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Land degradation assessment for some areas in the Northwestern coast of Egypt using geospatial techniques

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ABSTRACT

Land degradation refers to the decline in land quality and productivity caused by human activities and natural processes. This environmental issue has negative consequences for ecosystems and human well-being. In this study, the Global Assessment of Human-induced Soil Degradation (GLASOD), geographical information system (GIS), and remote sensing (RS) techniques were integrated to assess and understand the land degradation processes on the northwestern coast of Egypt. Land degradation severity levels were categorized as low, moderate, high, and very high, depending on the degree and extent. The main physiographic units were defined using GIS and remote sensing data. The results revealed that the study area is dominated by Aeolian Plain (A), Coastal Plain (C), Deltaic Plain (D), Lacustrine Plain (L), Pediment Plain (P), and Plateau (U) landforms. Salinization, alkalinization, soil compaction, and waterlogging were identified as the key indicators of land degradation in the study area. Salinization severity classes in the lacustrine plain were classified as medium, representing 82%, high representing 14%, and very high representing 4%. Alkalinization severity classes in the Aeolian plain were classified as low and high, representing 98% and 2% respectively. Soil compaction in this unit was high, covering an area of 136 km^2, i.e., 14%, and very high, covering an area of 1018 km^2. The land degradation assessment due to waterlogging in the lacustrine plain unit was categorized as very high, covering an area of 1021 km^2. Salinization, alkalinization, soil compaction, and waterlogging were identified as the most consequential processes contributing to land degradation over the study area.

Keywords: Land degradation, GLASOD, Salinization, Alkalinization, compaction, waterlogging, GIS, Remote sensing techniques.

1. INTRODUCTION

Land degradation is a complex issue influenced by natural, social, and economic factors. To effectively combat land degradation, it is necessary to understand its causes, impacts, degree, and extent. The integration of remote sensing (RS) and geographical information system (GIS) can help in better understanding and managing land degradation (Ahmed et al., 2019; Ali et al., 2019). Methods are available for assessing the early phases of land degradation through laboratory analysis of soil properties, plant monitoring, and modeling (Diouf et al., 2001; Shepherd et al., 2003; Symeonakis et al., 2004; Omuto, 2008). Remote sensing can also provide valuable information about land use and land degradation (Porarinsdottir, 2008; Ahmed et al., 2019; Ali et al., 2019).

Scientists worldwide have been working on addressing land degradation and developing methods for monitoring and assessment. These techniques determine the extent of land degradation and aid in planning conservation efforts. Precise methods for assessing land degradation are essential in order to plan interventions and investments aimed at reversing land degradation and protecting ecosystems.

The World Overview of Conservation Approaches and Technologies (WOCAT) presents a uniform methodology that can be applied across different scales, ranging from community-based to international. It offers a comprehensive set of instruments for documenting, monitoring, and evaluating soil and water resources. This valuable data is disseminated globally, fostering the exchange of expertise and enhancing the quality of decision-making and strategic planning (van Lynden et al., 2004).

The Land Degradation Assessment in Drylands (LADA) program initiative is all about assessing land degradation in drylands. LADA use a bunch of different methods to gather information about how the land is changing. It involves the local experts, field measurements, remote sensing and GIS modeling. The project is intended to devise an innovative and enhanced approach for monitoring land degradation by utilizing authentic data (Koohafkan et al., 2003).

The Global Assessment of Human-induced Soil Degradation (GLASOD) method offers accurate information to address soil and land degradation issues, informing policy makers and governments about the importance of soil conservation. It is a global approach based on input from worldwide experts, providing essential data on the extent and severity of different types of degradation (Bridges and Oldeman, 1999).

Over the course of numerous decades, efforts have been made to restore degraded land through rehabilitation activities. Despite these efforts, land degradation persists. This ongoing issue may stem from a lack of comprehensive data on the balance between land sustainability and degradation, as well as the appropriate schemes for rehabilitation. Spatially categorizing the vulnerability of land to degradation is essential for establishing priorities in the restoration of degraded land (Basuki & Wahyuningrum, 2014).

The categorization of degraded land can be accomplished through the examination of land properties acquired through geospatial techniques. Alongside the spatial data pertaining to degraded land, the appropriateness scheme for reforestation plays a crucial role in enhancing the effectiveness of land restoration efforts (Sudarmadji & Hartati, 2016).

