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Desertification Sensitivity Analysis East of Siwa Using GIS and Remote Sensing

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ABSTRACT

Desertification is one of the major environmental challenges facing sustainable development in arid, semi-arid and subhumid regions. Environmental and anthropogenic qualities are significant indicators to measure the sensitivity of land to desertification. The objective of this study is to evaluate the desertification sensitivity in East Siwa oasis (1763 ha), Egypt, based on the modified MEDALUS approach, using remote sensing and GIS. The application of MEDALUS was based on environmental and anthropogenic qualities such as soil, vegetation, climate, management and water qualities, where five quality indices were calculated based on 22 desertification indicators. Finally, an integrated index was calculated to evaluate the desertification sensitivity. The field data were collected from 73 locations, while the remote sensing data were extracted from Landsat image acquired in 2017. The results revealed that about half of the study area has low quality soils (50.3%) with respect to desertification risks followed by moderate quality soils (49.7%), due to high soil salinity and alkalinity levels. The majority of the study area is characterized by moderate climate quality (72.7%). This is mainly attributed to the scarcity precipitation occurring in the region. The vegetation quality exists in the area is characterized as high (57%) and moderate quality (43%). The areas of high management quality were very limited, representing 14.3% of the study area and the remaining area (85.7%) was under the moderate management quality. The entire study area is characterized by low water quality due to the high salinity levels of irrigation water. It was found that the entire study area is under the critical level of desertification sensitivity, which mainly resulted from natural and human factors. In light of the high desertification risk in the study area, action measures are very necessary to combat desertification and for the sustainable agricultural development.

Key words: Desertification Sensitivity; MEDALUS; Remote Sensing; GIS, Siwa oasis.

INTRODUCTION

Desertification is one of the serious challenges facing sustainable development in many countries of the arid, semi-arid and subhumid regions. It is a worldwide phenomenon caused by natural processes and human activities, including water erosion, wind erosion, soil salinization, overgrazing, rapid urban sprawl and sand encroachment (MALR 2018; MALR 2005; Abahussain et al. 2002; Katyal and Vlek 2000; Kosmas et al. 1999). These processes and activities lead to gradual environmental degradation (Rapp 1974). The bio-physical characteristics and anthropogenic activates coupled with land degradation processes may lead to an irreversible environmental degradation process, which refers to desertification (Montanarella 2007). According to the framework of the United Nations Convention to Combat Desertification (UNCCD), which was presented on June 1994 in Paris, desertification was defined as the land degradation in arid, semiarid, and sub-humid areas as a result of several factors, such as climate change and human activities (Zonn et al. 2017). Desertification is considered as the final stage of the land degradation process (Hill 2005). Land degradation refers to the decrease or loss of biological and economic productivity and the complex structure of irrigated, rainfed, and pasture lands in arid, semiarid, and subhumid areas (Zonn et al. 2017). Desertification affects about 25% of the total global area (UNCCD 2008) and more than a billion hectare in Africa (Thomas 1995). Every year, about 200,000 km^2 of the productive lands in the globe is converted by desertification to nonproductive land (Abahussain et al. 2002). Globally, about one billion people are at risk due to desertification and 250 million people are directly affected by this phenomenon (Tchakerian 2015). Egypt is among the top world countries affected by desertification due to its arid and hyperarid climate conditions (MALR 2005).

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Since 1983, several projects have been carried out, both in individual regions and the global scale, for assessing and mapping land degradation and desertification. The most significant of them are: the provisional methodology for assessment and mapping of desertification (FAO/UNEP 1983), global assessment of human-induced soil degradation (GLASOD) (Oldeman et al. 1990), guidelines for the assessment of soil degradation in central and eastern Europe (SOVEUR) (van Lynden 1997), assessment of the status of human-induced soil degradation in south and southeast Asia (ASSOD) (van Lynden and Oldeman 1997), Mediterranean desertification and land use (MEDALUS) (Kosmas et al. 1999), and land degradation assessment in drylands (LADA) (FAO/UNEP 2013).

MEDALUS was developed for the analysis of desertification sensitivity in the Mediterranean region where physical loss of soil by water erosion is the dominant problem (Kosmas et al. 1999). In the arid and semi-arid regions, soil salinization and wind erosion are considered to be more significant to desertification than water erosion. These regions are more vulnerable to desertification due to several ecological factors such as; rainfall variability, scarcity of water resources and low plant cover intensity (Kassas 1995). The standard MEDALUS is used to analyze desertification sensitivity in relation to several parameters including soil, vegetation, landforms, climate, geology, and human activity. These parameters are clustered with respect to their behavior on desertification and weighting factors are assigned for each parameter. In MEDALUS, four qualities are assessed (i.e., soil quality, vegetation quality, climate quality and management quality). Finally, a desertification sensitivity index is identified based on the combination of these qualities (Kosmas et al. 1999). Although, MEDALUS was developed for Mediterranean region, it was widely used for desertification assessment in different regions of the world including Egypt (Afifi et al. 2010; Gad and Shalaby 2010; Ali and El Baroudy 2008). MEDALUS can be calibrated to the arid region by considering certain parameters of the arid conditions. For example, Bakr et al. (2012) studied desertification sensitivity of an arid fragile area in Egypt by introducing a modification on the standard MEDALUS through adding some parameters such as soil salinity, soil pH, soil organic matter and irrigation water characteristics. Also, Salunkhe et al. (2018) used a modified MEDALUS to evaluate the desertification risk in an arid zone in India by introducing some parameters including soil salinity, air temperature, and wind speed. Remote sensing data are feasible and cost-effective source in mapping land desertification risks. Additionally, the integration of remote sensing and GIS allows the creation of thematic layers that provide the most comprehensive modeling for desertification assessment (Hadeel et al. 2010). Therefore this study aims at evaluating the desertification sensitivity in East Siwa oasis using remote sensing and GIS, according to the modified MEDALUS approach.

MATERIALS AND METHODS

Study area

The investigated area is located in the eastern part of Siwa oasis, Egypt, and extended over about 1763 ha (Fig. 1). It is situated at latitudes 29° 06' 13" and 29° 11' 4" N and longitudes 25° 44' 54" and 25° 48' 55" E. The selection of the study area was based on the presence of features of land desertification, whether in the old or new agricultural lands. Thus, the study area is divided into two parts, the northern part representing the old agricultural land (1009 ha) and the southern part representing the newly reclaimed desert land (754 ha) (Fig. 1).

