km northwest from Cairo between longitudes, 30° 02' to 30° 29' E and latitudes, 30° 16' to 30° 32' N. The area is about 4748 Km<sup>2</sup>, extended in a NW-SE direction and 23 m below sea level (bsl).

Landsat 8 (OLI) satellite image, acquired in 2018 (**Fig. 1**) and ASTERDEM satellite data of the investigated area, were used in this study (<https://earthexplorer.usgs.gov/>). ENVI (5.3) software was

used for image processing, while ArcGIS (10.4.1) was used for modeling and mapping the thematic layers. ASTERDEM data was used to extract the DEM of the investigated area (**Fig. 2**). Landsat-TM images were used for preparing the physiographic map (**Wulder et al 2008**), thus they were used for allocating 121 soil profiles representing different physiographic units. Soil profiles were dug down in the field and morphologically described and 332 soil samples were collected for analysis based on morphological features (**Fig. 1**). The samples were analyzed for physical and chemical characteristics.

### Desertification sensitivity analysis

There are four thematic indicators used for quantifying the environmental quality including; land management, soil, vegetation, and climate that were used in modeling the sensitivity to desertification (**Kosmas et al 1999 and Sepehr et al 2007**). The model includes the following formula: **DSI = (SQI\*VQI\*CQI\*MQI)<sup>1/4</sup>**. Where DSI is Desertification Sensitivity Index, SQI is the Soil Quality Index, VQI is the Vegetation Quality Index, CQI is the Climate Quality Index and MQI is the Management Quality Index. The soil indicator was calculated using seven parameters including; soil texture, slope gradient, soil depth, soil drainage condition, soil electric conductivity and soil Calcium carbonates content (**Le Bissonnais, 1996 and Mohamed, 2013**). Two additional variables were taken into account in soil quality index calculation i.e. salinity and alkalinity. The SQI indicator was obtained using the geometric mean of the score sub-indicators' values, with the formula: **SQI = (Soil depth \* Slope \* Texture \* Drainage \* Calcium carbonates \* Soil salinity and Alkalinity)<sup>1/7</sup>** (**Kosmas et al 1999**).

The vegetation indicator was assessed based on three parameters; plant cover density, drought resistance and erosion protection. The Plant cover was computed by deriving the Normalized Difference Vegetation Index (NDVI) retrieved from the Landsat image of the investigated area. The Vegetation Quality index (VQI) was estimated using the following equation: **VQI = (Drought resistance \* Erosion protection \* Plant cover)<sup>1/3</sup>** (**Kosmas et al 1999**). The management indicator was calculated based on Grazing intensity and land use. The Management Quality Index (MQI) was estimated using the next equation: **MQI = (Land use \* Grazing intensity)<sup>1/2</sup>**.

