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Using of Remote Sensing and GIS to Estimate Environmental Sensitivity to Desertification in East Nile Delta Using MEDALUS Model.

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ABSTRACT

This study employs the MEDALUS model, developed by the European Union, to estimate the degree of desertification in European Mediterranean countries. The model classifies environmental sensitivity to desertification (ESD) to five degrees based on soil, vegetation cover, and climatic conditions. The study area was carefully selected due to its location in the eastern margin of the Delta of the Nile, overlapping between Nile silt and delta sediments and the sands of the eastern desert. The area encompasses various land uses, including ancient agricultural lands, agricultural reclamation, and vacant lands suitable for future agricultural and urban expansion. The study revealed that 76.4% of the area has an average soil quality index, 23.6% has a low one, and 23.9% has a good vegetation cover index, 29.1% is average quality, and 47% has a low one. The study also revealed that 65.1% of the area has an average climate quality index, while 34.9% has a low one. The study concluded that 2.4% of the area has a very high environmental sensitivity index to desertification, 61.2% is environmentally sensitive, 22.8% of its area is medium sensitive, and 13.6% is low (ESD).

1. Introduction:

Soil is a crucial natural resource in agricultural production, requiring advanced scientific methods for sustainable exploitation. The UN Initiative to Confront Desertification, established in 1994, give definition to desertification as degradation of land in waterless, semi-waterless, and sub-humid regions owing to the change of climate and the activities of humans, with mathematical models being developed to study its quantitative nature, (Gad,A.A., 2008), so that a focus on ecosystems highlights low plant productivity, changing biomass, and reduced diversity of life forms (Farajzadeh,m., Egbal, M.N., 2007).

Drought is a complex and poorly understood environmental issue that significantly impacts population and activities, making it a significant environmental risk according to scientists and agricultural experts. This phenomenon occurs in all zones of climate, including areas of low and high rainfall, and is defined as a prolonged period of decreasing precipitation, for example a year or season (Orimoloye, I, R., et al, 2022). Desertification, particularly in waterless and semi-waterless regions, is of common occurrence all over the world. Historical droughts have led to severe environmental disasters, including crop shortages, animal and plant life destruction, and massive population migration. This has resulted in severe damage to agricultural crops, ecosystems, and human life. Drought can lead to soil degradation due to decreased rainfall and increased evapotranspiration, exposing it to aeolian erosion (Xue, Z., et al, 2017). On the contrary, desertification is an extreme environmental issue affecting waterless, sub-humid, and semi-waterless regions, causing imbalance in the environment, soil deterioration, and reduced productivity, which poses a threat to development processes. (Dragović, N., Vulević, T., 2020). Dry, semi-arid, and sub-humid regions are facing severe environmental degradation, leading to increased drought frequency and desertification factors due to population growth and unsuitable climatic conditions. This is particularly concerning as the lands in these regions are more susceptible to desertification. ESD refers to the soil's capacity to withstand changes caused by various natural and human conditions, affecting its natural characteristics and its capacity to germinate and cultivate.

The MEDALUS model is an international project investigating the impact of desertification on Mediterranean lands, supported by the European Union, to estimate the extent of desertification along the Mediterranean in the European region, under the "European Union- Environments of Mediterranean Land Use and Desertification project (EU-MEDALUS)" initiative, (Kosmas, C., et al., 1999). The model classifies lands based on their degree of (ESD) by measuring a group of elements that play a clear role in this classification (Kosmas, C., et al., 2003). The MEDALUS model is a complex model that relies on numerous variables with intricate spatial relationships, The model integrates the soil, climatic, vegetation, and surface characteristics throughout the area of study.

2. Study area

The area of study is located on the eastern and southeastern margin of the Nile River Delta, extending between latitudes 30° 52' 27.1" - 30° 9' 36.7" north and longitudes 32° 21' 35.4" - 31° 19' 27.9" east, (Fig. 1), the region's land is divided among three governorates: Ismailia (47.3%), Sharqia (42.3%), and Qalyubia (9.4%), covering an area of 3256.9 km2. The study area is a boundary between desert backlands in the south and east and agricultural deltaic lands in the north and west, with the exception of agricultural alluvial lands on both sides of the Ismailia Canal. The region offers a favorable environment for human development processes, particularly in agriculture and urban areas. The area is situated between the Cairo-Ismailia Agricultural Road and the Cairo-Ismailia Desert Road, and is connected by major roads like the Ring Road, Central Ring Road, Regional Road, and 30 June Road. The study area comprises 55 urban communities, including 47 villages and 8 cities, inhabited by 1.9 million people, as per the 2017 census, including Ismailia, El Tal El Kabir, Al-Qassasin, Abo Sower, Belbes, El Salahaia El Gadida, 10th

Ramadan, and Al-Obour.

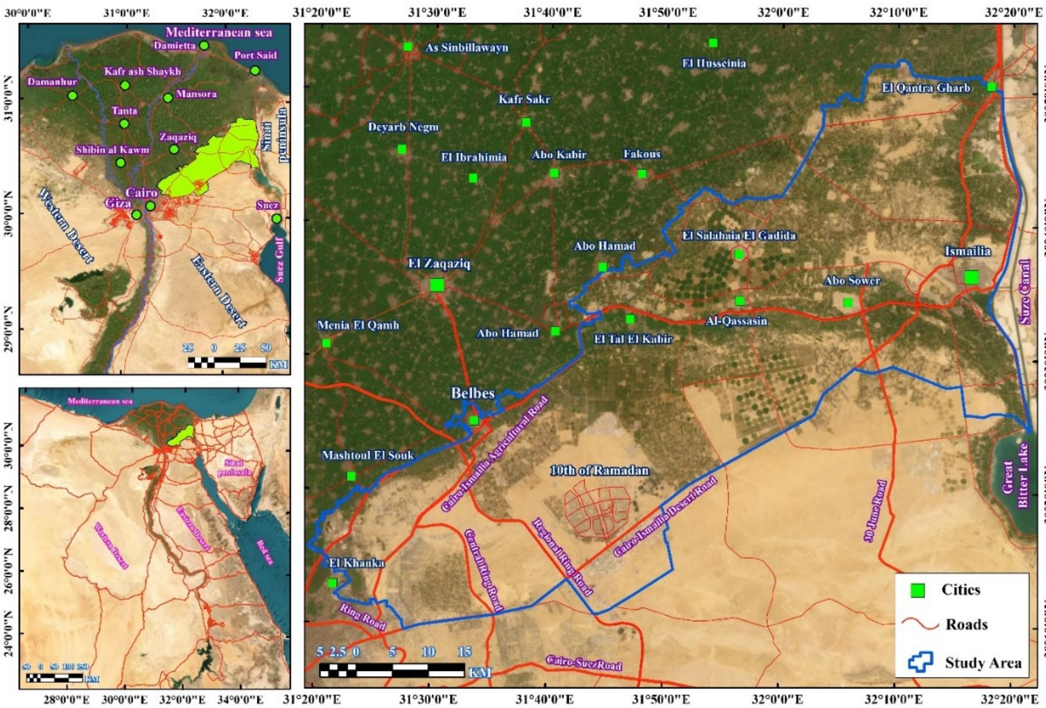

Fig. (1) location map of The Study Area

2.1 Geology

The study area has a rich history of geological formations dating back to the Tertiary period, specifically the Upper Eocene. The Maadi Formation, a mix of marine shale, limestone, and carolia placunoides, is the oldest, covering about 20.4% of the total area. The Holocene period saw the emergence of the modern Nile silt, which covers 20.4% of the area, (Table 1) and (Fig. 2). The Quaternary geological time formations, covering 84% of the area, are the most widespread, containing various sediments such as Prenile deposits, Neonile deposits, Nile Silt, Wadi Deposits, and sand dunes. These formations are highly sensitive to desertification in terms of parent material and soil texture. The limestone and calcareous fragment formations, covering 16% of the area, are mainly found in the western part of the mountainous range and have a high sensitivity to soil profile depth index.