The climatic data collected over the last 20 years from the meteorological station in Siwa indicate that Siwa oasis is characterized by annual mean temperature of 21.3 °C. The maximum temperature is recorded on July (38 °C) and the minimum temperature is recorded on December (5.5 °C). Siwa oasis receives a total annual rainfall of 9.6 mm. The driest annual months extend from June to September, where no rainfall value is recorded. The maximum rainfall value is recorded on December (2.8 mm month 1) with an average annual value of 0.8 mm. The evapotranspiration is generally very high and reaches its maximum value on July (283 mm month 1). Wind speed has an average annual value of 2.97 m sec-1. The collected data reflect the extremely arid climate conditions in the region. The study area is composed of siliciclastic rocks with limestone, sandstone and sand dunes, belonging to the Oligocene, Miocene and Quaternary times (Sallam et al. 2018; El Gindy and El Askary 1969). It is situated on the eastern border of Lake Zeitun (Fig. 1) and bounded by several sand dunes in the southeastern ward. The southern part of the study area is affected by the wind erosion hazard. Agriculture is the main activity in the study area, which depends on the groundwater for irrigation. The northern part of the area is cultivated with mixed olive and date palm trees using the surface irrigation system, while the southern part is mostly cultivated with olive trees under the drip irrigation system. Noticeably, most of the northern part of the study area is affected by the bad drainage conditions and consists of abandoned and

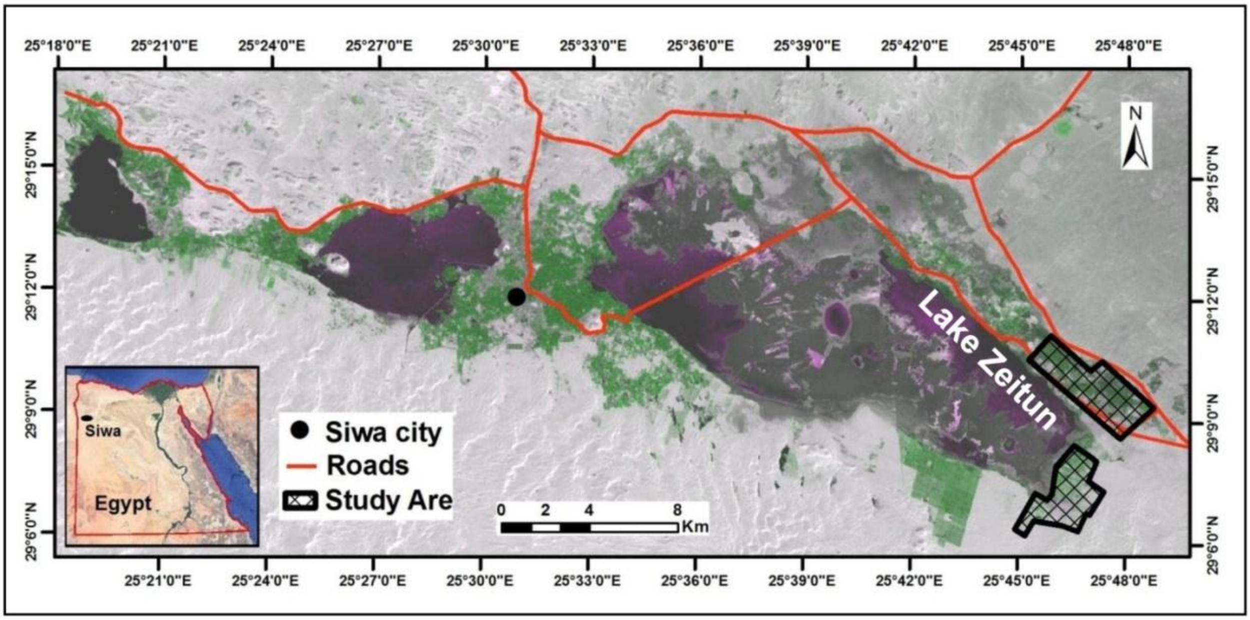

Fig.1. Location map of the study area

unmanaged palm tree plantations and large areas of natural grass (Fig. 2); therefore the northern part of the study area is more vulnerable to fire risks.

Field work

The field work was started on May 2017 based on a 0.5 km-grid sampling strategy, where locations of 73 soil augers were assigned for soil sampling and georeferenced using GPS. In the field, locations of soil augers were located on the grid intersections and justified based on land marks in the study area (i.e. roads, drains, wetlands … etc.). Soil samples were collected from the surface soil layer (0-30 cm). The soil depth, surface rock fragments, drainage status, and vegetation types were addressed at the location of each soil auger. Water samples were collected from twelve wells and springs in the study area. The collected soil and water samples were subsequently laboratory analyzed (Page et al. 1982; Jackson 1973; and Richards 1954). Results of soil analyses were dedicated to the production of soil maps, which subsequently used for soil classification and desertification sensitivity. The soil maps were created in GIS environment using the inverse distance weight (IDW) as an interpolation technique. The soil properties with high spatial variability, as assigned by their high coefficient of variance (CV%, as documented in the result section), were selected to produce the soil classification map. These properties included the soil salinity, soil calcium carbonate, soil depth, and organic matter content. A soil units' map was created using map overlay processes of the selected soil properties. According to the resulted soil units' map, a representative soil profile was assigned to each unit. On December 2017, eight soil profiles were excavated, georeferenced, and described macro-morphologically in the field according to the FAO procedure (2006), where soil horizons were differentiated. Soil profile samples were collected for further physical and chemical analyses. Results of soil profile' description and analyses were used for soil classification based on the American system of soil taxonomy (USDA 2014). Finally, a soil classification map was created by clustering of the similar taxonomic units.

Satellite data and vegetation analysis

The digital elevation model (DEM) of the study area was obtained from the US geological survey website "https://earthexplorer.usgs.gov/" (USGS 2019). DEM was developed by the Advanced Spaceborne Thermal Emission and Reflection Radiometer. DEM was analyzed using ArcGIS 10.1 (ESRI 2012) to generate the slope percent and aspects, which used as inputs in the process of desertification sensitivity analysis. Also, a Landsat-8 image acquired on March 2017 was obtained from the above mentioned USGS website to extract the vegetation cover type and percent (Fig. 2). The maximum likelihood supervised classification technique (ERDAS 2008) was applied to the image to extract and map the existing land use/cover types (LULC) in the study area. The observed LULC types in the field were: managed olive/palm trees, grass land, mismanaged palm trees and bare soil (Fig. 2). Areas with mismanaged palm trees were discriminated from the managed farms by delineation based on their pattern and texture on the image as well as field inspections with the aid of 38 ground truth points and 33 points from Google Earth. The normalized difference vegetation index (NDVI) was calculated from the image to estimate the plant cover intensity (%) according to the following equations.