The utilization of the Global Assessment of Human-induced Soil Degradation (GLASOD) in assessing land degradation is crucial for understanding the impact of climate and human activities on soil capacity, leading to reduced present and future potential and ultimately resulting in land degradation (ISRIC/UNEP, 1991; Bridges et al., 1999; Ahmed et al., 2019; Ali et al., 2019). Using the Food and Agriculture Organization (FAO) framework allows for the monitoring and assessment of land degradation, land cover suitability, and sustainable land at various scales.

This framework provides valuable information for decision-making regarding investment and planning interventions for sustainable agricultural development and addressing land degradation.

This work aims to assess the land degradation processes on the northwestern coast of Egypt using geospatial analysis following the GLASOD and FAO guidelines.

2. MATERIALS AND METHODS

2.1. Study area

The study area is located on the northwestern coast of Egypt, between longitudes 28° 58' and 30° 00' E and latitudes 30° 35' and 31° 20' N (Figure 1). The geology of the area is characterized by various formations, including Moghra, Alexandria formations, and Sabkha deposits (Shata, 1955; Purzner, 2008; Mahmoud et al., 2009). The area comprises three geomorphological units i.e. (a) plateau (b) coastal plain and the (c) depressions. The northwestern coastal plain is highlighted by nine ridges separated by sabkhas and lagoonal areas (Zahran et al., 1985; Abdel-Kader, 1986; Zahran et al., 1990; Yousif et al., 2012; Yousif, 2015; El-Ramady et al., 2018; Hassanein et al., 2020). The soil of the study area are in general calcareous and are classified as Aridisols or Entisols. The area mostly relies on rainfall for agricultural activities during winter, while groundwater is used as a complementary irrigation source during summer period.

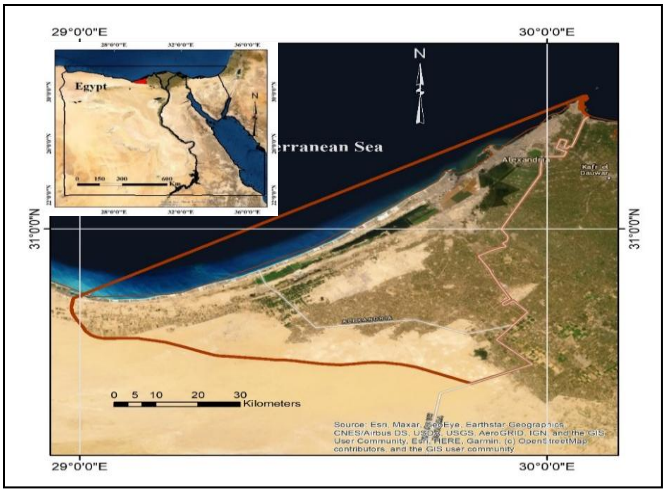


Figure 1. Location of study area.

2.2. Data Collection

2.2.1. Satellite data

Four Landsat 8 satellite images acquired during 2023, available from the United States Geological Survey (USGS), were used in this study to map the landform units and define the land cover in the study area. The study utilized Landsat-8 images, including the 14.25-meter resolution panchromatic band, to enhance the spatial resolution of the images. The Identification numbers (ID) of the used images are:

- LC08_L1TP_177038_20230806_20230812_02_T1
- LC08_L1TP_177039_20230806_20230812_02_T1
- LC08_L1TP_178038_20230712_20230718_02_T1
- LC08_L1TP_178039_20230712_20230718_02_T1

2.2.2. Shuttle Radar Topography Mission (SRTM)

Satellite images of Landsat 8 (OLI sensor) with identifiers; LC08_L1TP_178039_20230911_20220921_02_T&LC08_L1TP_178039_20230802_20220802_02_T1 available from the United States Geological Survey (USGS) of the study area of Egypt and Libya were used in this study for mapping the landform units and defining. The Landsat-8 images with 14.25 meters resolution panchromatic band to improve the image spatial resolution in ArcGIS x software (ESRI staff, 2019).

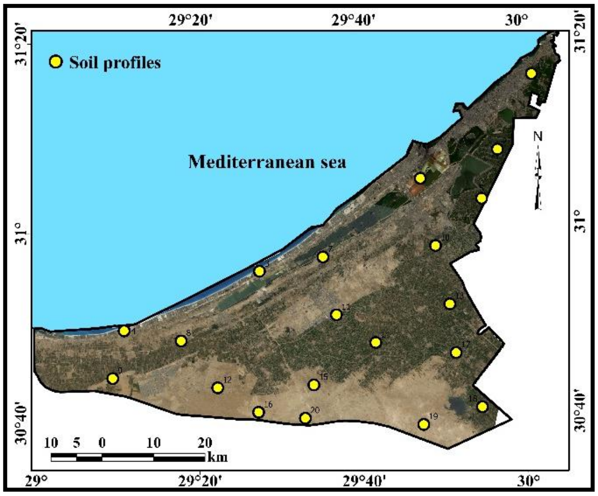
Digital Elevation Model (DEM) is an automated three-dimensional model of land surfaces; it is more capable than topographic maps (Brough, 1986). With precise positioning and periodic one-arc-second radar scanning of the earth, SRTM is a well-respected space data set of the land surface. To enhance terrain imagery, a digital elevation model (DEM) developed from SRTM data could be utilized (Lee et al., 1988).