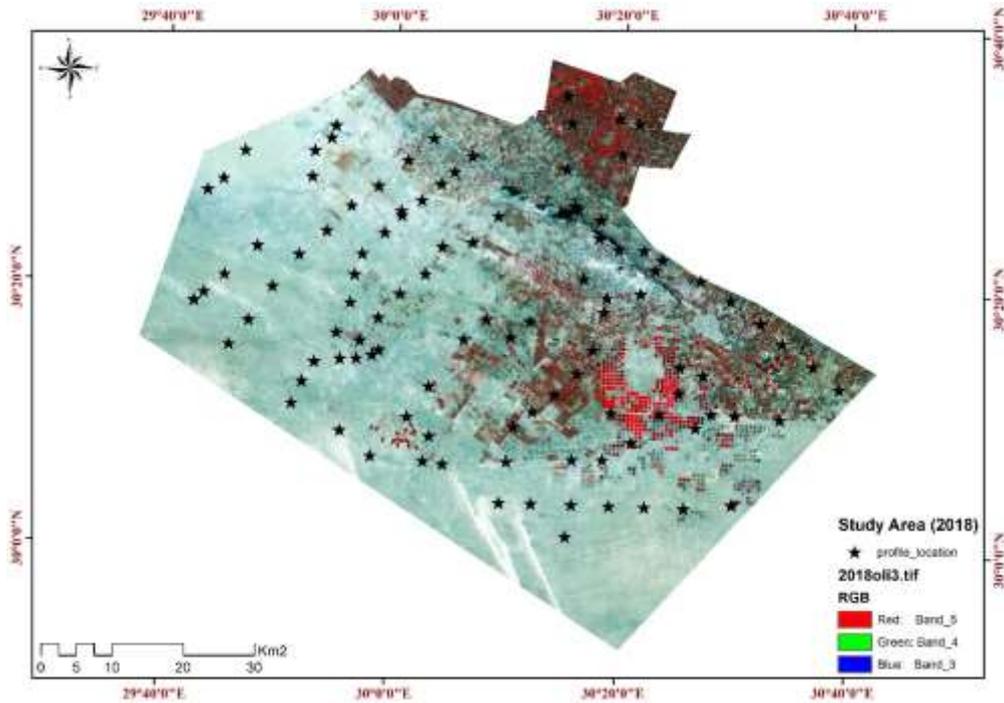


Fig. 1. Wadi El- Natrun Landsat 8(OLI ) image 2018 and the distribution of soil samples