$NDVI = (NIR-R)/(NIR+R) = (band4-band3)/(band4+band3)$ ……… (Rouse *et al 1974)*

Where, NIR is the near infrared reflectance, R is the visible red reflectance. The resulting NDVI values range between -1 and +1 (Tucker et al. 1985). The positive NDVI values indicate vegetated areas, while negative values associated with non-vegetated areas (Albarakat and Lakshmi 2019). The LULC data resulting from image classification were used to identify the best NDVI thresholding, which estimates the vegetated areas and non-vegetated areas. The NDVI histogram pixels of the vegetated area were used to determine the lowest vegetation ($NDVI_0$) and the highest vegetation ($NDVI_\infty$) and then the plant cover intensity (%) was calculated according to the following equation:

$Plant\ cover\ intensity\ (\%) = [(NDVI - NDVI_0)/(NDVI_\infty - NDVI_0)] \times 100$ …. (Liang et al. *2008)*

For the non-vegetated area, the plant cover intensity (%) is considered as zero (Salunkhe et al. 2018). The resulted LULC types and the plant cover intensity (%) were then used as inputs in the process of desertification sensitivity analysis.

Analysis of desertification sensitivity

Desertification sensitivity analysis in the study area was performed based on the procedure of the standard MEDALUS approach developed by Kosmas et al. (1999) and modifications made by Bakr et al. (2012) and Salunkhe et al. (2018). MEDALUS input parameters include data collected from field survey, data from DEM analysis (slope and aspect), data from Landsat image processing (LULC types and plant cover intensity %), data of soil and water analyses, and meteorological data. To analyze the desertification sensitivity in the study area using the modified MEDALUS, the following indices were calculated: the soil quality index (SQI), the vegetation quality index (VQI), the climate quality index (CQI), the management quality index (MQI), and the irrigation water quality index (IWQI).

$$SQI = (soil\ texture * soil\ depth * rock\ fragments * parent\ material * slope\ percent * drainage\ status * soil\ salinity * soil\ pH * organic\ matter)^{1/9}$$

$$VQI = (fire\ risk * erosion\ protection * plant\ cover\ intensity * drought\ resistance)^{1/4}$$

$$CQI = (rainfall * aridity * aspect * wind\ speed)^{1/4}$$

$$MQI = (land\ use\ intensity * policy\ management)^{1/2}$$

$$IWQI = (EC_w * SAR * Cl)^{1/3}$$

Where EC_w is the irrigation water salinity (dS m^{-1}), SAR is sodium adsorption ratio of irrigation water and Cl is chloride concentration (meq L^{-1}) of irrigation water.

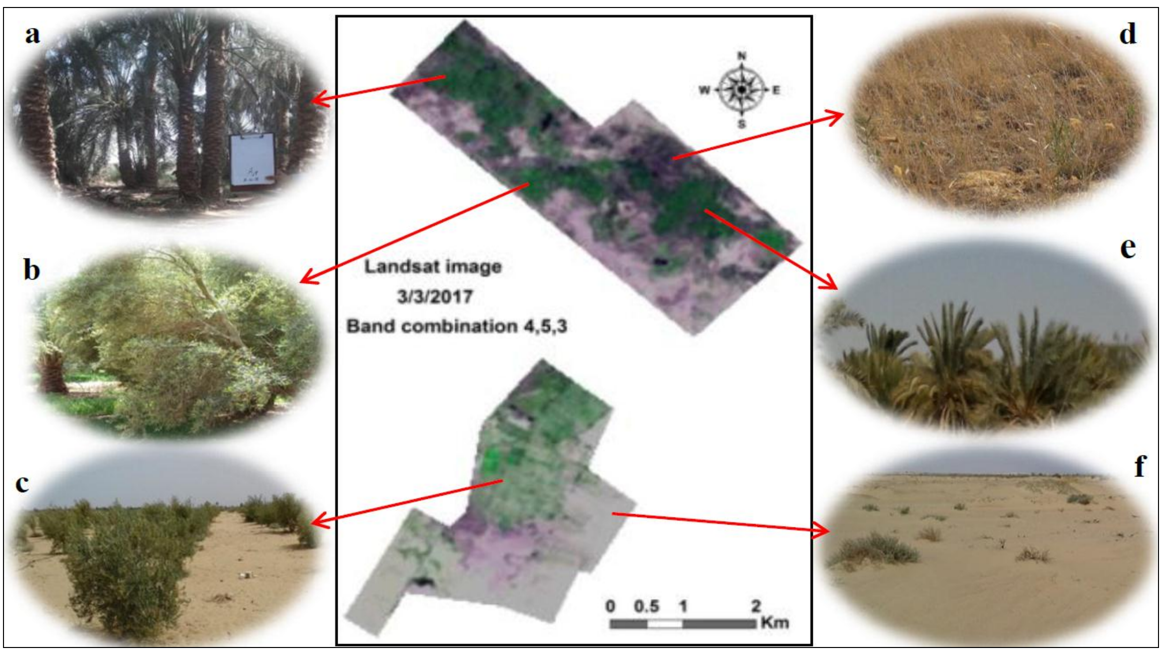

Fig.2. The selected Landsat 2017 image used for the study and the observed LULC types: a) managed palm trees, b) managed old olive trees, c) managed new olive trees, d) grass land, e) mismanaged palm trees and f) bare soil

Table 1. Description, classes, scores and data source of the indicator parameters included in the calculation of SQI