2.3. Landform and soil mapping

To identify the various landforms and generate the soil database, the Landsat ETM+ image and SRTM data were processed using ENVI 4.7 software (Zinck and Valenzuala, 1990; Dobos et al. 2002). The soil physiographic map was created by implementing correlations between physiographic and taxonomic units as detailed by Elberson and Catalon (1987).

2.4. Fieldwork

A semi-detailed survey was conducted throughout the surveyed area to verify the accuracy of the preliminary physiographic map and collect soil samples. To represent the different physiographic units, twenty (20) soil profiles were excavated, including sand flats, shore ridges, high, moderate,



and coastal plains, deltaic plain, lacustrine plain, pediment plain, and plateau (Figure 2).

Figure 2. Location of soil profiles.

2.5. Soil analysis

Soil physics analysis involves assessing the properties and characteristics of soil to understand the phenomenon of soil degradation, including particle size distribution and soil bulk density, which were determined using the pipette and core methods, respectively (Page, 1982). Estimating waterlogging in a particular area typically involves assessing the water table depth. Finally, soil structure assessment was carried out using visual observations, assessing aggregation, compaction and root penetration. For chemical analysis of the soil, pH was measured using a pH meter and electrical conductivity (EC) was measured using the conductivity meter described by Jackson (1967). The values were measured at 250 °C. The ESP (Exchangeable Sodium Percentage) is used to assess the sodium hazard and the potential for sodicity in the soil. ESP is expressed as a percentage and is calculated using the following formula: ESP = (Exchangeable sodium/cation exchange capacity) x 100 (Richards, 1954).

2.6. Land degradation assessment

2.6.1. GLASOD Approach:

Assessing land degradation through the utilization of the Global Assessment of Soil Degradation (GLASOD) is critical to understanding the correlations between climate forces and human interventions, which ultimately lead to a reduction in the current and future soil capacity (ISRIC/UNEP, 1991). The extent of land degradation is determined by the level of soil deterioration, the percentage of the mapped area (physiographic unit) affected, and the severity of degradation, reflecting the apparent speed of the soil degradation process. In this study, the GLASOD approaches described by Oldeman et al. (1991) were used to evaluate the levels of land degradation in the study area (Table 1).

Table 1. Level of degradation severity for mapping units (Oldeman et al., 1991).

	Relative extent (%)	0 - 5	6 - 10	11 - 25	25 - 50	50 - 100
		Infrequent	Common	Frequent	Very frequent	Dominant
Degree of Soil degradation	Slight	(1,1)	(1,2)	(1,3)	(1,4)	(1,5)
	Moderate	(2,1)	(2,2)	(2,3)	(2,4)	(2,5)
	Strong	(3,1)	(3,2)	(3,3)	(3,4)	(3,5)
	Extreme	(4,1)	(4,2)	(4,3)	(4,4)	(4,5)

Level of severity	Low	Medium	High	Very high

2.6.2. FAO criteria

The FAO criteria were used to assess the extent, category, and velocity of different types of land degradation related to salinity, sodicity, Waterlogging and compaction, as shown in Tables 2 and 3.

Table 2. Criteria for determining the degree of different types of land degradation.

Criteria/land degradation type	Indicator	Unit	Degree: Light 1	Moderate 2	Strong 3	Extreme 4
Salinity	**EC**	dS/m	<4	4-8	8-16	16-32
Sodicity	**ESP**	%	<10	10-15	15-30	30-50
Compaction	**Bulk density**	(gm/cm3)	<1.2	1.3-1.4	1.4-1.6	>1.6
Waterlogging	**Water table**	cm	>150	150 - 100	100-50	<50

Table 3. **Criteria for determining the rates of different types of land degradation.**

land degradation rate	Salinity/ increase in EC	Sodicity / increase in ESP	Compaction / increase in Bulk density	Waterlogging / Increase in Water table
None to slight	<0.5	<0.5	<0.1	<1
Moderate	0.5-3	0.5-3	0.1-0.2	1-3
High	3-5	3-7	0.2-0.3	3-5
Very high	>5	>7	> 0.3	>5