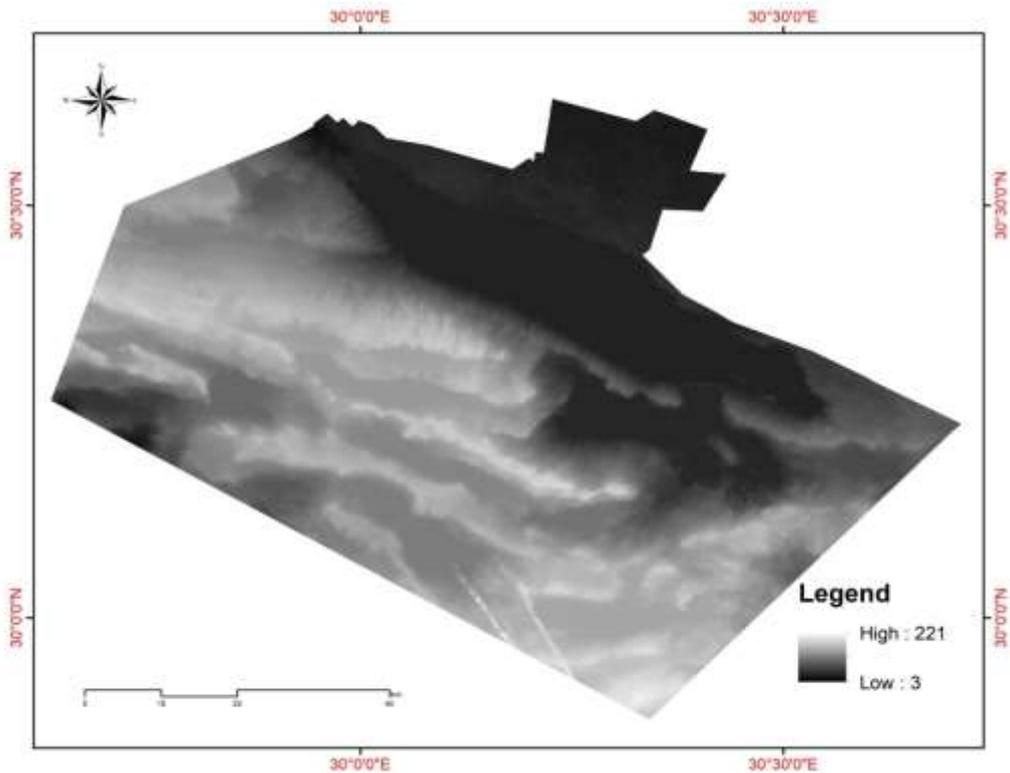


Fig. 2. Digital elevation model (DEM) of the study area

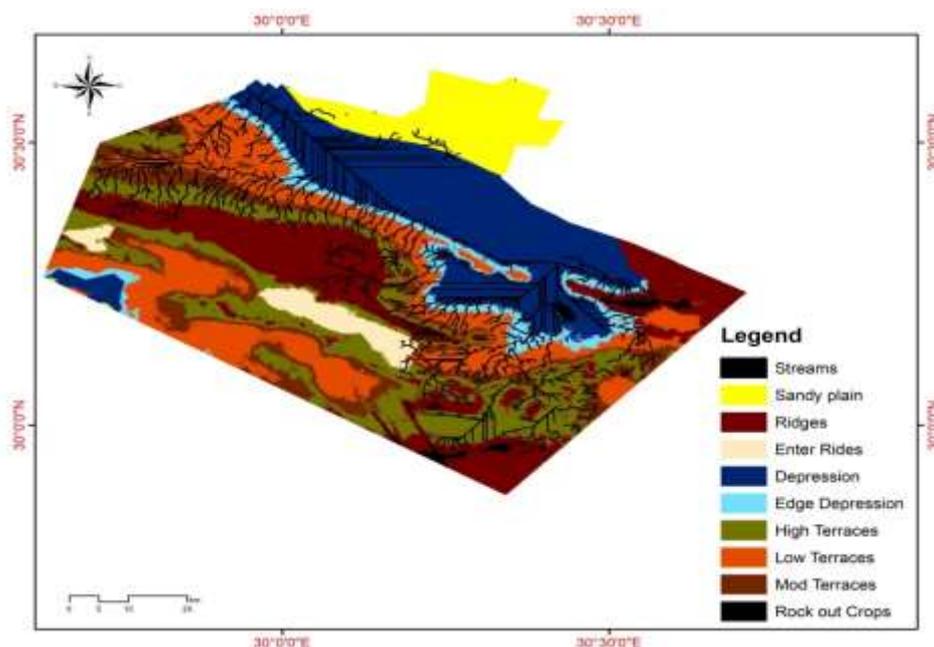
The climate indicator was calculated based on annual rainfall (R); wind speed (W) and slope aspect (Sa). The different classes of all the indicator parameters and weights are shown in details at **Kosmas et al (1999)**. The slope aspect was derived from ASTERDEM satellite image and calculated using the aspect function of ArcMap 10.4.1. The climate quality index (CQI) was acquired by combining the revealed parameters using the following formula:  $CQI = (Rainfall * wind\ speed * Slope\ aspect)^{1/3}$ .

Finally, the Desertification sensitivity index (DSI) was calculated from the four quality indicators using the following equation:  $DSI = (CQI * SQI * VQI * MQI)^{1/4}$ . According to the value of the DSA index, The quality indicators and the DSI index were mapped using Inverse Distance Weighting (IDW) interpolation method in ArcGIS 10.4.1 software.

## RESULTS AND DISCUSSION

### Soil physiographical units

The results of physiographic units extraction indicated that within Wadi El Natrun area there are major landforms, namely, streams, sandy plain, ridges, enter ridges, depressions, and terraces (**Fig. 3**). The streams are characterized as dry wadis ephemeral stream channel, especially in semiarid regions which only moves water in response to intense, infrequent precipitation as reported by **Schoeneberger and Wysocki (2005)**. Sandy plain is formed from sand sheet and a rather flat sandy area without any apparent surface structure. Terraces (high, low and medium) are structures of varying size and shape consisting of a flat section, which is cultivated, and an almost vertical riser protected by a stone wall. Rock out crops is a visible exposure of bedrock or ancient superficial deposits on the surface of the earth as shown in **Fig. 3**.



**Fig. 3.** The physiographic units of the study area.

**Soil quality index:** Data in **Table (1)** represent some chemical and physical properties of representative soil profiles of the studied physiographic units. It indicated that most of the studied soil samples are sandy textured soil with low silt and clay, very low in calcium carbonate content and variable soil salinity and alkalinity levels. The results of soil

quality indicators and soil quality evaluation are presented in **Fig. (4)** and **Table (2)**. It indicated that 91.6 % (4349.84 Km<sup>2</sup>) of the studied area is classified as "high soil quality". They occupy areas where slopes are strong and are dominated by a fine texture which promote good drainage. The moderate

soil quality class occupied about 199.45 Km<sup>2</sup> representing 4.2 % of the total area. Moreover, the soils of low qualities, which are very vulnerable to degradation, are about 3.02% (143.41 Km<sup>2</sup>) of the total

area. The low soil quality areas are distributed in small patches in the middle of the study location. The limiting factors of soil quality are salinization and soil alkalinity.

