

Monitoring and evaluation of desertification and land degradation processes on northwestern coast Egyptian territories

Abstract

The submitted research activities and outcomes include assessing and mapping the environmental sensitivity and desertification of the northwestern coast of the Arab Republic of Egypt Located in the hyper-arid climatic zone. The desert (96% of Egyptian territories) is characterized by its abundance of natural resources, such as arable land, pastureland, economic minerals and wild animals and plants.

Egypt suffers from an increase in population density in the Nile Delta and Valley, necessitating the establishment of new, integrated urban communities in desert areas. The priority given to Egypt's northwestern coast is clear, given its history as a geographical extension of the Western Desert. It is one of the most important development areas, as it is one of the regions recorded in history as a granary during Roman civilization. This is due to its abundant groundwater resources and natural biodiversity, along with the adaptation of its inhabitants to these unique environmental conditions.

Land use/ cover were mapped, on bases of multi-temporal satellite images (Landsat TM 2004 and sentinel 2018), applying several contrast-stretching processes. Rectification of the scenes studied was performed using enough GCP's, distributed randomly all over the images. The studies revealed that northwestern coast represents productive and adaptive biodiversity areas in Egyptian Western Desert. Environmental sensitivity leads to the coastal sand dunes formation and encroachment, which leads to the intrusion of salty seawater into lands with highly porous sandy soils, leading to salinization and waterlogging of the lands, leading to a reduction in the productivity of these areas. It could be concluded that developing a quantitative model of concept will identify the sensitivity factors, which supports decision-making for sustainable development.

Keywords: assessing, mapping, Environmental sensitivity, desertification, northwestern coast, Egypt

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Introduction

Desertification refers to the process of land degradation occurring in arid, semi-arid, and dry sub-humid areas as a result of climatic variability and/or human activities.¹ The increasing pressure exerted on land resources by human activities has intensified land degradation and contributed to the expansion of desertification, which has consequently attracted considerable attention in recent scientific research. When mapping desertification worldwide, the FAO/UNEP described and considered the following six processes: vegetation degradation, The major forms of land and soil degradation include erosion caused by water and wind, soil salinization, depletion of soil organic matter, soil crust formation and compaction, as well as the accumulation of toxic substances that may adversely affect plants and animals. It is possible to incorporate other processes that have negative impacts, including the urbanization of agricultural land.² Monitoring desertification takes into account three criteria: status, rate, and inherent risk. By integrating man-made and natural components, it is possible to estimate the hazard of desertification.

Ideal indicators for assessing desertification should be quantitative, sensitive to minor changes, easy to measure, and limited in number.³ These indicators should encompass various dimensions, including climate conditions, soil characteristics, topography, vegetation, wildlife, socio-economic factors related to land and water use, as well as human biological and social parameters.

Desertification assessment is conducted by assigning numerical ratings to land affected by each process contributing to desertification, categorized within defined classes of severity. Desertification intensity is commonly classified into four levels: slight, moderate, severe, and very severe, with the very severe category representing the most extreme degree of desertification conditions.⁴ Mapping desertification serves to illustrate its underlying causes and dynamic patterns, providing a valuable tool for planning preventive and mitigation strategies.

In 1977, the United Nations Conference on Desertification established a comprehensive Plan of Action aimed at addressing and combating desertification.⁵ While international, regional, and sub-regional cooperation is essential due to the trans boundary nature of the issue, effective and impactful measures should primarily be implemented at the national level.

Effective implementation of development plans requires accurate and up-to-date information. This includes real-time data integrated with technical methods and analyses to produce environmental sensitivity maps and geospatial databases for soil, water, and environmental resources. Desertification continues to represent a major environmental challenge, particularly across arid and semi-arid regions, where limited water availability constitutes a primary constraint on land productivity. This phenomenon is driven by a range of interconnected and complex processes operating within these fragile ecosystems (Batterbury and Warren, 2001).

Environmental processes typically maintain a dynamic equilibrium in response to external pressures. Small variations in driving factors, including temperature and land-use changes, are generally accommodated or buffered by the system. Resulting in only slight adjustments. However, when specific thresholds are exceeded, the land components may undergo irreversible changes, leading to desertification (Tucker et al., 1991; Nicholson et al., 1998).