2.7. Geostatistical analysis:

Geostatistical analysis concerns the description of patterns in spatial data, where each known data point has a geographic location and a value, and the connection between them is exploited to predict values at unknown locations. The Interpolation by Inverse Distance Weighting (IDW) technique, along with histogram normalization, was employed to estimate unknown values based on specified search distance, closest points, power settings, and barriers technique. This technique was applied to random samples of the study area for four soil properties: EC, ESP, bulk density, and waterlogging, following the methods described by Ahmed et al. (2019) and Ali et al. (2019). The geostatistical analyst module in ArcGIS 10.x software was used for these analyses (ESRI staff, 2019).

The attribute data of salinity, alkalinity, and bulk density were compiled into the units of the digital geomorphologic map within a geographic information system. These attributes were used to obtain thematic layers depicting the spatial distribution of land degradation hazards. The produced layers included information on the distribution of each soil characteristic. The soil characteristics (EC, ESP, bulk density, and water table depth) related to land degradation were produced using the following series in the GIS environment:

1- **Normalization of soil data:** when the IDW method is used to produce a quantile map, the data should be in a normal distribution because the kriging method assumed that the data is normally distributed as shown in Figures 3 & 4 and Table 4. For the data that don't follow the normal distribution, it was transformed to normality using the following equations according to Abramowitz and Stegun, (1964):

Step 1 $z = Percentile\ Rank = 1 - (Rank(Xi)/n]$

Where:

Rank (Xi) = rank of value Xi n = sample size.

Step 2 $p = \mu + \sqrt{2}\,\sigma\, erf^{-1}\,(-1 + 2pr)$

Where:

p= Z-score resulting from Step 2

μ = mean of P (recommandation is 0 for standardized z-score)

σ = standard deviation of p (recommandation i 1 for standardized z-scores)erf^{-1} = inverse error function

Pr = probability that is the result of Step1

Table 4. **Tests of Normality before and after transformation of soil data**

	Kolmogorov-Smirnov[a]		Shapiro-Wilk	
	Sig. (before)	Sig. (After)	Sig. (before)	Sig. (After)
EC (ds/m)	.000	.200*	.000	.144
ESP %	.019	.200*	.000	.999
Bulk density (g.cm^{-3})	.007	.200*	.007	.999
Water table depth (cm)	.200*	.200*	.447	.144

*. This is a lower bound of the true significance.

[a]. Lilliefors Significance Correction.

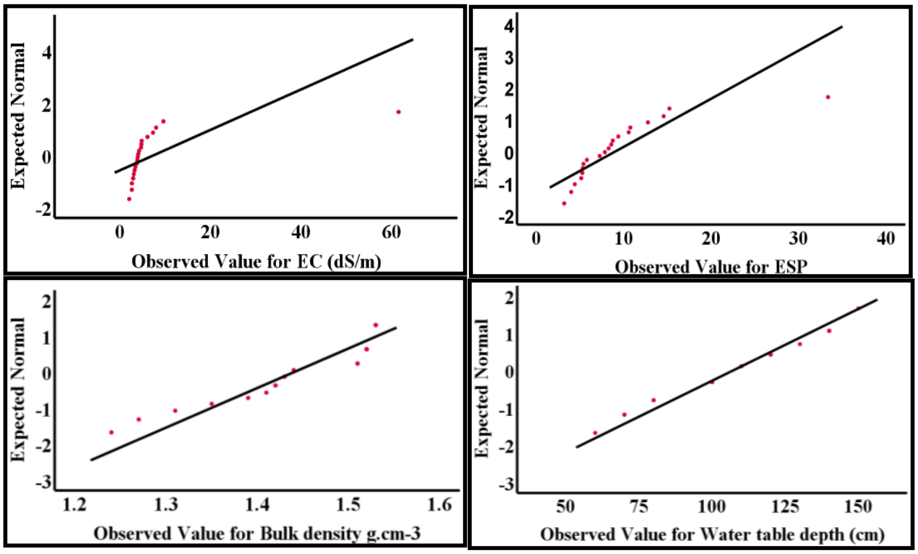


Figure 3. Q-Q Plot of EC, ESP, Bulk Density and Water table before using the transformation to normal distribution soil data.