**Table 1.** Some Physical and Chemical properties of representative soil profiles

Prof. No	Depth	Texture	%clay &Silt	pH	EC dS/m	CaCO <sub>3</sub>	Physiographic unit
16	0-30	Sand	1.15	8.59	0.12	0.2	Mod Terraces
	30-60	Sand	2.68	8.84	0.80	0.2	
22	0-30	Sand	4.18	8.31	0.86	0.1	Low Terraces
	30-60	Sand	3.93	8.87	1.34	0.2	
	60-150	Sand	4.93	8.48	5.64	0.3	
48	0-30	Sand	1.5	8.5	1.10	0.1	Edge Depression
	30-60	Sand	2.5	8.51	0.70	0	
	60-150	Sand	2.3	8.82	0.70	0	
51	0-30	Sand	1.7	7.19	6.35	0.4	Enter Ridges
	30-60	Sand	2.4	8.22	1.10	0.6	
	60-150	Sand	2.6	8.22	4.10	0.7	
68	0-30	Sand	2.71	7.28	5.87	0.2	Depression
	30-60	Sand	2.22	7.72	5.70	0.4	
	60-120	Sand	2.33	7.85	3.60	0.4	
84	0-30	Sand	1.5	8.44	2.10	0.1	Ridges
	30-60	Sand	1.15	8.24	0.90	0.1	
	60-150	Sand	1.35	8.15	1.20	0.1	
94	0-30	Sand	2.19	7.43	1.3	0.2	Sandy Plain
	30-60	Sand	2.16	7.63	0.69	0.1	
	60-150	Sand	2.26	7.74	0.49	0.1	
115	0-30	Sand	1.6	8.35	1.18	0.1	High Terraces
	30-60	Sand	1.71	8.24	0.97	0.1	
121	0-30	Sand	0.4	8.46	1.80	0.1	Rock out Crops
	30-120	Sand	0.62	8.20	1.50	0.1	

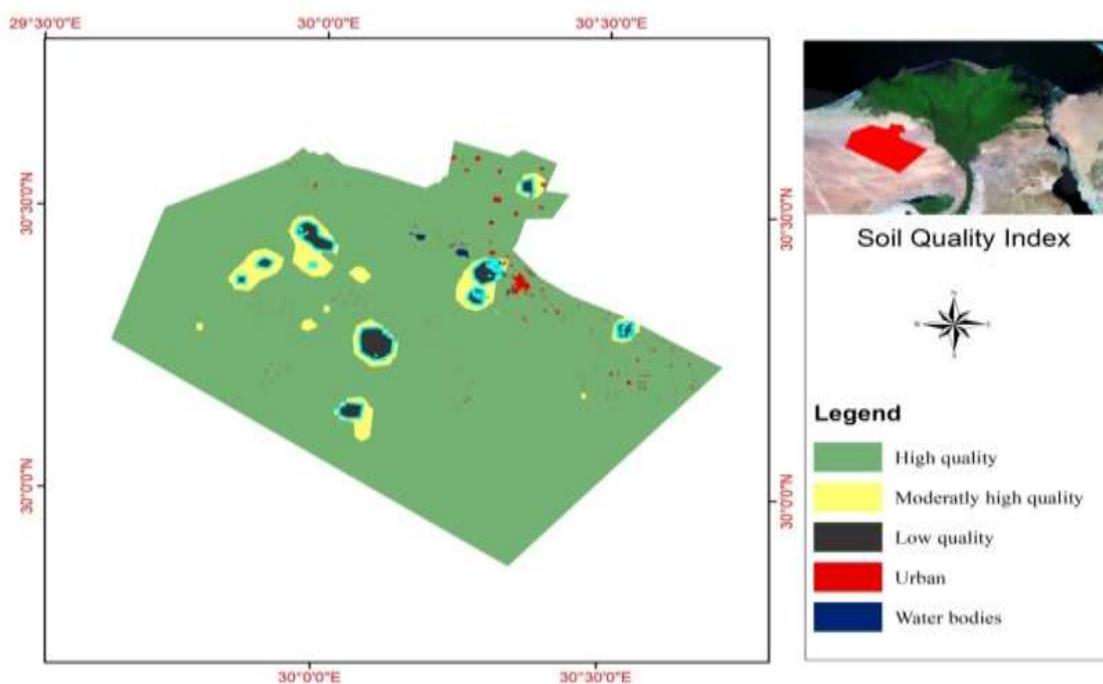


Fig. 4. Classes of soil quality index

Table 2. Soil quality classes in the studied area

SQL class	Score	Area %	Area (Km <sup>2</sup> )
High quality	<1.2	91.6	4349.84
Moderate quality	1.2-1.25	4.2	199.45
Low quality	>1.5	3.02	143.41
Urban and water bodies	-	1.2	56.98