Table (1) Geological formations and soil types in the study area

	Type	Area (km^2)	(%)
Geological Formation	Quaternary	2734.8	84
	Pliocene	4.6	0.1
	Meocene	474.5	14.6
	Oligocene	37.2	1.1
	Eocene	5.8	0.2
Soil Type	Soils of the River Terraces	900.4	27.6
	Soils of Deltaic Stage of Various River Terraces	394.3	12.1
	Soils of Fans and outwash plains	138.8	4.3
	Residual Soils	8.3	0.3
	Soils of the Wadis	152.1	4.7
	Windblown Soils	588.3	18.1
	Miscellaneous Land types	395.7	12.1
	Swamps	26.6	0.8
	Man-Made	4.2	0.1
	Cultivated Soils	648.2	19.9

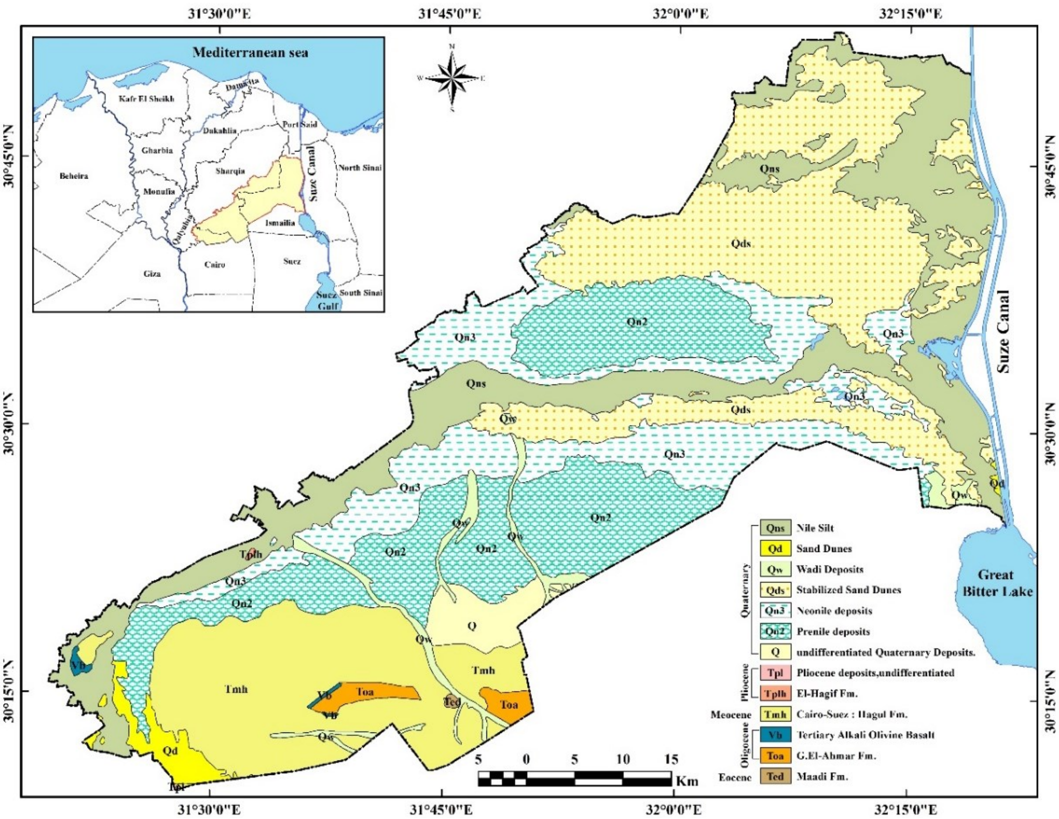

Fig. (2) Geological map of The Study Area

2.2 Soil

The study area's soil is classified under 10 primary soil categories, as per the Ministry of Agriculture's soil maps. The study area's soil type, Soils of the River Terraces, covers 27.6% of its area. These soils are composed of gravel and siltstone fragments, formed during the initial periods of the Nile River system, found in the southern and central part north of the Ismailia Canal, (Table 1) and (Fig. 3). Cultivated Soils make up 20% of the total area, extending from the southwest through the center to the eastern part, on both sides of the Ismailia Canal, it is fertile agricultural soil composed of Nile silt, clay, and sediments from the river and its deltaic branches from previous periods. Windblown soils, consisting of sand and gravel, form moving sand dunes, clusters, and sheets, covering 18.1% of the region's area and belong to transported soils, founded in the northeast of the region, between the River Terraces and Cultivated Soils, and in the southwest in the southern hills. The Miscellaneous Land types and Soils of Deltaic Stage of Various River Terraces cover 12.1% of the area. The first type is rocky lands cut by erosion, while the second is gravel, sand, and silt deposited during the formation of The Nile River Delta. The first is distributed in the southwestern highlands, while the second is spread in the center, south and north of the Ismailia Canal, and around Windblown Soils. The study area comprises 9% soils related to wadis, consisting of two main types: Soils of the Wadis and Soils of Fans and outwash plains. The first type is from Wadis bottoms plains, dominated by sandy, gravel, and clay formations, while the second type is from alluvial fans formed by torrents washing away sand and gravel fragments. These soils are found in the southwestern sector of the study area where wadis streams descend from the southern highlands. Swamps, Residual Soils, and Man-Made Soils comprises 1.2% of the study area. The first comprises gypsum swamps and sand lands, the second is shallow, coarse gypsum sand formations, and the third is man-made soils from canal excavations, found in the eastern part near the Suez Canal.

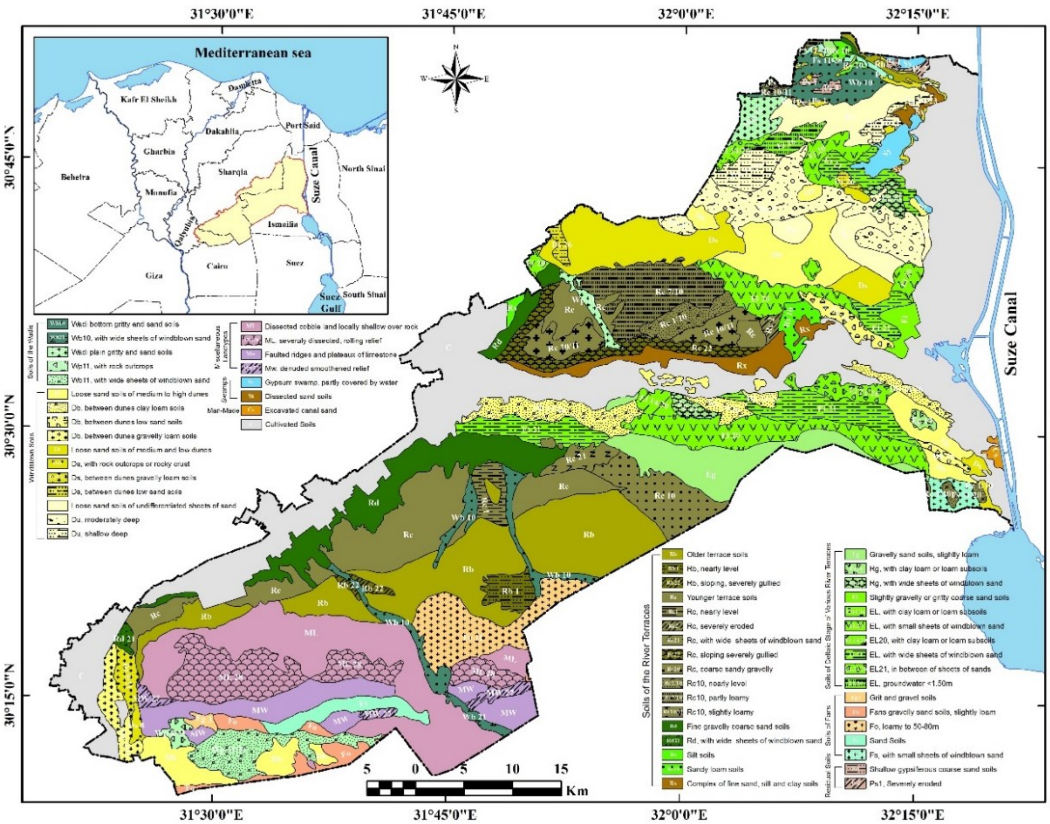

Fig. (3) soil types of The Study Area

2.4 Slopes

The study area comprises 60% flat and semi-flat lands, covering over half of the region's area, with very low (ESD). The study reveals that gently sloping lands, with slopes ranging from 2° to 5°, cover 34.7% of the region's total area. These lands, which extend along previous types, make up 95.3% of the area. They are low-sensitive (ESD) up to a slope of 3.5°, located within the low sensitivity category range, (Table 2) and (Fig. 4 - B). About 4.7% of the region's area is comprised of lands with slopes greater than 5 degrees, primarily found on high hills in the western part, particularly those with slopes exceeding 10 degrees.