Indicator parameters	Description	Class	Score	Data source
Soil texture*	Loamy, sand clay loam, sand loam, loamy sand, clay loam	Good	1	Field survey
	Sand clay, silt loam, silt clay loam	Moderate	1.2	
	Silt, clay, silt clay	Poor	1.6	
	Sand	Very poor	2	
Soil depth (cm)*	>75	Deep	1	Field survey
	75-30	Moderate	2	
	30-15	Shallow	3	
	< 15	Very shallow	4	
Rock fragments (%)*	> 60	Very stony	1	Field survey
	60-20	Stony	1.3	
	< 20	Bare to slightly stony	2	
Parent material*	Shale, schist, basic, ultra basic, conglomerates, unconsolidated	Good	1	Sallam et al. 2018
	Limestone, marble, granite, rhyolite, ignibrite, gneiss, siltstone, sandstone	Moderate	1.7	
	Marl, Pyroclastics	Poor	2	
Slope percent (%)*	< 6	Very gentle to flat	1	DEM analysis
	6-18	Gentle	1.2	
	18-35	Steep	1.5	
	> 35	Very steep	2	
Drainage status**	Well drained	Good	1	Field survey
	Imperfectly drained	Moderate	1.2	
	Poorly drained	Poor	2	
Soil salinity (dS m^{-1})**	< 2	Non Saline	1	Lab. analysis
	2 – 4	Slightly Saline	1.2	
	4 – 8	Moderately Saline	1.5	
	8 – 16	Strongly Saline	1.7	
	> 16	Very Strongly Saline	2	
Soil pH**	6.6 – 7.3	Neutral	2	Lab. analysis
	7.4 – 7.9	Slightly alkaline	1	
	7.9 – 8.4	Moderately alkaline	1.5	
	8.4 – 9.0	Strongly alkaline	1.7	
	> 9.0	Very Strongly alkaline	2	
Organic matter (%)**	> 3	Very High	1	Lab. analysis
	2-3	High	1.2	
	2 – 1	Moderately	1.5	
	1- 0.5	Low	1.7	
	< 0.5	Very Low	2	

***** Kosmas et al. 1999, ** Bakr et al. 2012.

Table 2. Description, classes, scores and data source of the indicator parameters included in the calculation of VQI, MQI and CQI

Index	Indicator parameters / (Data source)	Description	Class	Score
VQI	Fire risk and vegetation types * (Satellite data)	Bare land, perennial agricultural crops, and annual agricultural crops.	Low	1
		Annual agricultural crops (cereals, grasslands), deciduous oak, mixed Mediterranean, macchia/evergreen forests.	Moderate	1.3
		Mediterranean macchia	High	1.6
		Pine forests	very high	2
	Erosion protection* (Satellite data)	Mixed Mediterranean macchia/evergreen forests	Very high	1
		Mediterranean macchia, pine forests, permanent grasslands, evergreen perennial crops	High	1.3
		Deciduous forests	Moderate	1.6
		Deciduous perennial agricultural crops (almonds, orchards)	Low	1.8
		Annual agricultural crops (cereals), annual grasslands, vines,	Very low	2
	Plant cover intensity* (Satellite data)	> 40 %	High	1
		40-10 %	Low	1.8
		<10 %	Very low	2
	Drought resistance* (Satellite data)	Mixed Mediterranean macchia/evergreen forests, Mediterranean macchia	Very high	1
		Conifers, deciduous, olives	High	1.2
		Perennial agricultural trees (vines, almonds, ochrand)	Moderate	1.4
		Perennial grasslands	Low	1.7
		Annual agricultural crops, annual grasslands	Very low	2
MQI	Land use intensity* (Field survey)	low land use intensity		1
		Medium land use intensity		1.5
		high land use intensity		2
	Policy management* (Field survey)	Complete: >75% of the area under protection	High	1
		Partial: 25-75% of the area under protection	Moderate	1.2
		Incomplete: <25% of the area under protection	Low	2
CQI	Rainfall (mm year^{-1})* (Siwa meteorological Station)	> 650		1
		280 to 650		2
		< 280		3
	Bagnouls-Gaussen aridity index* (Siwa meteorological Station)	<50		1
		50 to 75		1.1
		75 to100		1.2
		100to125		1.4
		125to150		1.8
		>150		2
	Slope aspect* (DEM analysis)	Flat, north, northeast, east, northwest		1
		South, southeast, southwest, west		2
	Wind speed (m s^{-1})** (Siwa meteorological Station)	0-2	Slight	1
		2-3.5	Moderate	1.3
		3.5- 4.5	Severe	1.6
		> 4.5	Very severe	2

***** Kosmas et al. 1999, ** Salunkhe et al. 2018.

Tables (1, 2 and 3) illustrate the indicator parameters included in the indices calculation. These parameters are quantified in relation to their influence on the desertification process, assigning scores for each parameter. The scores assigned to most parameters range between 1 (the best value) and 2 (the worst value). The worst index value for the soil depth parameter is 4.

Although the wind speed is usually measured at 10 m height at metrological stations, it should be converted to 2 m height when used in agronomic purposes (Allen et al. 1998). Thus, to use the wind speed as indicator for the desertification sensitivity analysis in the study area, the wind speed data was converted from the standard 10 m height to the 2 m height using the following equation:

$$u_2 = (u_{10} * 4.87) / \ln[(67.8 * 10) - 542]$$ ………………… (Allen et al. 1998)

where u_2 is the wind speed (m s^{-1}) at 2 m height above ground surface, u_{10} is the measured wind speed (m s^{-1}) at 10 m height above ground surface.

The description and ratings of the calculated SQI, VQI, CQI, MQI and IWQI are listed in Table (4). The desertification sensitivity in the study area was estimated by calculating an integrated index of the previous anthropogenic-environmental qualities (soil quality, vegetation quality, climate quality, management quality and water quality). The desertification sensitivity index was calculated and defined based on the following equation and the ratings in Table (5) (Basso et al. 2000; Kosmas et al. 1999):

$$\text{Desertification sensitivity Index (DSI)} = (SQI * VQI * CQI * MQI * IWQI)^{1/5}$$

Table 3. Description, classes, scores and data source of the irrigation water parameters included in the calculation of IWQI

Index	Indicator parameters	Description	Class	Score	Data source
IWQI	EC_w (dS m^{-1})	< 0.7	High Quality	1	Lab. analysis
		0.7 - 3	Moderate Quality	1.5	
		> 3	Low Quality	2	
	Cl (meq L^{-1})	< 4	High Quality	1	Lab. analysis
		4-10	Moderate Quality	1.5	
		> 10	Low Quality	2	
	SAR	0 - 3	NO Risk	1	Lab. analysis
		3--6	Low Risk	1.2	
		6-12	Moderate Risk	1.5	
		12-20	High Risk	1.7	
		20 - 60	Very High Risk	2	

Table 4. Description and the corresponding ratings of SQI, VQI, CQI, MQI and IWQI

Description	SQI rating	VQI rating	CQI rating	MQI rating	IWQI rating
High quality	< 1.13	1 - 1.6	< 1.15	1 – 1.25	< 1
Moderate quality	1.13 - 1.45	1.7 - 3.7	1.15 - 1.81	1.26 – 1.5	1 - 1.41
Low quality	> 1.46	3.8 - 16	> 1.81	>1.5	> 1.41