**Vegetation quality index:** VQI is an important factor for evaluating the degree of desertification sensitivity. The obtained data revealed that the areas characterized by moderate vegetation quality index occupied an area of about 1.6 % of the investigated area (75.98 km<sup>2</sup>). About 45% of the total area was characterized by low vegetation quality index, as shown in Table 3 and Fig. 5. The decrease in vegetation quality index was due to the non-existence of forests and drought resistance crops in the study area.

Table 3. Vegetation quality classes in the studied area

VQL class	Score	Area %	Area (Km <sup>2</sup> )
Moderate quality	1.2-1.4	1.6	75.98
Low quality	> 1.4	45.8	2174.92
Bare land	-	51.4	2440.85
Urban and water bodies	-	1.2	56.98

**Management quality index:** MQI contained within grazing intensity and land use, which were essential factors controlling the desertification phenomena. The results in Fig. (6) and Table (4) indicate that about 46.4 % of the total area is suffering from mismanagement of land resources and over-grazing. The areas of moderate quality index represent about 44.1 % of the total area while 8.2 % of the total area is characterized by a high-quality index. These results could be returned to that most of the study area is a non vegetated desert and management plans were not used.

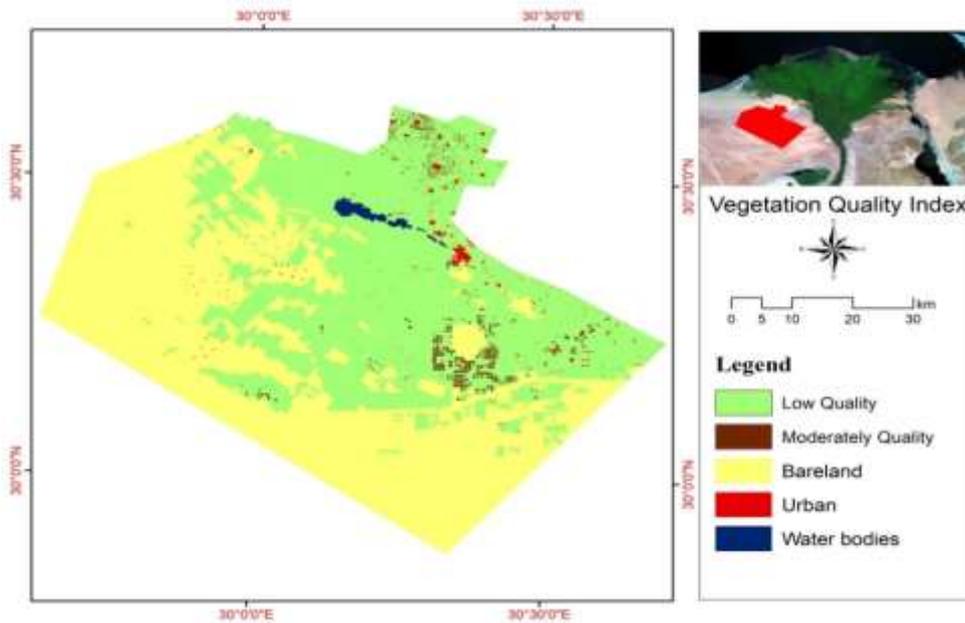


Fig. 5. Vegetation quality index classes of the studied area

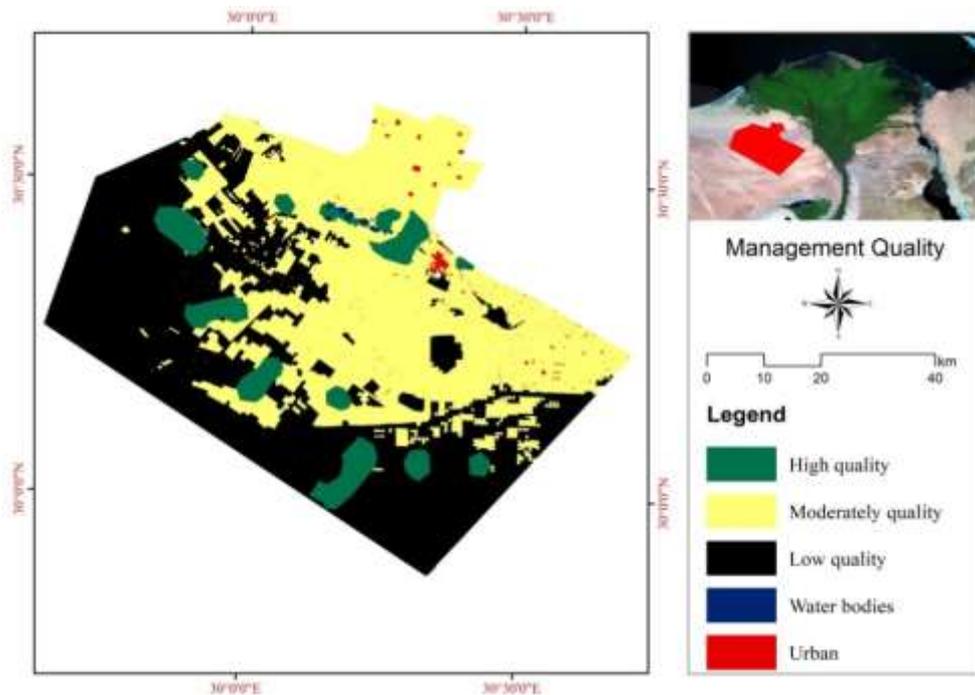


Fig. 6. Classes of management quality index

**Table 4.** Management quality classes in the studied area

MQL class	Score	Area %	Area (Km <sup>2</sup> )