2.5 Aspects

Flat lands, located to the east near the Suez Canal, make up 1.5% of the study area's total area. These ones have high sensitivity to desertification owing to high temperatures, evaporation rates, and soil water loss, increasing the likelihood of desertification, (Table 2) and (Fig. 4 - C). The north, south, southeast, and southwest lands cover 55.6% of the total area, with low ESD. The center and southwest lands cover 26.5%, with high ESD. The east lands cover 7.2% of the area, with low ESD. The west lands cover 9.2% of the area, with high ESD. These lands are particularly vulnerable to desertification due to their high temperatures, high evaporation rates, and soil water loss.

Table (2) Topographical characteristics of the study area

	Type	Area (km^2)	(%)
Elevation	- 50	2230.2	68.5
	- 100	582.8	17.9
	- 150	304.4	9.3
	- 200	137.9	4.2
	200+	1.6	0.1
Slope	0 – 2	1972.1	60.55
	2 – 5	1131.1	34.73
	5 – 10	142.4	4.37
	10 - 18	10.4	0.32
	18 - 30	0.5	0.02
	30 - 45	0.3	0.01
	45 +	0.1	0.01
Aspects	Flat	49.5	1.5
	N	831	25.5
	NE	429.3	13.2
	E	235.1	7.2
	SE	229.1	7.1
	S	352.1	10.8
	SW	280.6	8.6
	W	300.1	9.2
	NW	550.1	16.9

3. Methodology

The model of MEDALUS, also known as the Environmental Sensitivity Index (ESI), is a significant tool which assesses the sensitivity of soil to desertification in Mediterranean Sea countries. It consists of four sub-indicators as follows: the quality of soil, the quality of vegetation, the quality of climate, and the quality of management. This study utilized these indicators

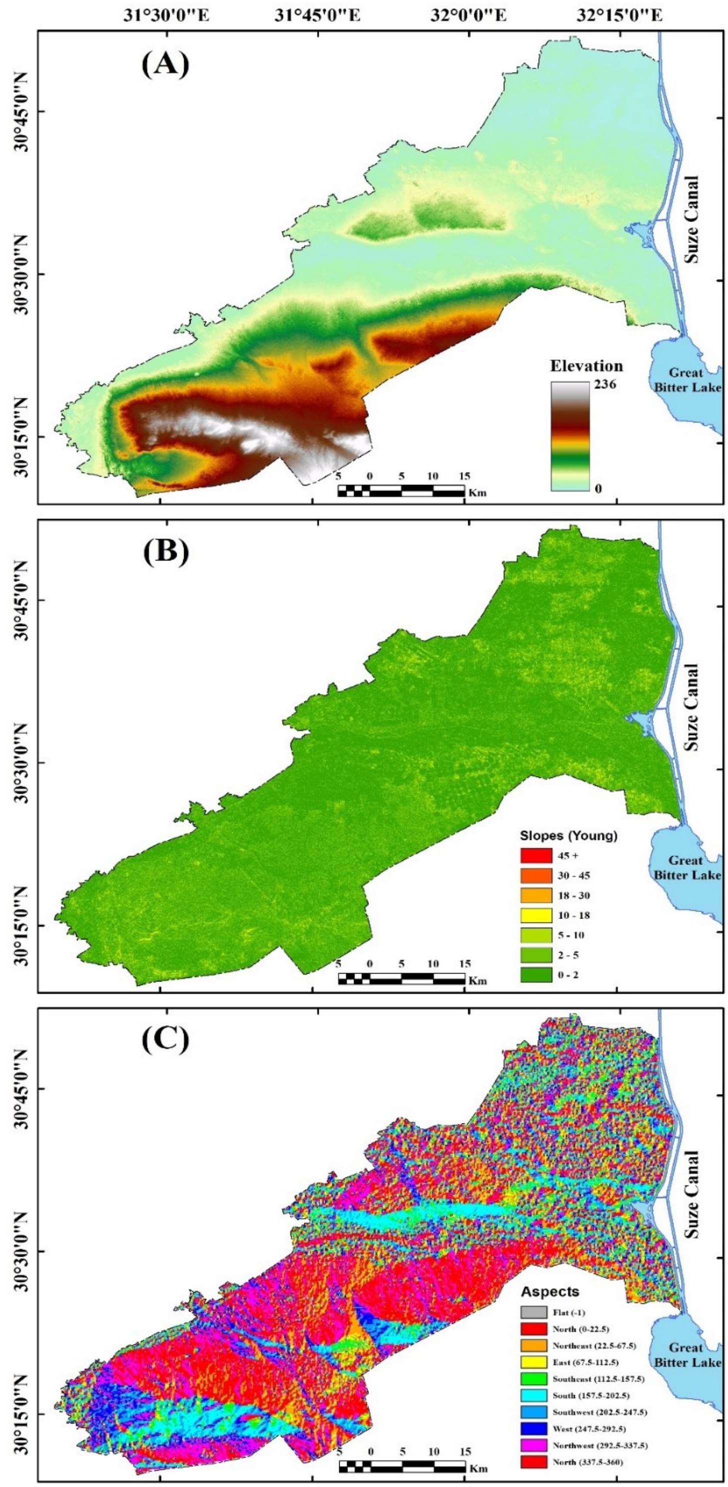

Fig. (4) Topography of The Study Area

to evaluate soil quality, vegetation quality, and climate quality. (Gad, A., & Lotfy, I., 2006) used three indicators to measure (ESD), which is soil quality, vegetation quality, and climate quality, while (Gad, A.A., 2008) used only Soil and vegetation quality indicator. This model aims to assess the risks of desertification in a local area using the Environmental Sensitivity Index by combining available data on soil quality, vegetation, and climate. This tool is flexible in calculating the degree of risk based on the available data, and some new elements can be added according to the Environmental data. The secondary objectives of this model are to investigate potential land use and soil degradation scenarios. This model integrates soil, vegetation, and climate information to determine (ESD), allowing for a standard system to assess specific environmental conditions. (Fig. 5). The equation for calculating the (ESI) to desertification is as follows:

$$DSI = (SQI * VQI * CQI)^{1/3})$$ Gad, A., and Lofty., 2006, p6)

Where ***DSI*** is the Desertification Sensitivity Index, ***SQI*** is the Soil Quality Index, ***VQI*** is the Vegetation Quality Index, and ***CQI*** is the Climate Quality Index.