Assessing the influence of environmental factors

Area of supported case of study: The present study focuses on the northwestern coastal region of Egypt, encompassing a buffer zone

Table 1 Climatic meteorological station of the north coast of Egypt

Station	Latitude	Longitude	Relative humidity (%)	Temp. mean (°C)	Temp. Max (°C)	Temp. Min (°C)	rain total (mm/yr)	wind speed (m/sec)
Sallum	31.53	25.18	59	20.4	25	16.4	105	8.5
Barrani	31.63	25.47	67	19.4	23.7	15	171.4	9.7
Matrouh	31.33	27.22	67	19.2	24.2	14.5	137.7	10.3
Ras hekma	31.07	27.83	67	19.7	23	16.4	147.1	10.4
Eldabaa	30.93	28.47	68	19.2	24.3	14.2	140.4	10.6
Ras teen	31.2	29.85	68	20.4	23.1	17.8	179.2	8.1
Alex	31.2	29.95	68	19.8	25	15.8	199.4	7.8

extending approximately 20 km inland from the Mediterranean Sea coastline. The study area stretches from the western part of Alexandria Governorate to the Al-Saloum region in Marsa Matrouh Governorate, extending westward to the Egyptian–Libyan border (Figure 1) a from 7 climatic station, located in the study area (Table 1) and (Figure 2). Climatic factor, contributing to desertification sensitivity was calculated to all the available climatic station.

Main climatic features of the Egyptian northern coast

Rainfall

Climatic conditions and rainfall distribution: The climatic data indicate that the rainy season generally begins in October, with approximately 75% of the annual rainfall occurring between November and February. December and January are considered the wettest months, while rainfall received from March onward accounts for no more than 10% of the total annual precipitation. Consequently, the region experiences a relatively prolonged dry season lasting approximately seven months.

Alexandria receives the highest annual precipitation along the northwestern coast of Egypt, with average values of approximately 180–190 mm. In contrast, El Dabaa, Mersa Matruh, and Sidi Barrani receive relatively similar amounts of rainfall, averaging about 145 mm annually. The coastal area extending from Alexandria to Burg El Arab generally records greater precipitation than these locations, with annual rainfall ranging between 156 and 180 mm. Spatial variations in topography also contribute to differences in rainfall distribution; consequently, areas such as Fuka and El Sallum receive comparatively lower amounts of precipitation.

According to FAO (1970), rainfall decreases by approximately 30–50% at a distance of about 15 km inland from the coastline. The spatial distribution of rainfall along the northwestern coast of Egypt is presented in Figure 3 and Table 2.

Table 2 Distribution of the rainfall in the studied area (A)

Rainfall (mm/yr)	Area (Km ²)	Area %
84 – 122	662.87	7.89
122–160	5777.9	68.78
160 – 228	1959.23	23.32
Total	8400	100

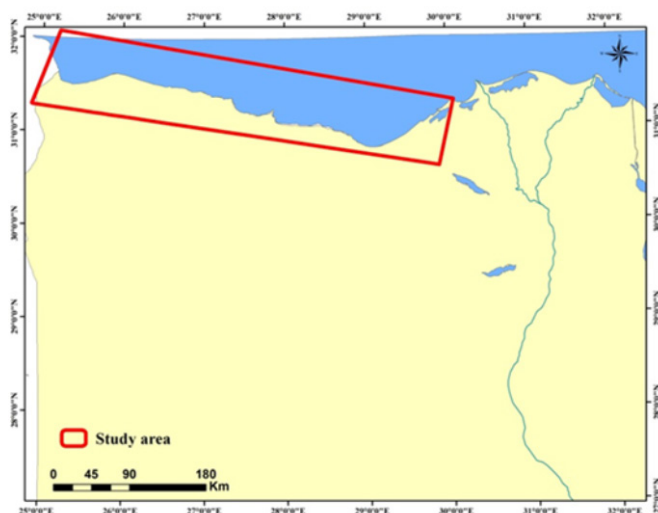


Figure 1 The area of study.

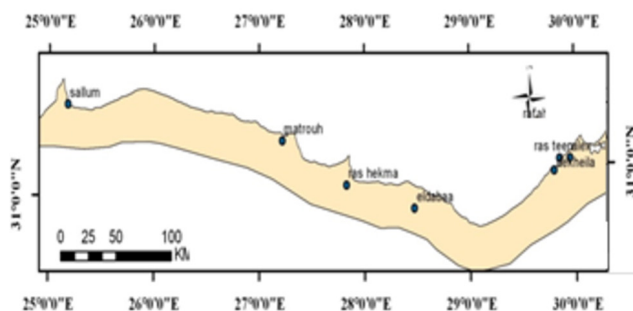


Figure 2 Location of 7 meteorological stations records.

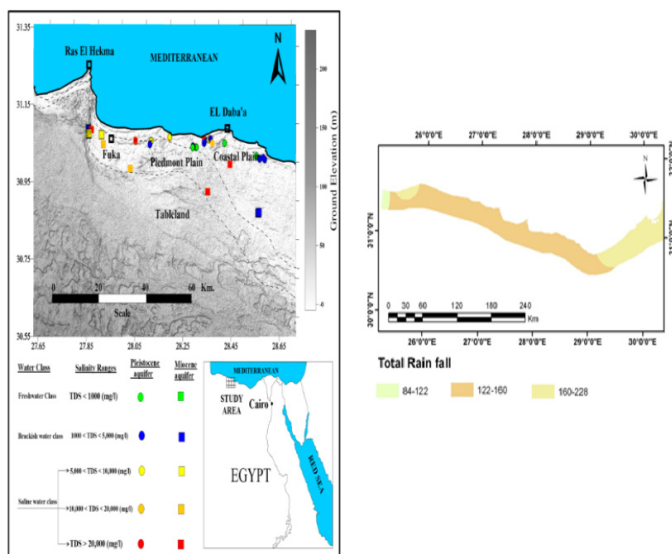


Figure 3 Rain fall distribution map of Egyptian Northwestern coastal area.