High quality	1-1.3	8.2	389.40
Moderate quality	1.3-1.5	44.1	2094.19
Low quality	>1.5	46.5	2208.16
Urban and water bodies	-	1.2	61.73

**Climate quality index:** Meteorological data, average of 10 years between 2008-2018 were recorded in **Table (5)**. Data revealed that Wadi El Natrun area

is characterized by an extremely arid region. The mean annual wind speed, temperature and rainfall are 3.2 Km/h, 16.4°C, and 26.62 mm, respectively.

The rainfall, aspect and wind speed are the main climatic attributes that contribute to the desertification processes. The result illustrated 37.8 % of the total area characterized by a moderately climatic index (arid). It occupies an area of about 1870.77km<sup>2</sup> as shown in **Table 6 and Fig. 7**. However, the area which represented 61.3% is characterized by semi-arid conditions. Arid areas are characterized by high elevation thus receiving rainfall which then accumulated in the low lands that are classified as semi-arid areas.

**Table 5.** The climatological data of the study area

Month	Average temperature °C			Rainfall (mm) total	Relative humidity %	Wind velocity km/h
	Max. °C	Min. °C	Mean			
Jan.	18.4	9.7	13.4	4.20	64.6	3.2
Feb.	19.9	9.9	14.3	6.20	61.4	3.2
Mar.	22.6	11.3	16.3	5.90	58.1	3.3
Apr.	26.2	13.7	19.4	0.60	54.1	3.2
Jun.	29.2	16.8	22.5	0.30	52.6	3.2
Jul.	32.6	20.4	26.0	0.00	53.8	3.4
Aug.	33.6	22.2	27.4	0.00	57.8	3.5
Sep.	34.0	23.1	27.9	0.00	58.5	3.2
Oct.	32.2	21.9	26.3	0.03	58.9	3.1
Nov.	28.7	19.4	23.3	0.19	60.8	3.0
Dec	24.1	15.3	19.3	2.00	64.7	2.8
	19.9	12.3	15.3	7.20	65.8	3.2
<b>Mean</b>			<b>16.4</b>		<b>59.2</b>	<b>3.2</b>
<b>Total</b>				<b>26.62</b>		