Table 5. Types, description and ranges of desertification sensitivity

Type	Description	DSI rating
Critical	High, C3	> 1.53
	Moderate, C2	1.53 -1.42
	Low, C1	1.41 - 1.38
Fragile	High, F3	1.37 - 1.33
	Moderate, F2	1.32 - 1.27
	Low, F1	1.26 - 1.23
Potential	P	1.22 - 1.17
Non-affected	N	< 1.17

RERSULTS AND DISCUSSION

Terrain and vegetation analyses

The elevations in the study area ranged from 20 m below sea level to 10 m above sea level and the majority of the study area (79.8%) laid below the sea level (from -15m to -10 m). The slope percent and aspects in the study area were derived from the elevations, where 96.5% of the area is characterized by slope percent less than 6% and about 56% of the slope directions (aspects) are to the North, Northwest and Northeast wards (Fig. 3).

Results of vegetation analysis revealed that the NDVI values ranged from -0.39 (No vegetation) to 0.62 (the maximum vegetation). The plant cover intensity was estimated from NDVI, where 61.7%, 32.7% and 5.6% of the study area has plant cover intensity <10%, 10-40% and > 40%, respectively. Four LULC types were identified in the study area, which extracted from the Landsat 2018 image. These LULC types include “the managed olive/palm trees”, “the grass land”, “the bare soil” and “the mismanaged palm trees”, which represent 32.6%, 32.5%, 23.7% and 11.1%, respectively, of the study area (Fig 4).

Soil characterization and classification

The descriptive statistics of the soil analysis’ results (Table 6) indicated very high variability (CV %) in soil salinity (EC), organic matter (OM) content, silt percent and calcium carbonate content ($CaCO_3$). The soil salinity values varied between 2 (dS m^{-1}) and 242 (dS m^{-1}) with an average value of 93.9 (dS m^{-1}) and CV value of 85.9%. The organic matter content in the soil ranged from zero to 8.4% with an average value of 1.6% and CV value of 111.7%.

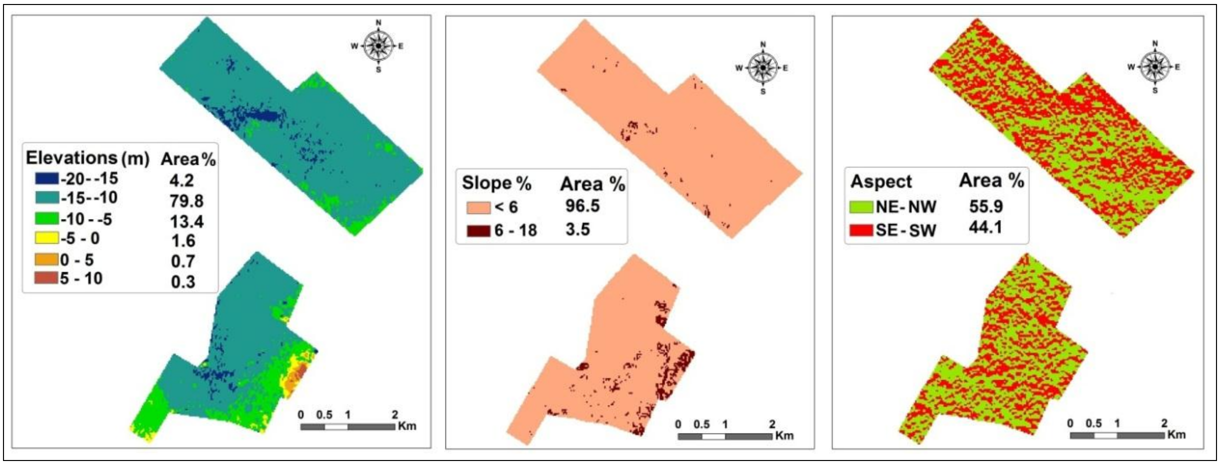

Fig.3. Elevations, slope and aspects in the study area

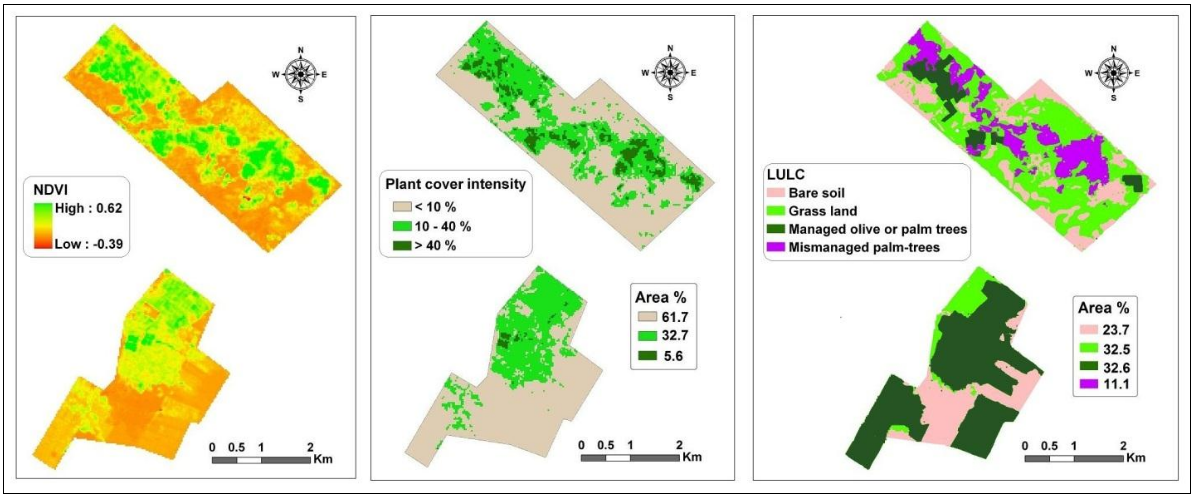

Fig.4. NDVI, the plant cover intensity and the existing LULC types in the study area