As illustrated, 40.24% of the total area receive 122-228 mm/yr rains, while 2.31% of the total area receive >228 mm/yr rains.

Air temperature

The northwestern coastal region of Egypt exhibits relatively limited interannual variability in air temperature. The mean annual maximum air temperature ranges from 22.9°C in 1979 to 24.9°C in 1978, whereas the annual mean minimum air temperature varies between 14.3°C in 1980 and 18.4°C in 1977. Overall, the differences in air temperature recorded among individual years are relatively small. The highest temperatures generally occur during July and August, followed by a gradual decline toward the lowest values in December and January. The prevailing temperature regime along the northern coast provides generally favorable conditions for the cultivation of a wide range of crops.

The region is also characterized by relatively high relative humidity, which contributes to favorable conditions for plant growth. The lowest air temperatures are typically recorded during January and February. Overall, the study area experiences a characteristic Mediterranean climate, with climatic conditions strongly moderated by the proximity of the Mediterranean Sea.

Springs begin in the first weeks of March and there is a marked increase of the maximum day temperature (above 20 °C) but the nights in general remain cool. April is characterized by frequent “Khamasin winds” bringing the maximum temperature over 30° C or even 35 °C for two or three days at time. The summer lasts over 5 months, from May till the end of October. The day temperature is warm and is fluctuating between 25 and 30 °C. the night temperatures are rather high particularly in August and September (more than 20 °C). The distribution of air temperature classes revealed that 58.14 % of the total area has air temperature between 31.2 and

31.7 °C while 4.11% of the total area has air temperature of 30.8 °C and the rest have temperature ranges from 30.8 to 31.2° C (Table3, Figure 4).

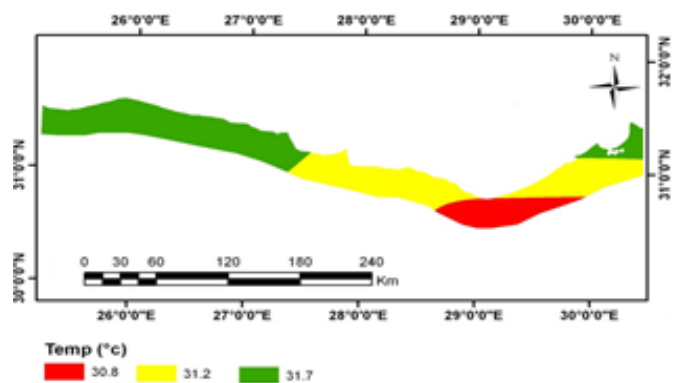


Figure 4 Distribution map of air temperature at the northwestern coast of Egypt.

Table 3 Distribution of air temperature classes in the studied area

Temperature (°C)	Area (Km ²)	Area %
30.8	344.85	4.11
30.8-31.2	3171.25	37.75
31.2-31.7	4883.9	58.14
Total	8400	100

Relative humidity

Relative humidity reaches its highest levels during July and August. Spatial differences are also evident across the study area, with El Sallum recording the lowest relative humidity, whereas Alexandria exhibits the highest values, as illustrated in Figure 5.

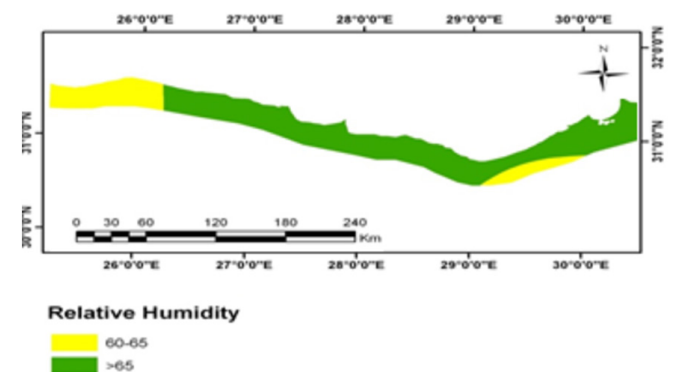


Figure 5 Relative Vegetation quality umidity distribution map of the studied area.

Saturation deficit, which is the difference between the saturated and the actual vapour pressure of the air is a better way to express the drying power of the air that has a more biological meaning than the relative humidity. Sidi Barrani along the whole coast seems to be climatically most favorable for vegetation growth of plants with a saturation deficit of 5-9mm.Hg against a general deficit of 5-11 mm.Hg.