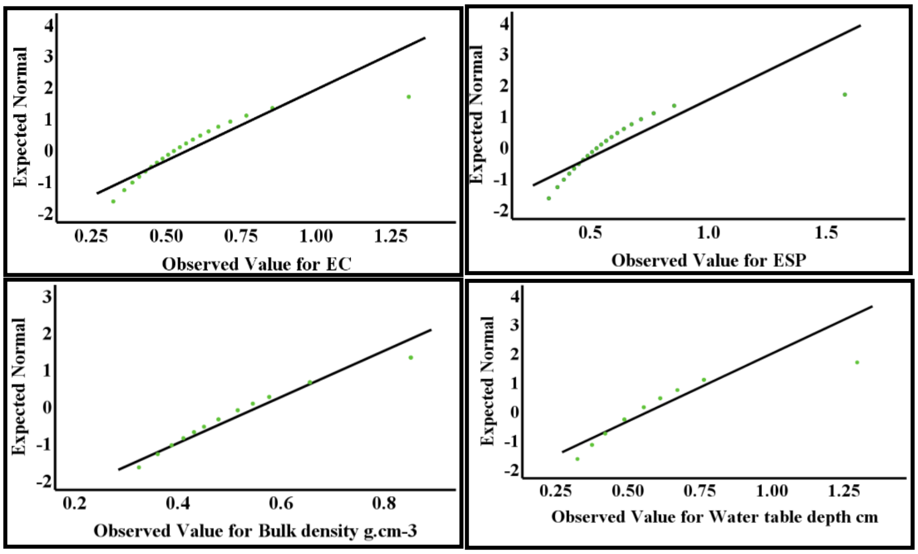


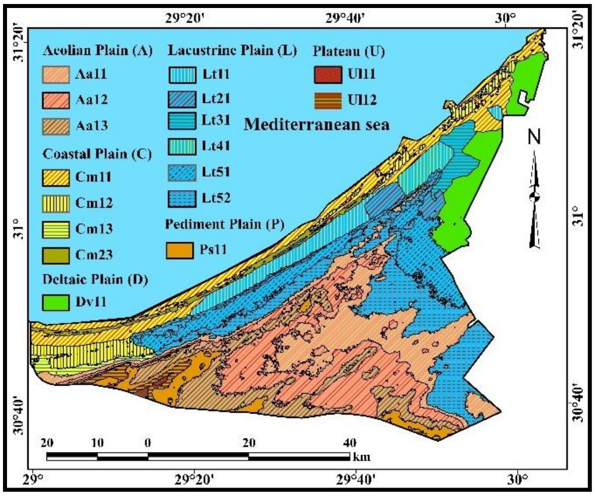
Figure 4. Q-Q Plot of EC, ESP, Bulk Density and Water table after using the transformation to normal distribution soil data.

2-**Prediction of soil properties map:** The map predicted values of Soil properties were created using the Inverse Distance Weighting (IDW) method as depicted in Fig. (5). This method had successfully undergone the preceding two steps, which involved data exploration and transformation to adhere to a normal distribution.

3. RESULTS AND DISCUSSION

3.1. Physiography and soils

The Physiographic units (Figure 5) of the study area were divided based on the topographic attributes i.e. slope, aspect and relief intensity; they were classified into six units including Aeolian plain (A), Coastal plain (C), Deltaic plain (D), Lacustrine plain (L), Pediment plain (P) and Plateau (U) representing 38%, 17%, 6%, 33%, 4% and 2% respectively. The physiographic units were sequenced over the area due to the interaction



between marine and continental conditions with the assistance of geologic and climatic factors. Areas and dominant soils in different mapping units are illustrated in Table 5.

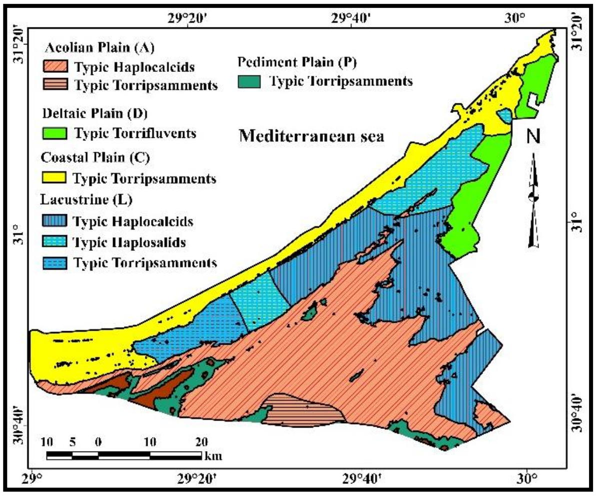
Figure 5. Physiography of the study area.