Table 6. The descriptive statistics of soil analyses

Statistical parameters	Soil								Water		
	pH	EC dS m^{-1}	Soil depth cm	$CaCO_3$ %	OM %	Sand %	Silt %	Clay %	EC dS m^{-1}	SAR	Cl meq L^{-1}
Mean	8.3	93.9	71.2	17.4	1.6	72.7	6.6	20.2	5.3	7.1	38.6
Standard Deviation	0.3	80.7	24.4	13.2	1.7	10.9	6.3	6.0	4.8	4.4	34.2
Minimum	7.6	2.0	20.0	0.1	0.0	48.7	0.0	10.8	1.9	0.7	11.5
Maximum	9.0	242.0	100.0	59.0	8.4	89.2	27.7	34.5	13.1	14.8	88.0
CV%	3.4	85.9	34.3	75.7	111.7	15.0	96.2	30.0	90.0	61.3	88.6

The calcium carbonate content ranged from 0.1% to 59% with an average value of 17.4% and CV value of 75.7%. Although the silt content was characterized by its very high variability (CV= 96.2%), the prevailing soil texture of the soil samples were sand clay loam, sand loam, and loamy sand. The soil depth varied between 20 cm and 100 cm with an average value of 71.2 cm and moderate variability (CV=34.3%). The soil pH was characterized by its very low variability (CV= 3.4%), where its values extended from 7.6 to 9. For the collected irrigation water samples, the salinity values varied between 1.9 (dS m-1) and 13.1 (dS m-1) with an average value of 5.3 (dS m-1). The minimum SAR value was 0.7, while the maximum value was 14.8. Chloride concentrations in water ranged from11.5 (meq L-1) to 88 (meq L-1).

According to the American system of soil taxonomy (USDA 2014), results of soil classification indicated that the soils in the study area are belonged to the soil orders *Aridisols* (68.8 %) and *Entisols* (31.2%). The main diagnostic horizons of *Aridisols* are *salic* and *clacic* horizons. *Salic* horizon is common in most of the investigated soils and usually exists in soils close to Lake Zeitun as well as the poorly drained soil. *Calcic* horizon is common in the old cultivated land, which is mostly located in the northern part of the study area. *Entisols* have no subsurface diagnostic horizons and could be characterized by a very weak *ochric* epipedon. Under *Aridisols*, three sub-great-group soils were recognized, which are *Calcic Haplosalids* (51.9%), *Typic Aquisalids* (8.7%) and *Lithic Haplosalids* (8.2%). The sub-great-group soil identified under *Entisols* is *Typic Torripsamments* (31.2%) (Fig 5).

Desertification indicators

A total of 22 key indicators describing different desertification factors (soil, vegetation, climate, management and water) were used to drive a desertification sensitivity index for the study area. These factors interact in time and space leading to a decrease in land productivity. The selected desertification indicators include nine soil parameters, four vegetation parameters, four climate parameters, two management practice parameters and three irrigation water parameters. Most of these indicators along with their index values, descriptions and areas are presented in Figs (6 and 7).

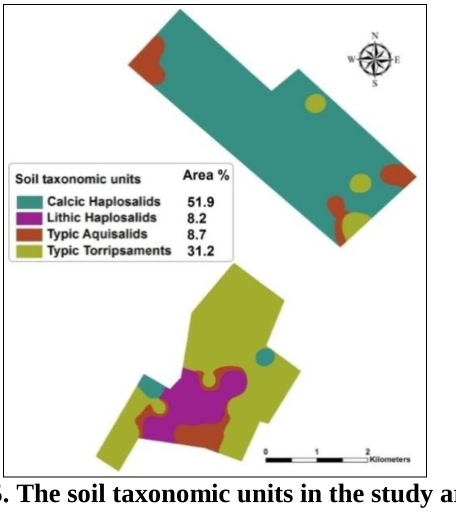

Fig. 5. The soil taxonomic units in the study area

It is clearly obvious from Figs (6 and 7) that the majority of the study area falls under the very strongly saline soil (87.9%), the moderately to strongly alkaline soil (94.5%), the moderate to very low organic matter content (56.1), the low to very low pant cover (94.4%), the low to very low drought resistance (55.8%) and the low to very low erosion protection (51.6%). Identically half of the study area was characterized by the moderate to shallow soil depth (Fig 6) and almost half (48.1%) of the area was under the moderate to high fire risks (Fig 7). On the other hand, the study area had 5.4% slightly to moderately saline soil, 5.5% slightly alkaline soil, 43.4% high to very high organic matter content in the soil, 50% deep soil, 5.6% high plant cover, 44.2% under

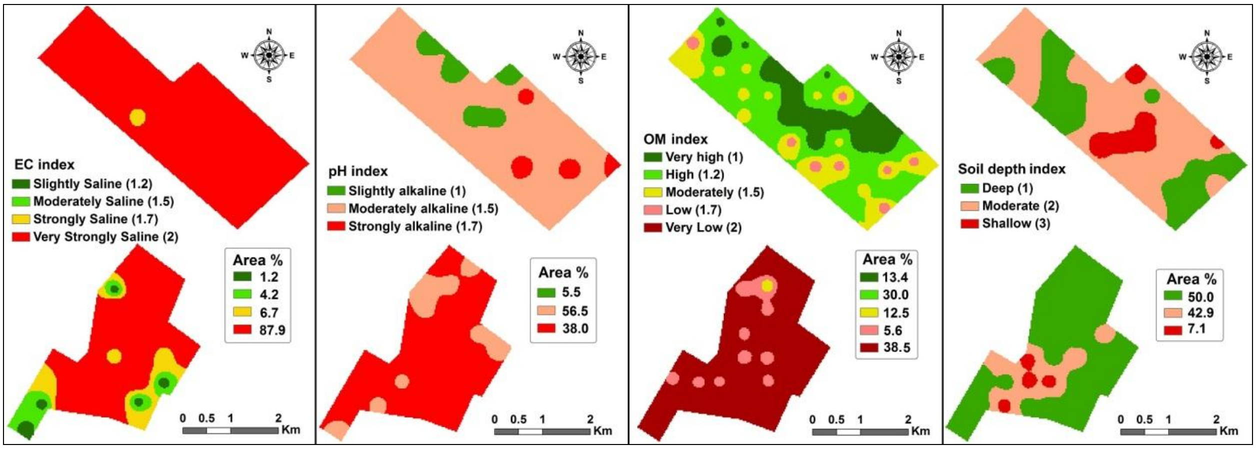

Fig.6. The soil salinity, alkalinity, OM, and soil depth quality indices in the study area