As illustrated in Table 4, 37.17 % (11530 km²) of the studied area have high relative humidity while 33.2% of the total area has moderate relative humidity and the rest of the total area have low in relative humidity.

Table 4 Distribution of the relative humidity classes

Relative humidity class	Relative humidity %	Area (km ²)	Area %
60-65	63-66	1788.13	21.29
>65	67-69	6611.87	78.71
Total		8400	100

Wind

Different investigations indicate that the wind speed, at an altitude of 10 meters, range between 3.8 to 5.2 m/sec (Figure 6). The prevailing wind is mostly from the north however, 25% of windy days record southerly dusty warm storms.

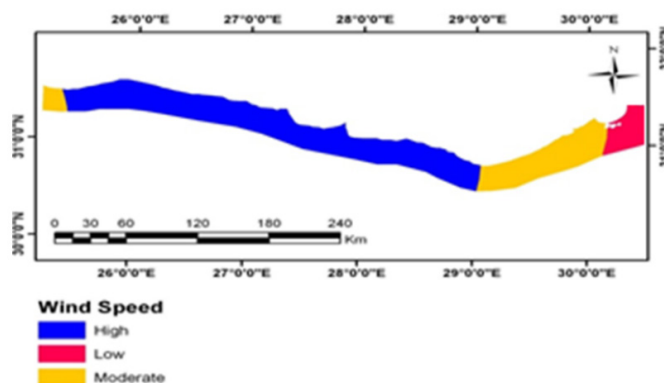


Figure 6 Wind speed distribution map.

The later harm cultivation and causes soil water loss through its influence on increasing evapotranspiration.

As illustrated in Table 5 the wind speed distribution of 65.15% (20207.43 km²) of the total area represented by >65 m/sec while 14.03% of the total area have <60 m/sec wind speed and the rest of the area have 60-65 m/sec wind speed.

Table 5 Distribution of the wind speed class

Wind Speed (m/sec)	Area (km ²)	Area (%)
Low	621.64	7.4
Moderate	1614.79	19.22
High	6163.58	73.38
TOTAL	8400	100

Soil factor

The soils of Egypt's northwestern coastal region are predominantly characterized by high calcium carbonate contents, which can be attributed to the nature of their parent materials and the relatively weak and restricted leaching processes. Under the prevailing arid climatic conditions, the downward movement of carbonates is limited, leading to their accumulation within distinct zones or soil horizons. In some soil profiles, carbonate accumulation is sufficiently pronounced to meet the criteria of calcic horizons, whereas in other profiles, the degree of secondary carbonate enrichment is insufficient for such classification.

The parent materials from which the soils have developed can be broadly classified into four main origins: alluvial, marine, aeolian, and lagoonal deposits. The northwestern coastal zone of Egypt forms a relatively narrow belt extending approximately 20 km inland from the coastline and covering nearly 500 km between Alexandria and Salloum near the Libyan border. The region covers an area of

approximately 10,000 km², corresponding to nearly 2.5 million acres. It comprises a variety of landforms and associated soil types that have developed in response to the prevailing environmental conditions and remain in a state of relative equilibrium with their surroundings. From a pedological perspective, the majority of these soils are considered relatively young.

Land use throughout the northwestern coastal zone is dominated by marginal rangelands that support pastoral activities. Nevertheless, extensive discontinuous areas are utilized for rainfed agriculture. Cereal crops, particularly barley and wheat, are cultivated during the rainy season following a prolonged fallow period extending from May to October. In addition, several fruit crops, including olive, fig, peach, date palm, and almond, are cultivated in the region, along with various vegetable crops. The total cultivated area within this coastal zone is estimated at approximately 0.3 million acres, while the overall cropping area reaches about 0.5 million acres

Topography

The topography of the North costal area shows variable terrain from the east to the west. The western section (i.e. north western desert) shows terrain landscape in the form of limestone plateau, steep escarpment with maximum elevation of 400 m asl. There are also mobile sand dunes, flat depressions and coastal sandy beach. Figure 7 shows. The elevation of the land surface within the study area.

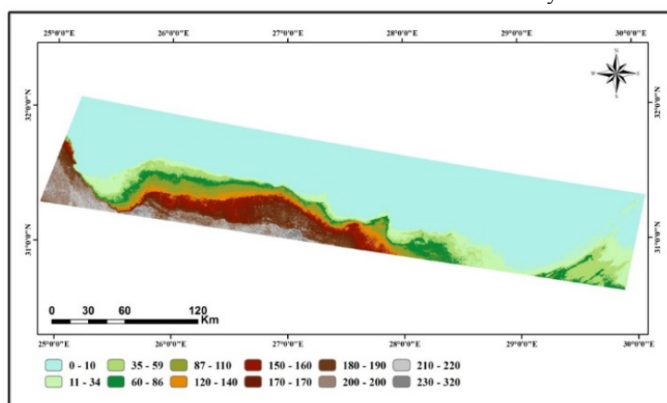


Figure 7 Digital elevation model of the study area.