Table 5. The physiography and soil units of the study area.

Landscape	Origin	Landform	Elevation/slope	Symbol	Total area				Soil profile	Soil Mapping	
					(km^2)	Percent	(km^2)	Percent		Taxonomy	Per
Aeolian Plain (A)	Aeolian deposits (a)	Sand sheet (1)	Low (1)	Aa11	430.58	14%	1181	38%	11, 12, 14, 15, 17, 18, 19 and 20	Typic Haplocalcids	**7**
	Aeolian deposits (a)	Sand sheet (1)	Moderate (2)	Aa12	457.08	15%					
	Aeolian deposits (a)	Sand sheet (1)	High (3)	Aa13	291.21	9%			20	Typic Torripsamments	**2**
Coastal Plain (C)	Marine deposits (m)	Sand sheet (1)	Low (1)	Cm11	310.88	10%	532	17%	3 and 4	Typic Torripsamments	10
	Marine deposits (m)	Sand sheet (1)	Moderate (2)	Cm12	132.71	4%					
	Marine deposits (m)	Sand sheet (1)	High (3)	Cm13	32.91	1%					
	Marine deposits (m)	Shore Ridge (2)	High (3)	Cm23	55.86	2%					
Deltaic Plain (D)	Alluvial deposits (v)	Basin (1)	Almost flat (1)	Dv11	179.49	6%	179	6%	1,2 and 5	Typic Torrifluvents	10
Lacustrine Plain (L)	Lacustrine deposits (t)	Lake and ponds (1)	Flat to almost flat (1)	Lt11	124.71	4%	1021	33%	7, 10 and 13	Typic Haplocalcids	2
	Lacustrine deposits (t)	Wetland and sabkha (2)	Flat to almost flat (1)	Lt21	49.09	2%					

	Lacustrine deposits (t)	Swamps (3)	Flat to almost flat (1)	Lt31	61.22	2%					
	Lacustrine deposits (t)	Former lakebed (4)	Flat to almost flat (1)	Lt41	53.96	2%					
	Lacustrine deposits (t)	Sand ripples (5)	Low (1)	Lt51	284.85	9%			6	Typic Haplosalids	2
	Lacustrine deposits (t)	Sand ripples (5)	High (2)	Lt52	445.15	14%			8	Typic Torripsamments	4
Pediment Plain (P)	Limestone/Sandstone (s)	Pediment (1)	Gently slope (1)	Ps11	118.25	4%	118	4%	16	Typic Torripsamments	10
Plateau (U)	Limestone (l)	foot slope (1)	Steep (1)	Ul11	8.65	0%	47	2%	9	Typic Haplocalcids	10
	Limestone (l)	foot slope (1)	Gently (2)	Ul12	40.61	1%					
					3077.21	100%	3077	100%			

The results indicate that the soils over physiographic units could be classified as Typic Haplocalcids, Typic Torripsamments, and Typic Torrifluvents. The Aeolian Plain (A) unit covers 1181 km^2 of the total area, representing about 38% of the total soil area. It is dominated by Typic Haplocalcids and Typic Torripsamments. The Coastal Plain (C) unit covers 532 km^2, accounting for 17% of the total area, and is dominated by Typic Torripsamments. The Deltaic plain (D) unit occupies 179 km^2, representing 6% of the total area, and is dominated by Typic Torrifluvents. The Lacustrine plain (L) unit covers 1021 km^2, representing 33% of the total area. It is dominated by Typic Haplocalcids, Typic Haplosalids, and Typic



Torripsamments soils. The Pediment plain (P) unit covers 118 km^2, accounting for 4% of the total area, and is predominantly characterized by Typic Torripsamments. The Plateau (U) covers 118 km^2, representing 4% of the total area, and is dominated by Typic Haplocalcids. (Figure 6).

Figure 6. Soil of the study area.

Calcium carbonate (CaCO3) content in the various areas ranged from 6.53% to 64.23%. The compaction of sandy soils in the study area can be attributed to the impact of calcium carbonate (CaCO3). Soil clay content ranged between 2.4% and 38.41%, while the sand fraction ranged from 37.20% to 94.39%. The soil contained minimal organic matter, ranging from 0.02% to 0.84%. The statistical analyses of electrical conductivity (EC) varied from 1.14 to 64.25 dSm-1, and Exchangeable Sodium Present (ESP) ranged from 3.17% to 36.47%. These values increased due to the proximity to Lake Mariout. Soil pH ranged from 7.81 to 8.58. The cation exchange capacity (CEC) varied between 1.55 and 30.11 [cmol (+)/ kg soil]. Table 6 displays the statistical parameters of the soil.