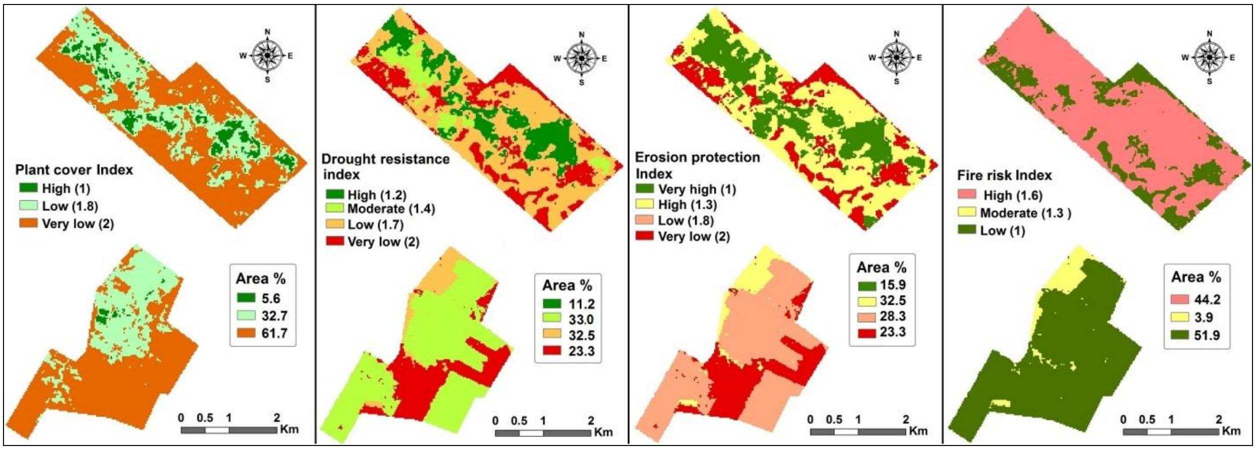

Fig.7. The plant cover, drought resistance, erosion protection, and fire risks quality indices in the study area

moderate to very high drought resistance, 48.4% under high to very high erosion protection, and 51.9% under low fire risk (Figs 6 and 7)

Noticeably, the majority of the northern part of the study area is characterized by the shallow water table. Thus, the low quality salinity index and the moderate to low quality soil depth index were a reflection of the poor drainage conditions in the study area as well as the extremely saline water table. A good drainage conditions can assure less soil salinization and consequently provide a good condition for vegetation development and growth. The high to very high quality of the organic matter index in most of the northern part of the study area may be due to the high vegetation cover of salinity tolerant plants (i.e., mismanaged palm trees and natural grass), which increase the accumulation rate of plant residual, especially under the extremely saline waterlogging conditions and slow rate of decomposition. Despite the high vegetation cover intensity and type in the northern part of the study area, sometimes it exposed to fire risks in light of the hyper arid conditions of the region (Fig 4, 7 and 8).

Fig.8. Impact of fire risks in the northern part of the study area

Desertification sensitivity

Five indices were calculated for the evaluation and mapping of desertification sensitivity in the study area. These indices represent the soil, vegetation, climate, management, and water qualities. Each index was calculated from its related key indicators. The spatial extend and areas of the five desertification indices (i.e., SQI, VQI, CQI, MQI, and IWQI) are presented in Figs (9 and 10). Results of SQI indicated that the areas under the moderate soil quality (SQI from 1.22 to 1.45)