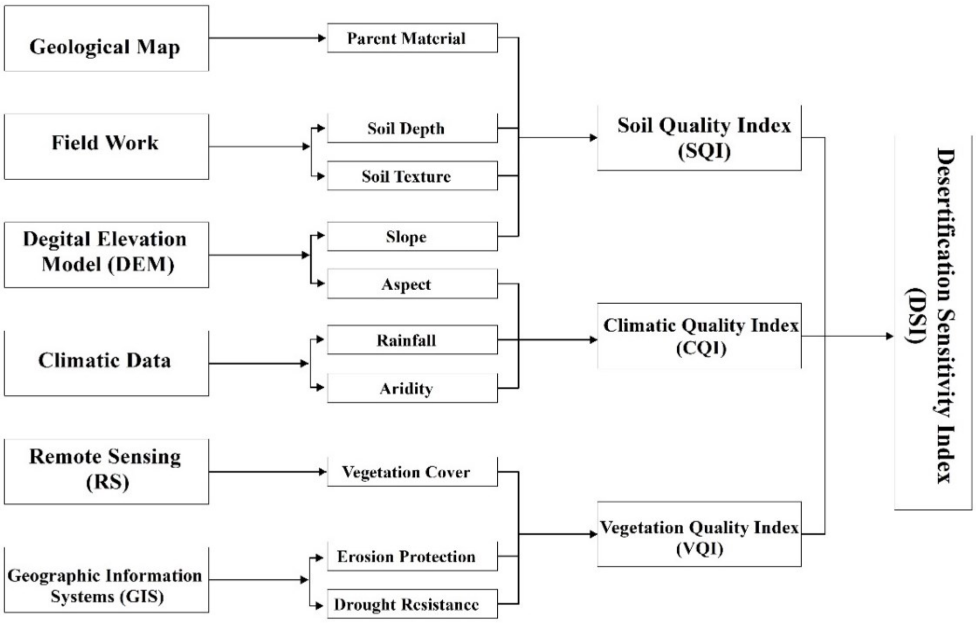

Fig. (5) Methodology of (DSI) mapping

The results of applying this indicator are divided into five sections that define the categories of environmental sensitivity to desertification, which are as follows:

- Very low sensitive lands to desertification: areas with low or non-existent critical factors, a balanced approach between environmental, social, and economic factors is achieved.
- Low sensitive lands to desertification: threatened areas by desertification resulting from the remarkable change in climate owing to improper land use or external influences, including unmanaged abandoned land, which could lead to serious problems.
- Medium sensitive lands to desertification: areas where the balance changes between human and natural activities seem to lead to the process of desertification in specific areas.
- Sensitive lands to desertification: areas which significantly degraded in misuse from the past, posing an environment threat and causing processes of desertification in the areas around.
- Very sensitive lands to the process of desertification: areas that have deteriorated to a very significant extent that impedes the possibility of their restoration.

4. Results and discussion

4.1 Soil quality index

Soils are a very significantly earthly ecosystems factor in sub-humid, dry and semi-waterless areas, especially in terms of their impact on soil productivity. The process of desertification begins when the soil becomes unable to provide plants with water and nutrients with shallow depth of the soil sector in which the plant roots penetrate to obtain water and food. The inclusive index of the quality of soil is determined through an equation as follows:

$$SQI = (Ip * It * Id * Is)^{1/4}$$ (Gad, A., and Lotfy, I., 2006, p3)

Where The Soil Quality Index (***SQI***), parent material index (***Ip***), soil texture index (***It***), soil depth index (***Id***), and slope index (***Is***) are all crucial factors in soil quality assessment. The following is a presentation of soil quality indicators:

4.1.1 parent material index

Parent or Raw material, a factor in soil-forming, significantly impacts soil properties, plant growth, erosion, and ecosystem resilience, and soils are closely linked to the parent material from which they originate. For example, Soils made of limestone have a fine texture, slow permeation, high pH, base saturation, and high nutrient state, while those made of sandstones have a coarse texture, high permeability, low pH, basic saturation, and low nutrient status (Kosmas, C., et al., 2003). The parent material index shows that 84% of the area has poor parent material, containing clay, sand and silt deposits. This dominates the surface and covers the central and eastern parts in the area. Moderately coherent source material, consisting of sandstone and limestone, covers 14.6% of the area in the southwestern part, while coherent parts cover 1.4% in the south. Overall, the parent material index reveals a significant variation in the region's surface features, (Table 3) and (Fig. 6 - A).

Table (3) Soil quality indicators in the study area.

	Class	Area (km2)	(%)	Score
Parent Material	Coherent (Good)	44.8	1.4	1
	Moderately coherent (Moderate)	475.5	14.6	1.5
	Soft to friable (Poor)	2736.6	84	2
Soil Depth	Very deep	1882.5	57.8	1
	Moderately deep	207.4	6.4	1.33
	Not deep	182.9	5.6	1.66
	Very thin	984.1	30.2	2
Soil Texture	Not very light to average	648.7	19.9	1
	Fine to average	686.6	21.1	1.66
	Fine	1890.8	58.1	2
	Coarse	30.8	0.9	2
Soil Slope	Gentle	2828.3	86.8	1
	Not very gentle	417.9	12.8	1.33
	Abrupt	9.9	0.3	1.66
	Very abrupt	0.8	0.1	2

4.1.2 Soil Depth Index

The depth of soil is a crucial indicator of soil quality, as it helps plant roots extend into the soil for water and nutrients, stabilizing it and preventing erosion. Degradation of soil resulting from erosion is considered as a remarkable threat to the productivity and quality of soil in desert and mountainous regions. The erosion of soil rates depends on surface soil thickness and underlying soil nature. Deep soil is generally resistant to desertification, while mountain soils are shallow or have undesirable characteristics, negatively impacting germination (Kosmas, C., et al., 2003). (The study area has 30.2% very thin soil, primarily found in desert plains and western highlands, with a high ESD. 57.8% of the area is very deep, found in the middle and east of the region and within agricultural plains. Moderately deep soil covers 6.4% of the area, mainly in dry valleys and fans, while areas with not deep soil cover 5.6%. The soil depth index categorization is based on the soil depth index, (Table 3) and (Fig. 6 - B).

4.1.3 Soil Texture Index

Soil texture refers to the size and percentage of particles in soil, including sand, silt, and clay, which changes over time and significantly impacts soil drainage, water holding capacity, temperature, erosion, fertility, and productivity. The study reveals that 59% of the region's soil texture index is soft or coarse, have a high sensitivity to desertification, primarily found in the eastern and central regions. This texture is characterized by coarse sandy soil, clay soil, and soft loam. Wind erosion significantly affects agricultural sandy soil in dry seasons, threatening desertification. Clay soil has poor drainage and may become saturated with water. Soil texture also affects soil resistance to erosion, with coarse and fine soil being less resistant than light to average and fine to average types. 19.9% of the area has a soil texture that is little sensitive to desertification, a mixture of sand and silt, widespread in the northern part of the region, and 21.1% being moderately sensitive, found in the northeast and south, and western, (Table 3) and (Fig. 6 - C).