Table 6. Some statistics on Soil properties

	Sand%	Clay%	Silt%	$CaCO_3$%	O.M%	Bulk density $g.cm^{-3}$	pH	EC dSm^{-1}	CEC [cmol (+)/ kg soil]	ESP
Minimum	37.20	2.47	2.33	6.53	0.02	1.23	7.81	1.14	1.55	3.17
maximum	94.39	38.41	37.26	64.23	0.84	1.56	8.58	64.25	30.11	36.47
Mode	93.56	-	-	-	0.02	1.51	8.27	4.21	4.33	8.32
Mean	79.38	12.31	8.32	24.06	0.25	1.44	8.17	7.60	9.50	9.46
Median	85.79	7.53	6.50	21.35	0.17	1.43	8.17	4.21	5.49	7.12
Std. deviation	16.06	10.10	7.18	12.22	0.20	0.09	0.18	13.48	7.97	6.93

3.2. Land Degradation Assessment of the study area:

3.2.1. Salinization

Soil salinity varies across different physiographic units and within units at different locations. It extends to farmers' fields and uncultivated land in arid and semi-arid regions. The levels of salinization in the designated study area were categorized as slight, moderate, strong, and extreme. The Aeolian Plain, which constitutes the largest portion of the study area (38%), is classified as high (2,2) and very high (1,5) severity classes. The very high severity class (1,5) encompasses 89% of the mapping unit. The Coastal Plain covers 17% of the total area and is classified as medium (1,4) and (3,2), high (2,4) and (4,1), representing 48%, 11%, 36%, and 6%, respectively. The Deltaic plain consists of the severity class (2,5). The Lacustrine plain is classified as medium (1,4) and (4,1), high (3,3), and very high (2,4), representing 41%, 4%, 14%, and 41%, respectively. The Pediment plain covers 4% of the total area and is classified as medium (2,2) and very high (1,5), representing 91% and 9%, respectively. The Plateau is classified as high (2,4) and very high (1,5), denoting 29% and 71%, respectively. Table 7 and Figure 7 show the spatial distribution of soil properties.

Table 7. **Degree, extent, and severity levels of salinization.**

Landscape	**Area (km^2)**	**Landscape total area (km^2)**	**Percent**	**Degree**	**Percent of mapping unit**	**Extent**	**Severity**	
							code	**class**
Aeolian Plain (A)	1048.73	11801	38 %	Slight	89 %	Dominant	(1, 5)	Very high
	127.19			Moderate	11 %	Common	(2, 2)	High
	3.56			Strong	0%	Infrequent	(3, 1)	Medium
	1.27			Extreme	0%	Infrequent	(4, 1)	Medium
Coastal Plain (C)	253.32	532	17 %	Slight	48 %	Very frequent	(1, 4)	Medium
	190.05			Moderate	36 %	Very frequent	(2, 4)	High
	56.51			Strong	11 %	Common	(3, 2)	Medium
	31.82			Extreme	6%	Infrequent	(4, 1)	High

Deltaic plain (D)	178.65	179	6%	Moderate	100%	Dominant	(2, 5)	Very high
Lacustrine plain (L)	419.18	1021	33%	Slight	41%	Very frequent	(1, 4)	Medium
	421.63			Moderate	41%	Very frequent	(2, 4)	Very high
	140.11			Strong	14%	Frequent	(3, 3)	High
	40.03			Extreme	4%	Infrequent	(4, 1)	Medium
Pediment plain (P)	107.71	118	4%	Slight	91%	Dominant	(1, 5)	Very high
	10.41			Moderate	9%	Common	(2, 2)	Medium
Plateau (U)	33.47	47	2%	Slight	71%	Dominant	(1, 5)	Very high
	13.57			Moderate	29%	Very frequent	(2, 4)	High
	3077.21	**3077.21**	**100%**					

The severity types are two numbers. The first number refers to degrees including Slight (1), Moderate (2), Strong (3), Extreme (4), and Salinization, the second number refers to the relative extent involved in Infrequent (1), Common (2), Frequent (3), Very frequent (4), Dominant (5). The Severity level includes Low (L), Medium (M), High (H), and very high (VH).