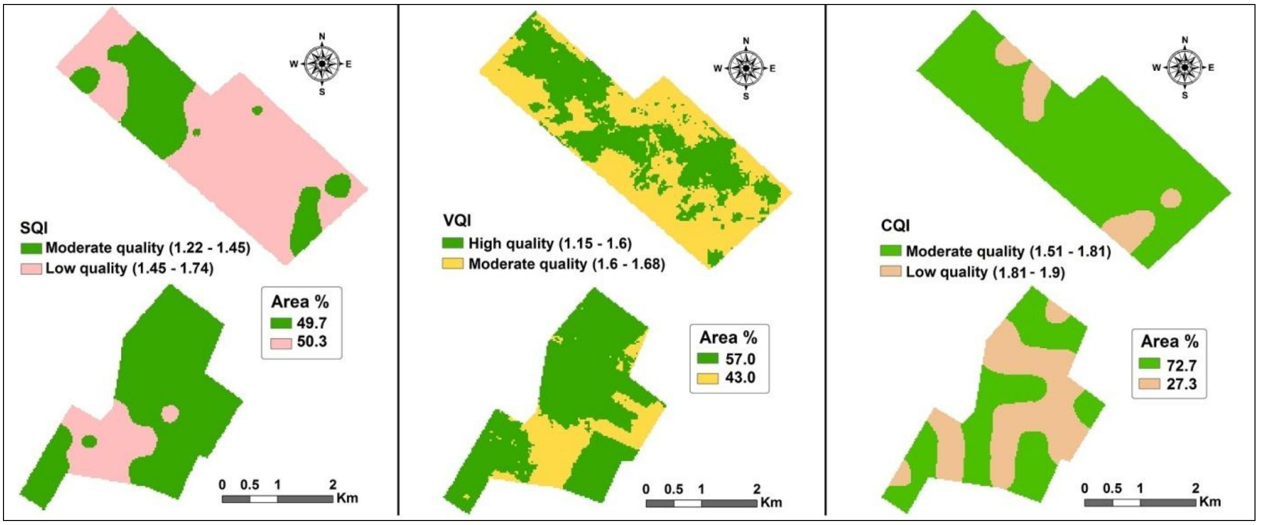

Fig.9. The soil, vegetation, climate qualities in the study area

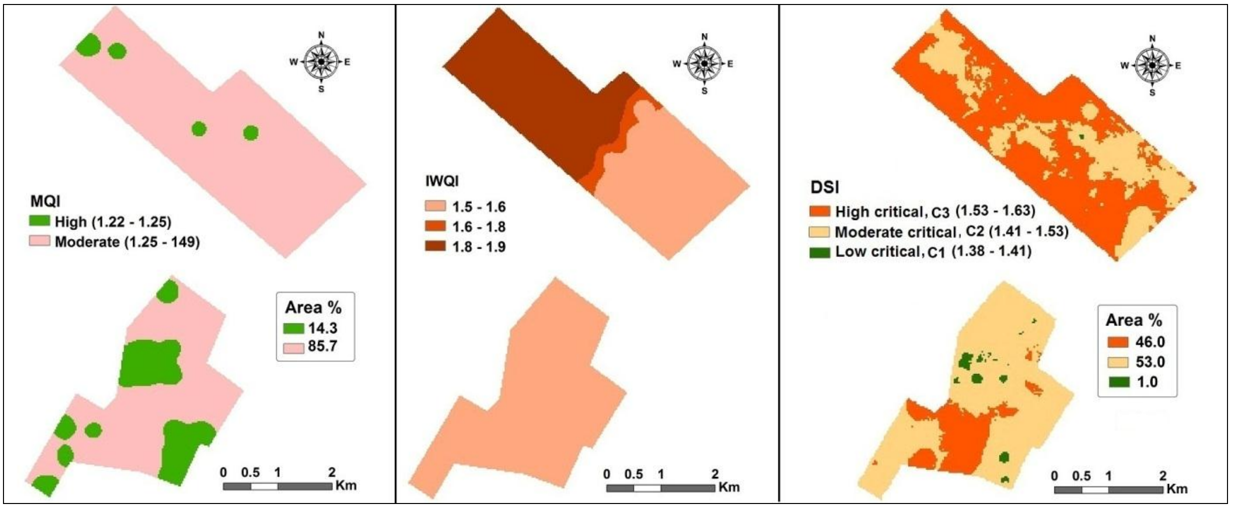

Fig.10. The management and irrigation water qualities as well as desertification quality index in the study area

represent 49.7% of the total area, while 50.3% of the area was under the low soil quality (SQI >1.45). The resulted VQI revealed that the areas of the high vegetation quality (VQI < 1.6) dominate most of the study area (57%), while areas of low vegetation quality (VQI >1.6) occupy 43%. The calculated CQI indicated that the majority of the study area (72.7%) was under the moderate climate quality (CQI from 151 to 1.81) and 27.3% of the area was subjected to the low climate quality (CQI > 1.81).

The obtained MQI reveals that the areas of high management quality (MQI from 1.22 to 1.25) were very limited representing 14.3% of the study area and the remaining area (85.7%) was under the moderate management quality (MQI > 1.25). As it presented in Fig (10), the resulted IWQI indicated that the available irrigation water resources in the study area have IWQI value more than1.41, which means that the entire study area comes under low water quality.

The desertification sensitivity index (DSI) for the study area was obtained by integrating the five quality indices (Figs 9 and 10). The obtained DSI ranged from 1.38 to 1.63, which means that the entire study area comes under the critical category of desertification sensitivity (Fig 10). It is obvious that the majority of the study area (53%) is considered moderate critical (C2) to desertification sensitivity, which covers most of the southern part of the study area. The desertification sensitivity level "high critical, C3" covers 46% of the study area and mostly concentrates in the northern part. Only 1% of the study area is considered low critical (C1) to desertification sensitivity, which mainly exists in several patches in the southern part of the study area.

CONCLUSION

This study demonstrates the analysis of desertification sensitivity in East Siwa oasis using the modified MEDALUS methodology. The application of this methodology revealed that more than half of the study area has low quality soils (50.3%) with respect to desertification risks followed by moderate quality soils (49.7%). The high percentage of moderate and low quality of soils is mainly attributed to the high soil salinity and alkalinity. The majority of the study area is characterized by moderate climate quality (72.7%). This is mainly attributed to the low amount of precipitation occurring in the region and the high aridity index. The existing vegetation quality in the area is characterized as high (57% of the area) and moderate qualities (43%). The areas of high management quality were very limited, representing 14.3% of the study area and the remaining area (85.7%) was under the moderate management quality. The entire study area is characterized by low water quality, which is attributed to the high salinity levels of irrigation water. It can be concluded that the entire study area is under the critical level of desertification sensitivity (DSI > 1.38). This level of desertification sensitivity was caused by natural and anthropogenic factors. Therefore, action measures are very necessary to combat desertification and for the sustainable agricultural development.

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الملخص العربي

تقييم حساسية منطقة شرق واحة سيوة للتصحر باستخدام نظم المعلومات الجغرافية والاستشعار عن بعد

أشرف محمد مصطفى، أسامة راضى محمد، يحيى ابراهيم محمد، نور الدين نصر خالد

يعتبر التصحر أحد أكبر التحديات البيئية التي تواجه التنمية المستدامة في المناطق الجافة وشبه الجافة وتحت الرطبة، حيث تعد العوامل البيئية والبشرية أهم المؤشرات التى يمكن الاعتماد عليها فى قياس حساسية منطقة ما للتصحر. الهدف من هذه الدراسة هو تقييم حساسية الأرض للتصحر بشرق واحة سيوة (١٧٦٣ هكتار)، مصر، حيث تم الاعتماد على منهجية MEDALUS المعدل فى تقييم حساسية المنطقة للتصحر. وتعتمد تلك المنهجية على العوامل البيئية والبشرية مثل صفات التربة والغطاء النباتي والمناخ والإدارة المزرعية وجودة مياه الرى، حيث اعتمدت هذه الدراسة على ٢٢ معيار لتقييم الحساسية للتصحر. تم تحديد عدد ٧٣ موقع خلال المنطقة المدروسة لتجميع بيانات عن التربة (عينات التربة) ومؤشرات التصحر الاخرى. أظهرت النتائج أن أكثر من نصف مساحة منطقة الدراسة تعتبر أرض منخفضة الجودة (٥٠,٣٪) فيما يتعلق بالحساسية للتصحر تليها الأراضى متوسطة الجودة (٤٩,٧٪)، حيث يرجع ذلك بشكل رئيسي إلى ارتفاع مستويات ملوحة وقلوية التربة. ايضا تتميز غالبية منطقة الدراسة (٧٢,٧٪) بمناخ متوسط الجودة، ويعزى ذلك إلى ندرة كمية الأمطار التي تتساقط على المنطقة وارتفاع قيمة دليل الجفاف. تتميز جودة الغطاء النباتى بالمنطقة بأنها متوسطة (٤٣٪) الى مرتفعة (٥٧٪). أما بالنسبة للادارة المزرعية فان ٨٥,٧% من منطقة الدراسة تقع ضمن الادارة المزرعية متوسطة الجودة وباقى المساحة (١٤,٣٪) يمارس بها ادارة مزرعية مرتفعة الجودة. أيضا تتميز منطقة الدراسة بأكملها بانخفاض جودة المياه المستخدمة للرى حيث مستويات الملوحة المرتفعة. وبشكل عام تقع منطقة الدراسة بأكملها تحت مستوى حرج من الحساسية للتصحر Critical. وفي ضوء هذا المستوى المرتفع من حساسية المنطقة للتصحر يجب وضع خطة فعالة تساعد فى التخفيف من مخاطر التصحر بالمنطقة وتحقيق التنمية الزراعية المستدامة.