**Table 6.** Climate quality classes of the studied area

CQL class	Score	Area %	Area (Km <sup>2</sup> )
Semi – arid	1-1.3	61.3	2910.97
Arid	1.3-1.5	37.5	1780.77
Urban and water bodies	-	1.2	56.98

#### Desertification-sensitive spatial modeling

The integration of soil parameters, climate conditions, vegetation cover, management, and soil quality were considered to derive the model process. There are four different degrees of desertification recorded in the study area; low, moderate, sensitive and very sensitive as shown in **Table 7 and Fig. 8**. The major part of the study area was covered by indicated low sensitive areas amounting 3623.28 km<sup>2</sup> (76%) of the studied area except some scattered areas. These areas are characterized by the

presence of dense crops and orchards, which reduces soil erosion, in addition to a part of these areas is not cultivated and characterized by high soil quality. However, the very sensitive areas were observed as small patches in different parts of the study area particularly the central zone; amounting 55.56 km<sup>2</sup> (1.17%). The total recorded areas of moderately sensitive and sensitive classes were nearly the same levels; 519 km<sup>2</sup> and 493 km<sup>2</sup>, respectively. The high sensitivity is attributed to low

soil quality, topographic condition, land use, as well as climate condition.

The DSI map showed that there is a spatial leveling in the desertification risk within different sites since the very sensitive areas are located in the middle of the region surrounded by the sensitive and the moderately sensitive areas, respectively. This indicates the negative impact of very sensitive areas on the surrounded lands.