Slope

The slope characteristics of the study area were derived from the Digital Elevation Model (DEM) and expressed in degrees relative to the north. Based on slope gradients, Sholtez (1972) classified the land within the study area (Figure 8) according to its suitability for various land uses and development activities into the following categories:

- Plain: 0.0–0.5°
- Slightly sloping: 0.5–2.0°
- Gently inclined: 2.0–5.0°
- Strongly inclined: 5.0–15.0°
- Steep to very steep slopes: >15.0°

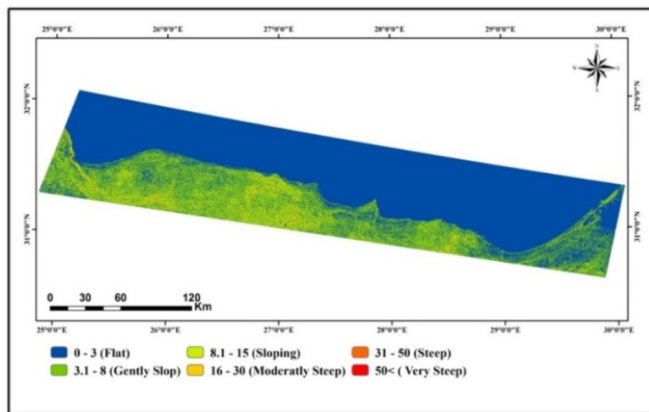


Figure 8 Slope of the area of study.

Slope aspect

Aspect is the direction of slope and is generated from the DEM. The area of study shows tilting in all directions (Figure 9). However, the high percentage are in the northern direction. The variable aspect directions may be attributed to the variety of the landforms in the area particularly the sand dunes. Such variable aspect should be considered in any of the development plans, particularly for irrigation and agricultural purposes.

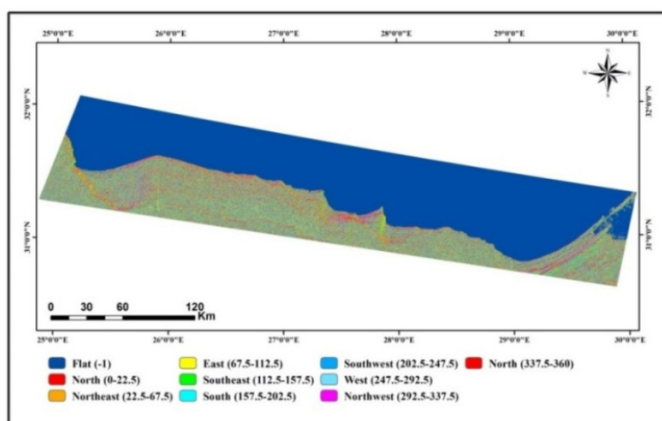


Figure 9 Aspect of the area of study.

Application of a provisional methodology for the assessment and mapping of desertification

The provisional methodology developed by FAO/UNEP (1984) for the assessment and mapping of desertification was adopted to investigate the active desertification processes occurring within the study area. This methodology provides established assessment criteria and class limits for evaluating four major desertification processes: salinization, water erosion, wind erosion, and vegetation degradation.

Table 6 Class limits for chosen criteria for assessing different aspects of salinization

Desertification aspect	Assessment factors	Class limits			
		Slight	moderate	severe	Very severe
Status	1. Morphological indication		Spots of salts	Spots and micelles of salts	Pseudo sand salt crust
	2. E _{Ce} (ds/m)	<4	04-Aug	Aug-16	>16
	3. ESP	<5	May-20	20-45	>45

Aspect of desertification

To facilitate the assessment and mapping process, the various components and characteristics of desertification must be systematically identified, described, quantified, and coded. desertification which will be as follows:

Status of desertification

The status refers to the existing condition of a specific area of land at the time of observation in comparison with the conditions that prevailed in the past. Accordingly, the assessment of land status requires comparison with an appropriate reference or baseline condition.

Rate of desertification

The rate of desertification is the changes which have occurred of the desertification processes per unit of time.

Inherent risk of desertification

The inherent risk of desertification is determined by the vulnerability of the landscape to various desertification processes, in addition to the prevailing natural conditions. These conditions include climatic characteristics, physiographic features, soil erodibility, water quality, and the depth of the groundwater table.

Hazard of desertification

The assessment of desertification hazard requires an integrated consideration of the current status, rate of change, and inherent susceptibility of the land to desertification, with particular emphasis on the dominant processes responsible for land degradation. It should also incorporate the effects of anthropogenic activities and grazing pressure exerted by livestock on the environment.