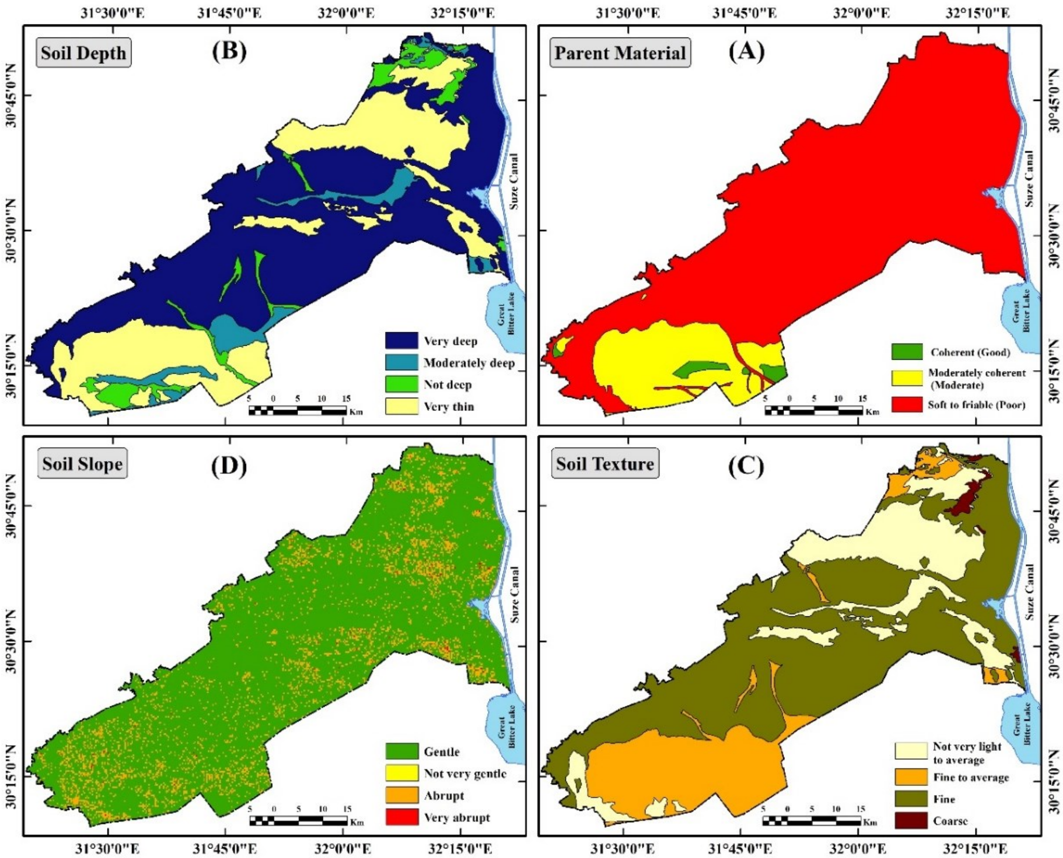

Fig. (6) soil quality parameters of study area

4.1.4 Soil Slope

The soil slope index measures the impact of slope on soil quality rates and environmental sensitivity to desertification. It measures the activity of external erosion agents, such as water and air, which increase with steep surfaces and decrease with decreasing slopes. It also reveals the movement of materials on slopes and soil quality deterioration. The study reveals that 86.8% of the region has a gentle slope rate of less than 3.5 degrees, indicating low environmental sensitivity to desertification. 12.8% has a not very gentle slope rate ranging between 3.5-10.0 degrees. 0.4% of the region has very steep slopes, with a degree exceeding 10.0 degrees, represented by hilltops south and west of the area of study, which are slopes with high (ESD), (Fig. 6 - D).

4.2 Vegetation quality index

The MEDALUS model for assessing (ESD) includes vegetation cover as a key indicator, calculated using three sub-indices: vegetation cover index, erosion protection index, and drought protection index. Vegetation cover is crucial in controlling desertification by stabilizing soil and protecting it from erosion and deterioration, particularly in fragile ecosystems like floodplain margins and dry desert backbone environments, such as the study area's dry desert backbone and floodplain margins. Plants lower soil temperatures by blocking sunlight, reducing evaporation rates and drought rates. However, decreasing vegetation density permanently or after harvesting can lead to soil deterioration due to winnowing, drought processes, or direct exposure to raindrops and water erosion. This can result in drought and desertification. Therefore, it is crucial to maintain plant cover and avoid permanent or temporary soil bareness. The following equation used to calculate vegetation quality index:

$VQI = (I_{Ep} * I_{Dr} * I_{Vc})^{1/3}$ (Ali, R., and El Baroudy, A., 2006, p159)

Where The Vegetation Quality Index (***VQI***), Erosion Protection Index (I_{Ep}), drought Protection Index (I_{Dr}), and Vegetation Cover Index (I_{Vc}) are all crucial factors in assessing vegetation quality. The following is a presentation of vegetation quality indicators:

4.1.5 Vegetation Cover Index

The vegetation cover index, also known as the leaf area index (LAI), is a measure of the area covered by green plants. (Chen, J.M., et al, 1997). Vegetation cover, a measure of the area of leaves per square meter, is crucial in preventing desertification by protecting soil from erosion, increasing organic matter, stabilizing aggregate, retaining water, and reducing surface runoff rates. It also helps in retaining sediments and soil components, thereby reducing the loss of land and promoting soil health. The study area's vegetation cover was determined using a Landsat (8) OLI_TIRS satellite image from July 22, 2023, for panel 176/39, with a 2.4% cloud cover and 30 meters resolution.

The vegetation cover was determined using the Normalized Difference Vegetation Index (NDVI) using the following equation:

NDVI = (NIR-R)/(NIR+R)

Where the orthogonal vegetation index (***NDVI***), near infrared region (***NIR***), and red region (***R***) are all important factors in determining vegetation types.

The study reveals that perennial cultivation covers 22.2% of the study area, primarily in agricultural lands around the Ismailia Canal and agricultural reclamation areas. Halophytes cover an area of 1.6%. Orchards and temporal, together with crop land cover 19.1% of the area appears around the agricultural reclamation areas center, while Desert vegetation <40% covers about 27.7%, especially its western deserted sector, and Desert vegetation >40% covers 29.4%, which appears in the middle, especially north of the Ismailia Canal.

Table (4) Vegetation quality indicators in the study area.

	Class	Area (km2)	(%)	Score
Vegetation Cover	Perennial cultivation	723.1	22.2	1
	Halophytes	51.1	1.6	1.3
	Temporal and orchards, mixed with crop land	622.2	19.1	1.7
	Desert vegetation <40%	903.6	27.7	1
	Desert vegetation >40%	956.9	29.4	1
Drought Resistance	Good	1730.9	53.1	1
	Average	622.3	19.1	1.3
	Weak	903.7	27.8	1.6
Erosion Protection	Good	723.1	22.2	1
	Average	51.1	1.6	1.3
	Weak	622.2	19.1	1.6
	Very weak	1860.5	57.1	2

4.1.6 Drought Protection Index

The drought protection index integrates vegetation patterns, soil type, and climate conditions, highlighting that decreased vegetation density leads to increased soil dryness and desertification. Plants respond to drought by decreasing leaf area index, which may reduce transpiration in the short term. However, this drought increases soil erosion during rain or wind, as protective