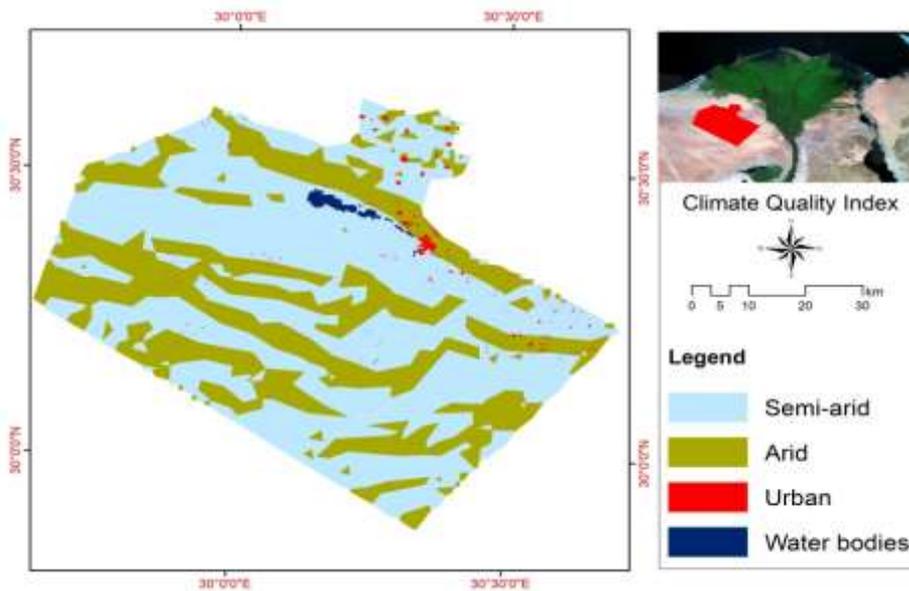


Fig. 7. Classes of the climate quality index

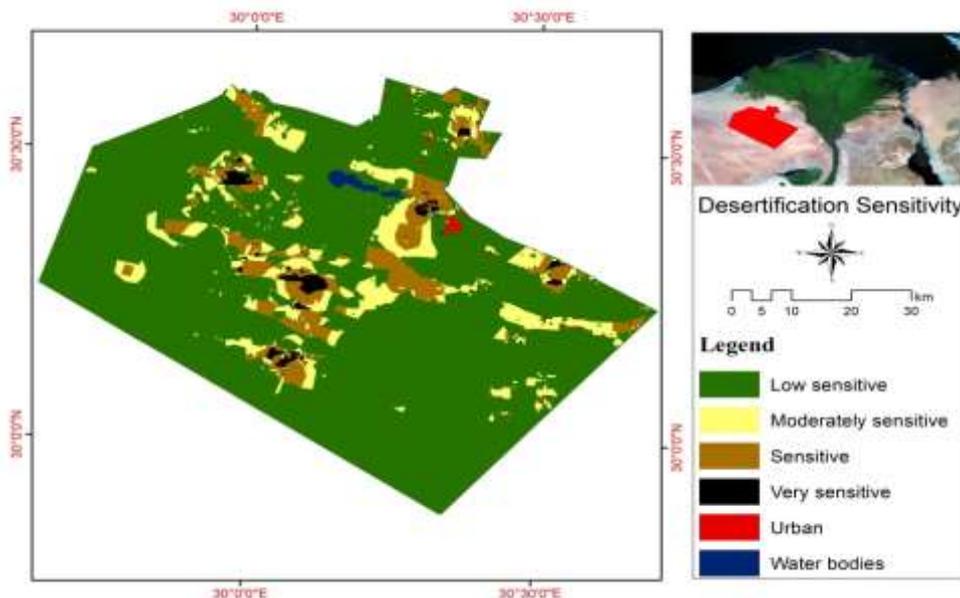


Fig. 8. Desertification sensitivity map of the study area.

**Table 7.** Desertification sensitivity classes of the studied area

DSI class	Score	Area %	Area (Km <sup>2</sup> )
Low sensitive areas	1.2-1.3	76.3	3623.28
Moderately sensitive areas	1.3-1.4	10.93	519.04
Sensitive areas	1.4-1.6	10.4	493.87
Very sensitive areas	> 1.6	1.17	55.56
Urban and water bodies	-	1.2	56.98

### CONCLUSIONS

The study area represents Wadi El Natrun which is one of the important areas for land reclamation and developmental projects. Present study represents one of the initial attempts to use the MEDALUS model for desertification assessment in the desert extension of El-Beheira Governorate. The MEDALUS is a distinguished model for evaluating the desertification phenomena in arid and semi-arid regions on basis of laboratory analyses, spatial data and various GIS thematic layers. To achieve this, several inputs criteria covering four different indicators (i.e., management quality, vegetation quality soil quality, and climate quality) were used. The model presented optimistic results showing that most of the study area (76 %) was covered by the low sensitive areas to desertification. A portion of the low sensitive areas are not yet cultivated and are characterized by high soil quality index. It can be concluded that the desert extension of El-Beheira Governorate (i.e. Wadi El Rayan) is one of the areas that possess valuable land resources which should be considered for future land reclamation projects. Similar international studies are recommended to be achieved with the use of multi-criteria GIS modeling (i.e. MEDALUS) which considered all relevant factors in the form of thematic layers for easier implementation and assessments.

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## التقييم والتحليل المكاني لحساسية التصحر في وادي النطرون، شمال غرب مصر

### باستخدام نموذج MEDLAUS

[50]

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### الموجز

النتائج أن 10.4% من منطقة وادي النطرون تعتبر منطقة شديدة الحساسية للتصحر بسبب القلوية والملوحة، بينما تحتل درجة الحساسية المتوسطة للتصحر 10.93% من منطقة الدراسة. تشغل درجة الحساسية المنخفضة مساحة قدرها 76.3% وتتميز تلك المنطقة بجودة التربة العالية حيث تمثل أحد مناطق التنمية الجديدة الواعدة التي لم تتأثر بعد بعوامل التصحر.

**الكلمات المفتاحية:** التصحر، MEDALUS، وادي النطرون، نظم المعلومات الجغرافية، الاستشعار من البعد

تؤدي ظاهرة التصحر الى انخفاض إنتاجية التربة وبالتالي تؤثر على المخزون الغذائي. تهدف الدراسة الحالية الى دمج بيانات الاستشعار من البعد ونظم المعلومات الجغرافية لتقييم الحساسية البيئية للتصحر في منطقة وادي النطرون، مصر باستخدام نهج التصحر واستخدام الأراضي في منطقة البحر الأبيض المتوسط (MEDALUS). تم الاعتماد على بيانات التربة التي تشمل الوصف المورفولوجي للقطاعات الممثلة وتحليل عينات التربة، بالإضافة إلى بيانات المناخ والغطاء النباتي وبيانات الإدارة لتقييم حساسية التصحر. أظهرت