Desertification classes

Assessing desertification is carried out by assigning numerical ratings to the various land characteristics that contribute to the evaluation of desertification. affected by each one of the process within the specific classes of desertification. Four classes of desertification are used to show the intensity (slight, moderate, severe and very severe). The very severe class indicates are used to characterize the intensity of desertification and classify its severity into four categories: slight, moderate, severe, and very severe. The extreme conditions. Mapping the desertification aims to demonstrate its causes and it provides valuable information on the dynamics of desertification and is particularly useful for planning and implementing preventive measures.

Assessment criteria for status, rate and inherent risk

Recommended Factors and Class Limits for Major Desertification Processes are given respectively in Table 6 to Table 9. The rate is evaluated over an average of 10 years period.

Table 6 Continued....

Rate	1. Increase in ECe per year	<0.4	0.4-0.8	0.8-1.6	>1.6
	2. Increase in ESP per year	<0.5	0.5-2	2-4.5	>4.5
Inherent risk	Depth to ground water table (cm)	<300	300-100	100-50	<50
	General drainage	Good	imperfect	poor	poor

Table 7 Class limits for chosen criteria for assessing of different aspect of water erosion

Desertification aspect	Assessment factors	Class limits			
		Slight	moderate	severe	Very severe
Status	1. surface status (% of gravels)	<10	Oct-25	25-50	>50
	2. soil thickness (cm)	>90	90-50	50-10	<10
Rate	1. Increase in erode area per year	<1	01-Feb	02-May	>5
	2. soil loss, t/ha/yr	<2	2-3.5	3.5-5	>5
Inherent risk	Rating of climate aggressivity	0.03	0.03-0.06	0.07-0.1	>0.1
	Rating of potential soil loss in t/ha/yr	<5	May-15	15-25	>25

Table 8 Class limits for chosen criteria for assessing of different aspect of wind erosion

Desertification aspect	Assessment factors	Class limits			
		Slight	Moderate	severe	Very severe
Status	1. soil thickness (cm)	>90	90-50	50-10	<10
	2. surface gravel %	<15	15-30	30-50	>50
Rate	1. soil loss, t/ha/yr	<2	2-3.5	3.5-5	>5
	2. Increase in erode area per year	<1	01-Feb	02-May	>5
Inherent risk	1. wind erodibility group (texture class)	Sand clay loam, sandy clay silt	Rest of textural class	Loamy sand	sand
	2. mean annual wind speed, m/sec	<2	2-3.5	3.5-4.5	>4.5

Table 9 Class limits for chosen criteria for assessing of different aspect of degradation

Desertification aspect	Assessment factors	Class limits			
		Slight	moderate	severe	Very severe
Status	1. canopy cover of perennial plant%	>50	50-20	20-May	<5
Rate	1. range condition degradation% per year	<2.5	2.5-5	5-7.5	>7.5
Inherent risk	Potential for reclamation (year)	<3	03-May	05-Oct	>10

Desertification hazard

To evaluate desertification hazards, consideration should be given to the natural susceptibility of the land to desertification, based on the assessment of its current status, rate of change, and inherent risk, as well as the influence of anthropogenic factors. For the purposes of the methodology described herein, it has been established that the principal elements to be considered in the quantification of anthropogenic factors are as follows: Livestock pressure on the environment Population pressure on the environment.

For mapping desertification, the following FAO/UNEP (1984) guidelines were followed, and the Classes of desertification hazard (Table 10) were used.

Table 10 Classes of desertification hazard

Class of desertification	% area in various desertification categories			
	Slight	Moderate	Severe	Very severe
Slight	>30	<30	<40	
Moderate	<30	>30	<40	
Severe	<30	>40		<30
Very severe	<20		>40	>30

Environmentally Sensitive and its impact on desertification at Northwestern Egypt

Environmental sensitivity to desertification is a complex concept to define and quantify, as it may result from a wide range of factors acting independently or in combination with one another (Rubio, 1995; UNEP, 1992; Basso et al., 2000). An Environmentally Sensitive Area (ESA) can generally be defined as a specific and spatially delimited unit in which environmental and socio-economic conditions are no longer balanced or are not sustainable under the prevailing environmental circumstances.

Across the Mediterranean region, Environmentally Sensitive Areas (ESAs) exhibit different degrees of sensitivity to desertification due to a variety of interacting factors. These include low rainfall and the occurrence of extreme climatic events associated with sparse vegetation cover, low vegetation resistance to drought, steep slopes, and highly erodible parent materials (Ferrara et al., 1999).

Desertification results from a combination of significant processes that operate actively within arid and semi-arid environments, where water availability represents the principal limiting factor controlling land-use performance and ecosystem productivity (Batterbury and Warren, 2001). The process of desertification may progress when specific land components exceed critical thresholds, beyond which further changes may result in irreversible environmental degradation (Tucker et al., 1991; Nicholson et al., 1998).

Different types of ESAs to desertification can be identified and spatially mapped using a set of key indicators that evaluate the capacity of land to withstand further degradation and its suitability for supporting particular forms of land use. At regional or national scales, these indicators can be grouped into four broad categories representing soil quality, climate, vegetation, and land management (Kosmas et al., 1999).