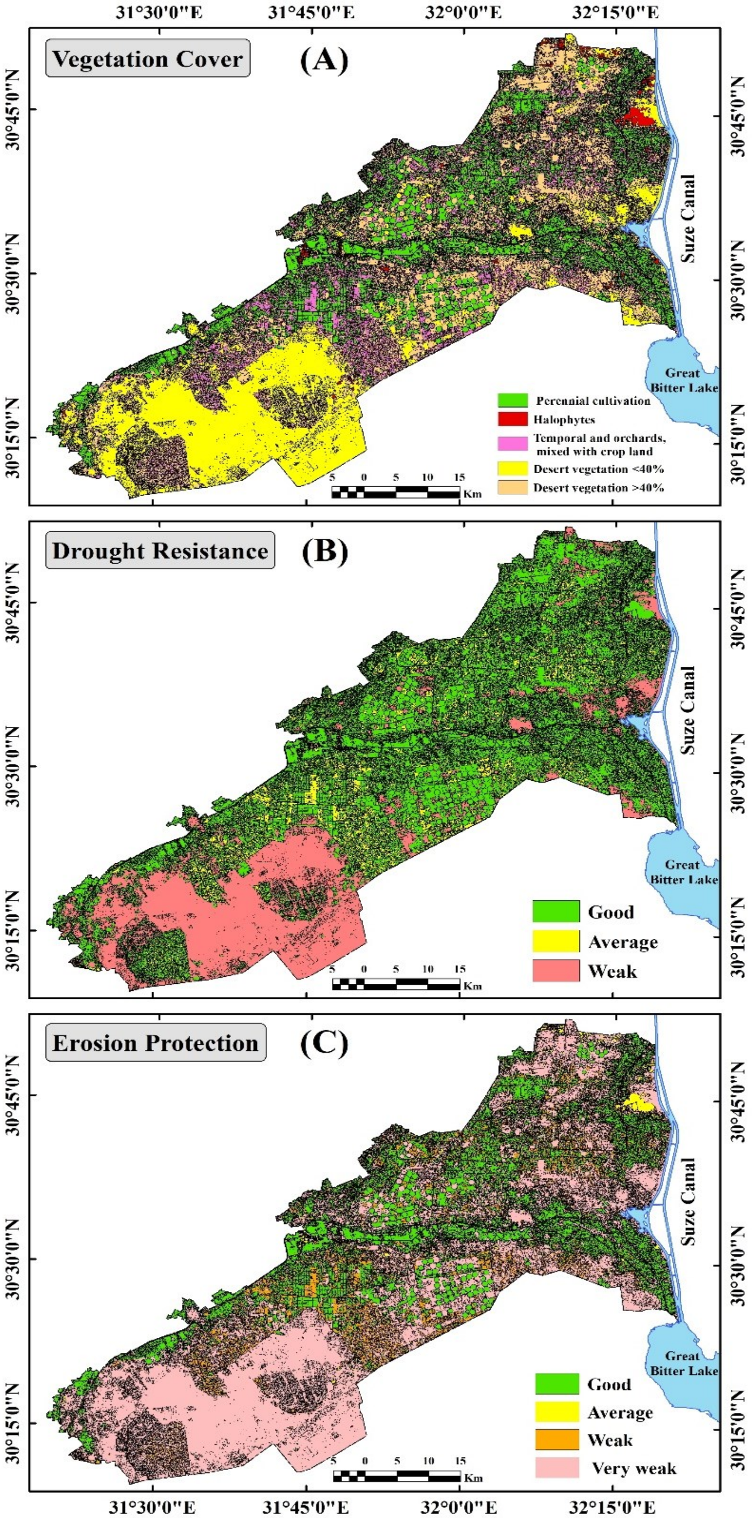

Fig. (7) Vegetation quality parameters of study area vegetation is reduced (Kosmas, C., et al., 1999). (Table 4) and (Fig. 7 - B) show that 53.1% of the study area has high protection from drought, which appear within Perennial cultivation, Halophytes, and Desert vegetation >40%, while Low protection areas cover about 27.8%, which distributed in desert vegetation <40%, and medium protection areas covers 19.1% in Orchards and temporal, together with land of crops.

4.1.7 Erosion Protection Index

Soil erosion and denudation are crucial for ecosystem health and balance, as external erosion causes soil deterioration and desertification. Loose and dry soils in dry environments lose components, decrease productivity, and subsequently deteriorate and desertify due to exposure to erosion factors. Soil erosion and denudation are influenced by factors such as depth, texture, elevations, slopes, climate, and vegetation cover, which determine the activeness of external erosion factors. soil erosion, whether by water or air, in limited depth of the soil sector and low density of plant cover, leads to its desertification (Hegazi, A.M. et al. (2009). (Table 4) and (Fig. 7 - C) show that 22.2% of the area has a high erosion protection index, mainly in Perennial cultivation, while 1.6% falls within medium protection, while 76.2% of this land lies in very low and low protection, mainly found in Orchards and temporal, together with land of crops and desert vegetation.

4.3 Climate quality index

Climatic factors significantly contribute to drought and desertification, both of which are considered climate-related environmental issues. Climate quality is evaluated by examining factors that influence plant water availability, including rainfall, air temperature, and dryness. Desertification is influenced by high evapotranspiration rates in desert areas, which exceed precipitation rates, leading to a water balance deficit. This results in drought and desertification. Decreased rain and high evaporation reduce soil moisture content, affecting plant growth, biomass production, organic matter content, and soil stability. This affects the accumulation and stability of the surface horizon against erosion. Rainfall increases soil erosion and deterioration in areas without plants, affecting their quality. the climate quality index is calculated using the following equation.:

$$CQI = (I_r * I_a * I_s)^{1/3}$$ (Hegazi, A.M. et al., 2009, p33)

Where The Climate Quality Index (***CQI***), precipitation index (I_r), aridity index (I_a), and aspect index (I_s) are key climate quality indicators.

4.3.1 Precipitation Index

The precipitation index measures the amount of rain received in a study area, which can impact desertification and soil quality. Long-term rain retention causes soil drying in non-irrigated areas like desert plains and agricultural reclamation areas irrigated by sprinklers or drips. The study area experiences low precipitation rates, leading to soil drying due to high temperatures. This deterioration and desertification are exacerbated by high evaporation rates. The area is part of the dry desert climate, with winter lack of rain, fall and spring decreases, and summer absence. The study area experiences rapid, heavy rains, which may negatively affect soil washing away, particularly in areas with steep slopes in mountainous hills due to the study's conditions of climate. The area of study, situated in a low-rainfall belt, whose annual rainfall average is under 280 mm, has a high (ESD) precipitation index, as indicated by (Table 5) and (Fig. 8 - A).

Table (5) Climate quality indicators in the study area.

	Class	Area (km2)	(%)	Score
Precipitation	Light rain (< 280 mm/year)	3256.9	100	1
	Moderate rain (280 - 650 mm/year)	-	-	1.5
	Heavy rain (> 650 mm/year)	-	-	2
Aridity	Hyper-arid (<0.05)	-	-	2
	Arid (0.05–0.20)	-	-	175
	Semi-arid (0.20–0.50)	3256.9	100	1.5
	Dry sub-humid (0.50–0.65)	-	-	1.25
	Humid (>0.65)	-	-	1
Aspect	North	2045.5	62.8	1
	South	1211.4	37.2	2

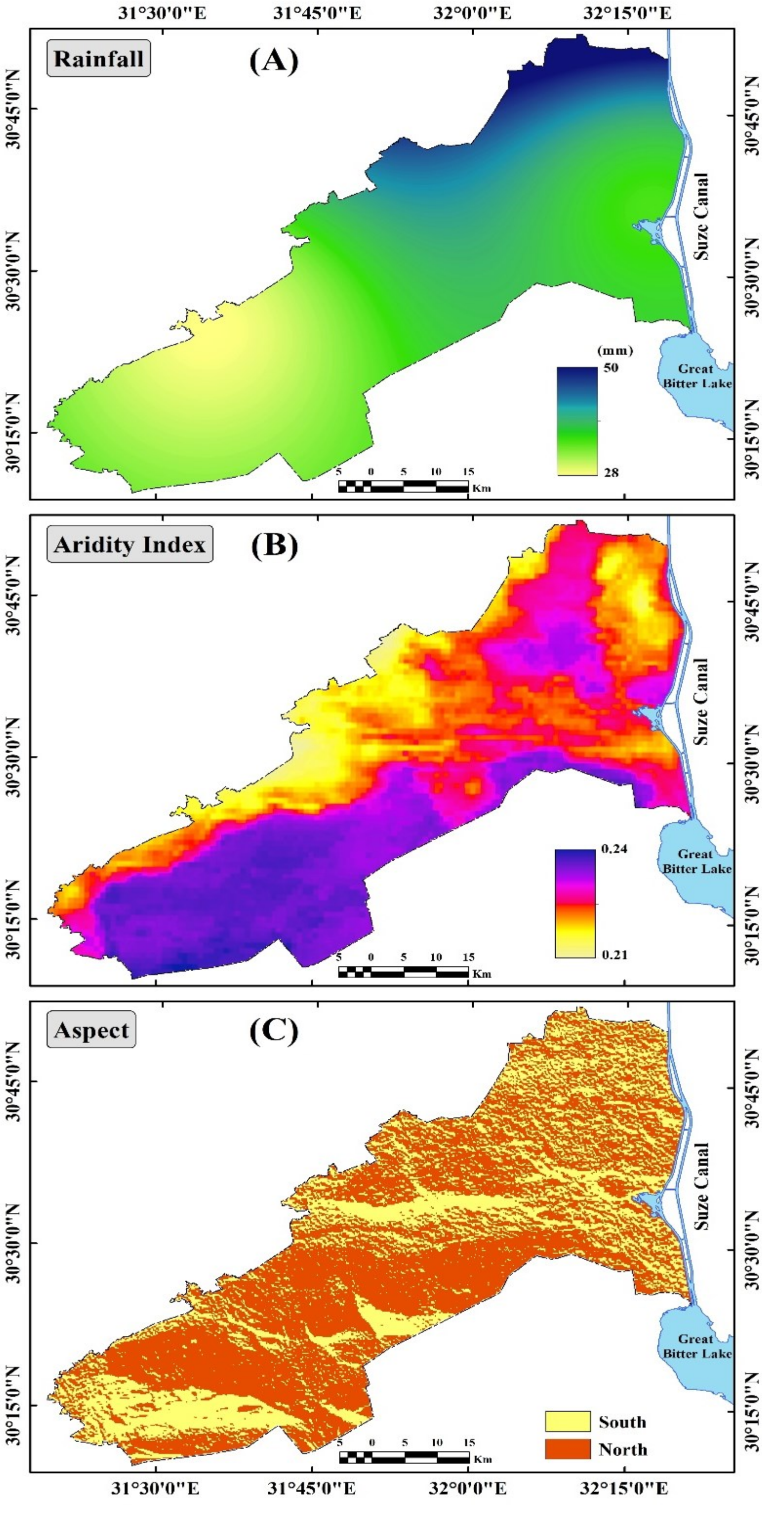

Fig. (8) Climate quality parameters of study area

4.3.2 Aridity Index

The aridity index measures the average water availability in soil, influencing the relationship between temperature and precipitation and its impact on desertification rates. We define it as the proportion of average yearly rainfall to average yearly evapotranspiration, which is a crucial environmental factor that influences vegetation cover development and rain erosion, influenced by rainfall and air temperature estimation. (Kosmas, C., et al., 2003). The study area's aridity index was calculated using the global aridity index, indicating its location in the semi-arid range, (Table 5) and (Fig. 8 - B).