The Environmental Sensitivity Index (ESI) to desertification can be considered as the outcome of interactions among a range of elementary factors represented by different information layers. These factors may be associated with either direct or indirect processes of land degradation and desertification (Basso et al., 1998). Severe and potentially irreversible environmental degradation may occur when poor land-management practices interact with various combinations of critical environmental conditions related to soil, climate, and vegetation.

Soil quality

Soil texture has a profound influence on several important soil properties and processes, including drainage, water-holding capacity, soil temperature, erosion susceptibility, fertility, and productivity. Wind erosion constitutes a major concern when sandy soils are cultivated in regions characterized by prolonged dry seasons. The removal or reduction of vegetation cover can substantially accelerate wind erosion by increasing the exposure of the soil surface to wind action. Clay-rich soils, in contrast, generally have a greater capacity to retain water that is available to plants. Clayey soils generally have a greater capacity to retain water available for plant growth than sandy soils. Moreover, the presence of water considerably influences soil thermal properties. Wet clayey soils respond more slowly to changes in air temperature than sandy soils, particularly during spring and autumn. However, clayey soils are often characterized by relatively poor drainage of excess water and may consequently become waterlogged.

Soil texture also has a significant influence on the susceptibility of soil to erosion. As soil texture becomes coarser, the active surface area of the soil particles decreases, resulting in lower resistance to erosive processes. Although soil texture commonly varies with depth, the texture of the surface soil horizon is considered particularly important in evaluating erosion susceptibility. In addition, soil texture strongly influences the formation, stability, and resilience of soil structure. As clay content increases, the properties of the soil matrix, including

its structural form and stability, become increasingly controlled by the characteristics of the clay fraction and by the nature and quantity of cementing materials. Soil crust formation is likewise influenced by several factors, including soil texture. Differential swelling and structural breakdown tend to increase with increasing clay content, whereas slaking generally decreases, thereby promoting surface crust development. The mineralogical composition of the clay fraction also plays an important role in crust formation. Soils containing high proportions of silt, such as those developed from marl deposits, are particularly susceptible to crusting, which can result in increased surface runoff and sediment loss.

Two landform characteristics are particularly relevant to the assessment of desertification: (a) slope gradient or steepness and (b) the depth from the soil surface to the groundwater table. Slope steepness is important because it affects both the velocity and volume of surface water flow. Surface runoff generally increases with increasing slope gradient. Slope orientation and steepness also influence the amount and intensity of solar radiation received by a given site. Soil desiccation or drying tends to increase on slopes that are exposed to solar radiation for longer periods and may become more pronounced when the slope is oriented perpendicular to the sun's rays. Because running water acts as an important erosion agent, soil particles may be transported from elevated areas toward flatter terrain or local depressions. Consequently, soils are generally shallower and coarser in texture near hilltops, whereas they tend to become deeper and finer-textured toward the foot of slopes. Desiccation is generally less pronounced on slopes that receive less direct solar radiation and remain shaded for longer periods, although this effect also depends on slope steepness and orientation. Similarly, areas situated in leeward positions and protected by intervening higher-elevation terrain may experience reduced desiccation. Where such elevated terrain is sufficiently high and abrupt, a rain-shadow effect may develop, resulting in reduced overall precipitation.

Groundwater depth is another important factor affecting land sensitivity to desertification. When the water table is located at excessive depth, plant roots may be unable to access the available soil moisture. Conversely, when groundwater occurs too close to the soil surface, excessive moisture and waterlogging may develop. Under such conditions, saline and alkaline soil environments may adversely affect vegetation, potentially resulting in vegetation mortality or reduced plant growth rates (Table 11).

Table 11 Classes and assigned weighting index for soil texture

Texture classes	Description	Score	
		Areas dominated by water erosion	Areas dominated by wind erosion
Not very light to average	Loamy sand, Sandy loam, Balanced	1	1
Fine to average	Loamy clay, Clayey sand, Sandy clay	1.33	1.66
Fine	Clayey, Clay loam	1.66	2
Coarse	Sandy to very Sandy	2	2

Two landform characteristics are of interest to this discussion of desertification: (a) degree or steepness of slope and (b) depth from soil surface to the water table. Steepness of slope is important because it influences the velocity and the amount of surface water flow. Runoff, of course, is greater if the hillside slope is steeper. Slope steepness also influences amount and intensity of sunlight that a particular site receives. Desiccation, or drying, is greater if the slope faces the sun for longer periods of time and increases further if the slope angle

is perpendicular to the sun's rays. Due to the erosion agent running water, particles are carried to flatter areas or areas of depression. Thus, soils tend to be shallower and of coarser texture near the top of a hill and are relatively deeper and finer textured at the foot of a slope. Desiccation is less severe in areas that face the sun less often and are therefore largely in shadow, again depending on the steepness of the slope. Desiccation is also lower in areas with leeward positions that are protected by intervening lands of higher elevations. If such elevations

are high enough and abrupt enough, a rain-shadow effect could be established that would cause a decrease in overall precipitation. Depth to ground water is important because if the water table lies too deep, the plant roots will not be able to obtain the available moisture. On the other hand, if the water table is too close to the surface, waterlogging will become a problem. And, in these areas, saline and alkaline conditions can kill vegetation or decrease their growth rates (Table 12) (Table 13).

Table 12 Classes, and assigned weighting index for Slope gradient

Classes	Description	Score
< 6%	Gentle	1
6 – 18 %	Not very gentle	1.33
19 – 35 %	Abrupt	1.66
> 35 %	Very abrupt	2

Table 13 Classification of soil quality index

Class	Description	Range
1	High quality	> 1.13
2	Moderate quality	1.13 to 1.45
3	Low quality	> 1.46

Vegetation quality

According to Basso et al. (2000), vegetation quality is evaluated based on three principal aspects: erosion protection, drought resistance, and vegetation cover. Landsat satellite imagery was used as the primary data source for identifying and mapping vegetation and vegetation-cover classes. Rating values assigned to the different classes of erosion protection, drought resistance, and vegetation cover were adapted from OSS (2004), as presented in Table 14.

Table 14 Classes, and assigned weighting index for different vegetation parameters

Class	Description	I _{Ep}	I _{Dr}	I _{Vc}
1	Perennial cultivation	1	1	1
2	Halophytes	1.33	1	1.33
3	Temporal and orchards, mixed with crop land	1.66	1.33	1.66
4	Saharan vegetation < 40%	2	1.66	1
5	Saharan vegetation > 40%	2	1	1

The Vegetation Quality Index (VQI) was calculated using the following equation, and the resulting VQI values were classified according to the ranges presented in Table 15:

$$VQI = (I_{ep} \times I_{dr} \times I_{vc})^{1/3}$$

Where:

I_{ep} = Index of erosion protection

I_{dr} = Index of drought resistance

I_{vc} = Index of vegetation cover

Table 15 Classification of vegetation quality index (VQI)

Class	Description	Range
1	Good	< 1.2
2	Average	1.2 to 1.4
3	Weak	1.4 to 1.6
4	Very weak	> 1.6

Climatic quality index (CQI)

Climatic quality is evaluated using a set of climatic parameters that influence water availability for plant growth, including precipitation, air temperature, and aridity, as well as climatic hazards that may adversely affect vegetation development (Thornes, 1995). The classification categories of the Climatic Quality Index (CQI), based on OSS (2003), are presented in Table 16.

Table 16 Classification of Climatic quality index (CQI)

Class number	Climatic zone	P/PET	CQI
1	Hyper-Arid	< 0.05	2
2	Arid	0.05 – 2.0	1.75
3	Semi-Arid	0.20 – 0.50	1.5
4	Dry Sub-Humid	0.50 – 0.65	1.25
5	Humid	> 0.65	1

In the present study, climatic quality was assessed using the Aridity Index (AI), following the methodology developed by FMA. Rainfall and evapotranspiration data collected from 33 meteorological stations were used to calculate the Climatic Quality Index according to the following equation:

$$CQI = P / PET$$

Where:

P = Average annual precipitation

PET = Average annual potential evapotranspiration

Calculation of environmentally sensitive areas (ESAs) to desertification

ArcGIS 9 software was employed to identify and map Environmentally Sensitive Areas (ESAs) to desertification following the methodology proposed by Kosmas et al. (1999). This approach involved the integration of spatial data representing the principal environmental components, namely soil, vegetation, and climate. The corresponding quality indices were calculated and subsequently converted into GIS-ready thematic maps, from which the areas associated with the different sensitivity classes were determined.

The Desertification Sensitivity Index (DSI) was calculated within the polygon attribute tables associated with the geographic data layers using the following equation:

$$DSI = (SQI \times VQI \times CQI)^{1/3}$$

Where:

SQI = Soil Quality Index

VQI = Vegetation Quality Index

CQI = Climatic Quality Index

The ranges and corresponding classes of the Desertification Sensitivity Index are presented in Table 17.

Table 17 Ranges and classes of desertification sensitivity index (DSI)

Classes	DSI	Description
1	> 1.2	Non affected areas or very low sensitive areas to desertification
2	1.2 < DSI < 1.3	Low sensitive areas to desertification
3	1.3 < DSI < 1.4	Medium sensitive areas to desertification
4	1.3 > DSI < 1.6	Sensitive areas to desertification

Conclusion

It can be concluded that desertification hazard reflects the susceptibility of land to desertification processes and the influence of anthropogenic activities. Desertification hazard is expressed as the combined effect of the current status, rate of change, and inherent risk of desertification, together with animal and population pressures exerted on the environment.

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Conflicts of interest

The author declares no conflicts of interest.

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