4.3.3 Aspect Index

This indicator measures the slope direction in the study area, influencing the angle and duration of solar rays. Slopes in the western and southern direction are hotter, with higher evaporation and temperature rates, less water storage capacity, and lower organic matter content than those in the north and east, resulting in less dense vegetation. Variation in slope directions affects the distribution of energy, rainwater, nutrients, and vegetation cover by influencing the extent of soil exposure to wind and rainfall, in addition to natural drainage conditions, surface runoff, erosion, and removal of sediments by wind. Measurements in the Mediterranean region show higher soil erosion rates on southeast and southwest slopes compared to northeast and northwest slopes. (Table 5) and (Fig. 8 - C) show that 62.8% of the area has northern, northeastern, northwestern and eastern directions, which are directions with less (ESD), while 37.2 % of the total area has southern, southeastern, southwestern, western and flat directions, which are directions with high (ESD).

4.4 Desertification Sensitive index

The Desertification Sensitivity Index (DSI) is calculated using the (ESD) indicator measures, following the previously mentioned equation.

4.4.1 Total Soil Quality Index

The soil quality index in the study area is calculated by combining maps of four soil indicators in geographic information systems software, resulting in an overall index of soil quality. The study area has a total soil quality index of 23.6%, with a soil quality index exceeding 1.45. This soil is coarse-textured, fragile, high slope, and shallow, extending to the northeast and southwest. On the other hand, 76.4% of the area is medium quality, characterized by a cohesive original material, an interwoven soil texture between silt and sand, a deep section, and a low slope, (Table 6), (Fig. 9 - A).

Table (6) The study area's total desertification quality indicators.

	Class	Area (km2)	(%)	Range
SQI	High quality	-	-	<1.13
	Moderate quality	2488.8	76.4	1.13 to 1.45
	Low quality	768.1	23.6	>1.46
VQI	Good	779.8	23.9	<1.2
	Average	947.3	29.1	1.2 to 1.4
	Weak	1529.8	47	1.4 to 1.6
	Very weak	-	-	>1.6
CQI	Good	-	-	< 1.15
	Average	2121.8	65.1	1.15 to 1.81
	Weak	1135.1	34.9	> 1.81
DSI	Very low sensitive areas to desertification	-	-	DSI<1.2
	Low sensitive areas to desertification	443.4	13.6	1.2<DSI<1.3
	Medium sensitive areas to desertification	741.1	22.8	1.3<DSI<1.4
	Sensitive areas to desertification	1993.1	61.2	1.4>DSI<1.6
	Very sensitive areas to desertification	79.3	2.4	DSI>1.6

4.4.2 Total Vegetation Quality Index

The overall vegetation quality index in the area of study was calculated by combining maps of three vegetation cover indicators in geographic information systems software. The area of study has 47% low-quality vegetation cover, with a quality index ranging from 1.4-1.6. This is mainly found in desert plains and high hill areas, with low erosion protection and drought resistance. Medium-quality vegetation cover, which constitutes 29.1%, is found in agricultural areas with different vegetation cover,

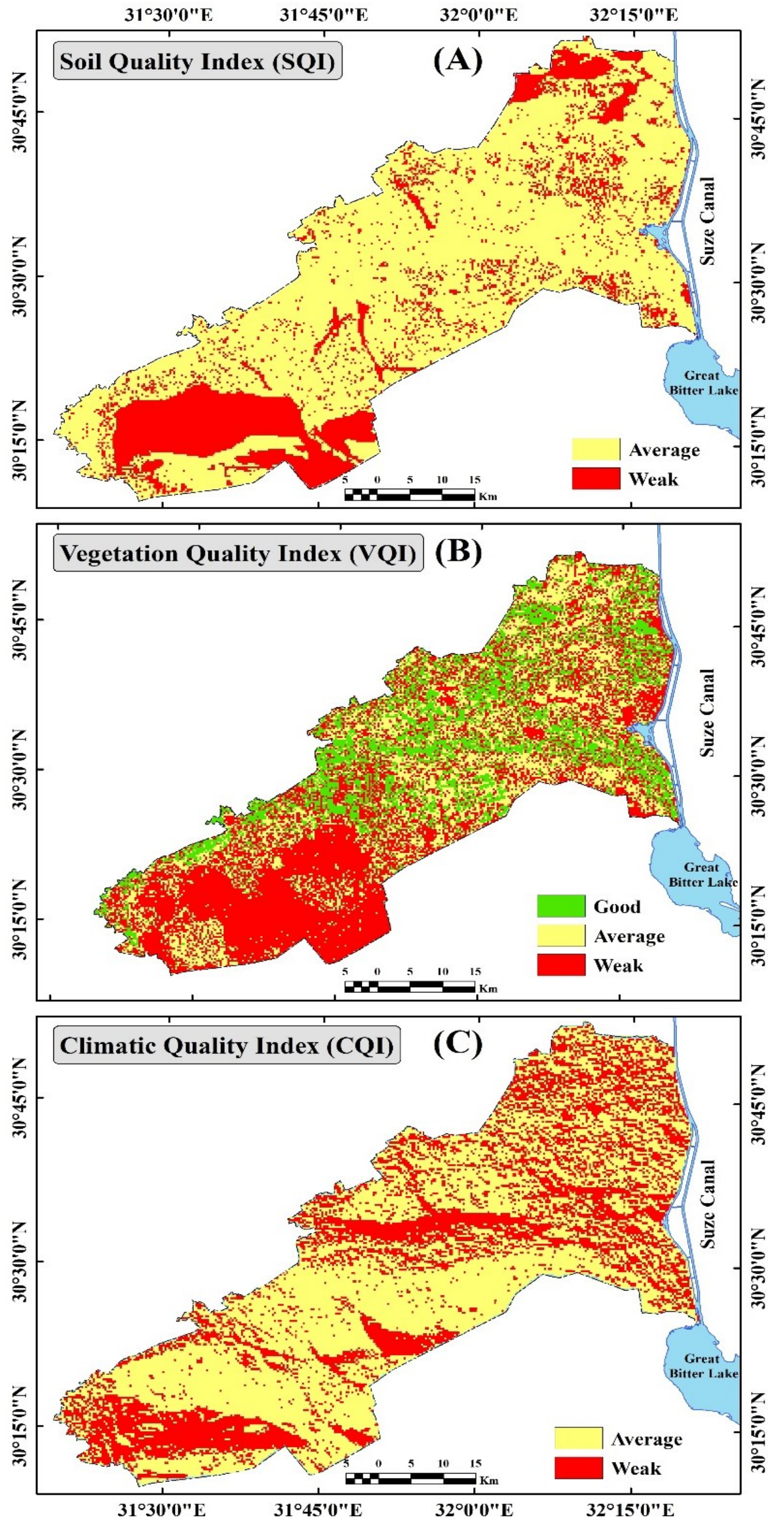

Fig. (9) Total indicators of soil, vegetation, and climate quality in the study area.

protecting soil from dryness and erosion, reducing evaporation and soil moisture loss. This contrasts with the high-quality vegetation cover found in desert plains and high hill areas. The study area has 23.9% of areas with good vegetation cover quality, primarily found in permanent agriculture areas in the middle.

4.4.3 Total Climate Quality Index

The study area's climate quality index, calculated using geographic information system software, indicates that 34.9% of the area has low climate quality, primarily in southern, western, and flat directions due to low precipitation and aridity index. On the other hand, 65.1% of the area has average climate quality, primarily in northern and eastern directions, indicating a diverse climate landscape, (Table 6) and (Fig. 9 - C).

4.4.4 Total Desertification Sensitive index

The study used Geographic Information Systems software to calculate an environmental sensitivity index to desertification. The indicator was combined with previous classes and their relative weights were determined using the main equation and sub-equations. A model was created, which can be applied to any area to obtain results. The study identified categories of desertification sensitive index in the study area.:

- Low sensitive desertification areas: where the desertification index ranges between 1.2-1.3, covering about 13.6% of the area of the region. These ones lied in the middle of area of study, north and south of the Ismailia Canal.
- Medium sensitive desertification areas: where the desertification index ranges between 1.3-1.4, cover about 22.8% of area of study. These lands located in the middle of area of study around the lands of the former range.
- Sensitive areas to desertification: The desertification index values range from 1.4-1.6, spanning 61.2%, is characterized by lands with a desertification index value of 1.4-1.6. These lands are distributed in three sectors: the western part of the region, northwest of Ismailia, and north of Qantara west.

– Very sensitive areas to desertification: where Desertification index exceeds 1.6, affecting 2.4% of the area of the region. These lands are found in the southwest and north, with poor soil, fragile sediments, and low vegetation cover. They also have low erosion protection and drought, with flat and semi-level lands dominating. These lands are dominated by low vegetation cover and slopes.

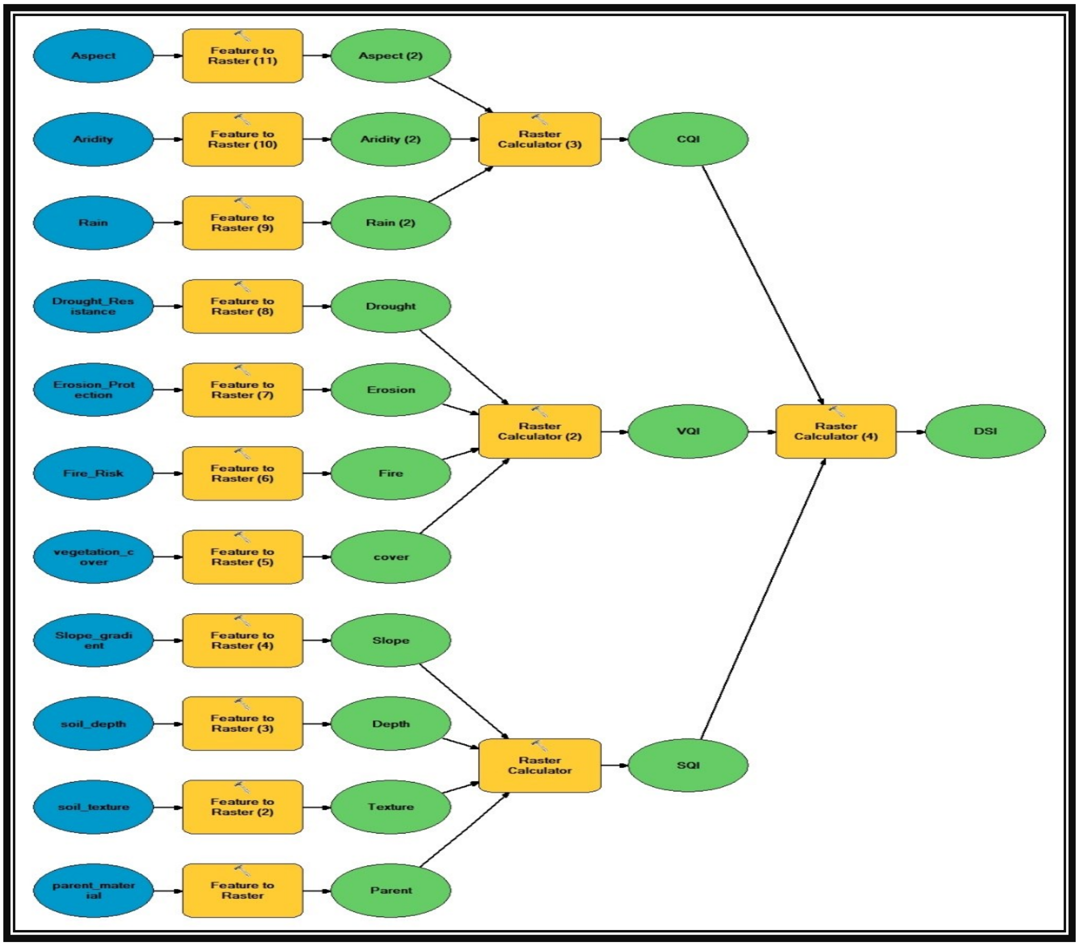

Fig. (10) Environmental sensitivity assessment model for desertification using Arc GIS 10.8.

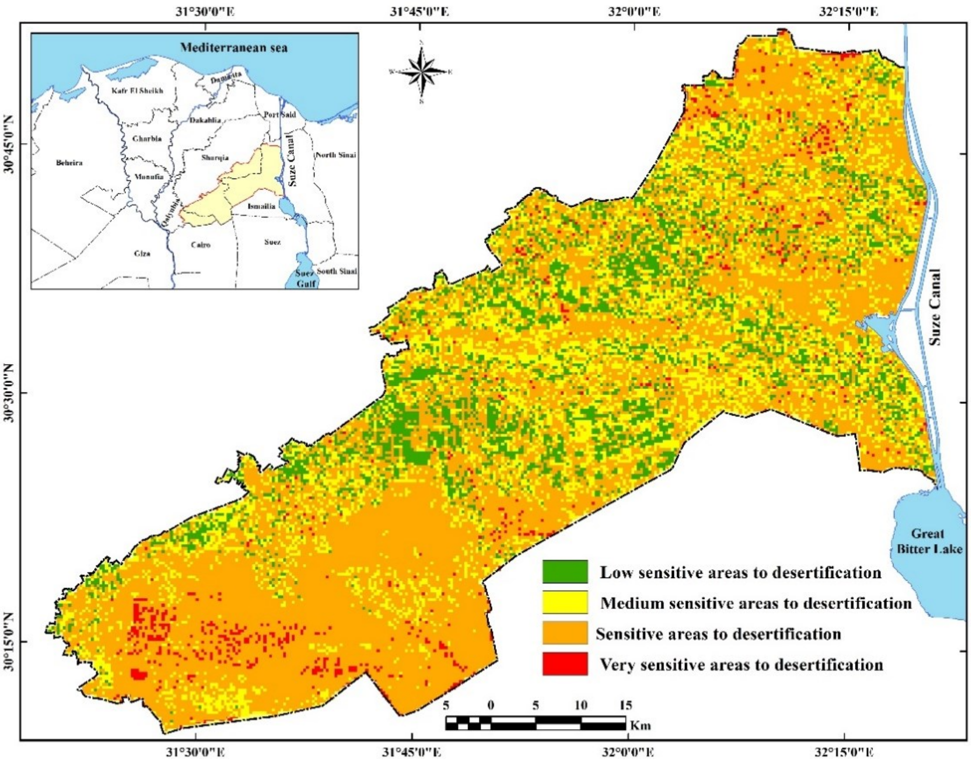

Fig. (11) Desertification Sensitive Index of study area

5. Conclusion

The study explores the use of geographic information systems and remote sensing techniques to calculate environmental sensitivity to desertification in the eastern Nile River Delta region. The MEDALUS model, consisting of soil quality indicators, vegetation quality, and climate quality, was used to measure these sensitivity levels. The data was gathered from various sources, including geological maps, soil maps, Landsat satellite images, digital elevation models, climate data, and digital global drought index files. The study used spatial modeling to create a digital model, identifying areas with high environmental sensitivity to desertification based on the indicators and their sub-indicators. The overall quality index for each indicator was calculated to determine the environmental sensitivity levels in the study area. The study found that 2.4% of the area had a very high environmental sensitivity index to desertification, 61.2% was environmentally sensitive, 22.8% medium sensitive, and 13.6% low (ESD).

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