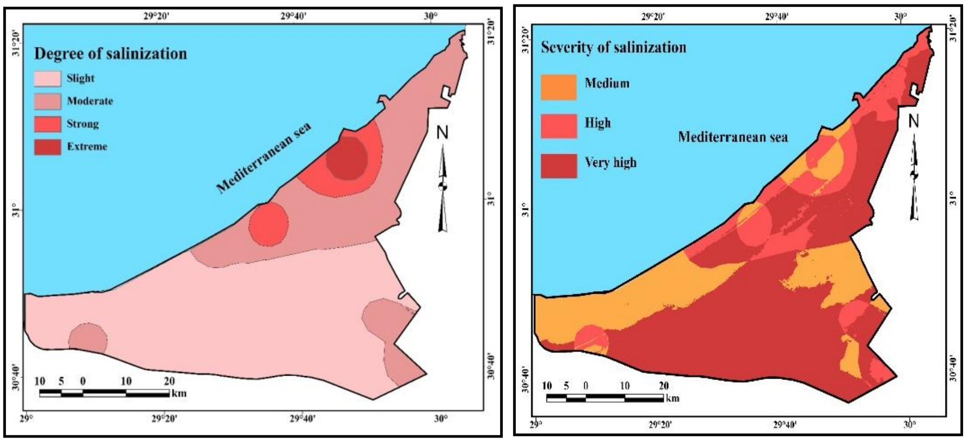


Figure 7. Degree, extent, and severity levels of salinization.

3.2.2. Alkalinization

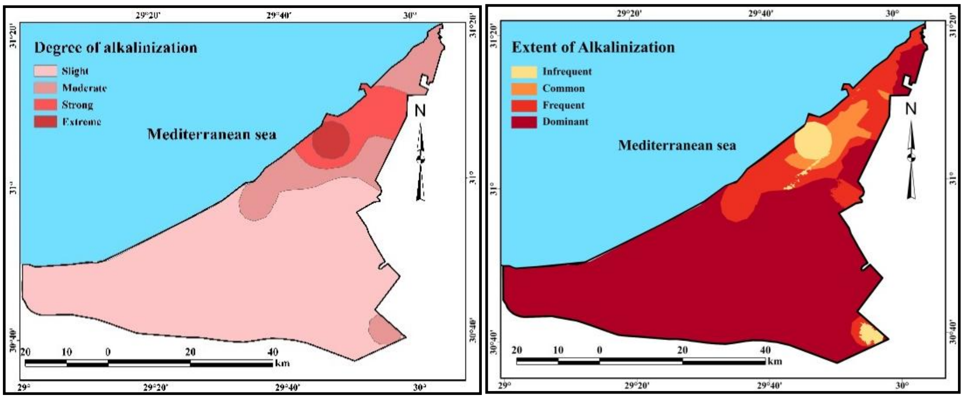
The results in Table 8 and Figure 7 indicate that the Aeolian plain unit is categorized as low (2.1%) and high (98%), representing 2% and 98% respectively. The coastal plain comprises medium (4.1%), high level (1.5%), (2.3%), and (3.3%), accounting for 5%, 57%, 22%, and 15% respectively. Deltaic plain divisions are classified into three different levels: medium (1.3%), high (3.3%), and very high (2.5%), representing 18%, 21%, and 61% respectively. The lacustrine plain consists of medium level (4.1%), high levels (1.5%), (2.3%), and (3.2%), representing 4%, 68%, 18%, and 11% respectively. The pediment plain and the Plateau include a high level (1.5%). The study shows that alkalinization differs with physiographic mapping units and within units at different locations. The area around Lake Mariout involves a combination of physical, chemical, and agronomic interventions aimed at alleviating salinity, improving soil quality, and ensuring sustainable land use practices. By implementing these strategies, land managers can restore the productivity of saline-alkaline affected lands and promote long-term agricultural sustainability.

Table 8. Degree, extent and severity level of Alkalinization

Landscape	Area (km^2)	Area (km^2)	Percent	Degree	Extent	Percent of mapping unit	Severity Code	Severity class
Aeolian Plain (A)	1154	1181	38%	Slight	Dominant	98%	(1,5)	High
	24			Moderate	Infrequent	2%	(2,1)	Low
	3			Strong	Infrequent	0%	(3,1)	Medium
	0.3			Extreme	Infrequent	0%	(4,1)	Medium
Coastal Plain (C)	305	532	17%	Slight	Dominant	57%	(1,5)	High
	117			Moderate	Frequent	22%	(2,3)	High
	81			Strong	Frequent	15%	(3,3)	High
	28			Extreme	Infrequent	5%	(4,1)	Medium
Deltaic	33	178	6%	Slight	Frequent	18%	(1,3)	Medium

plain (D)	109			Moderate	Dominant	61%	(2,5)	Very high
	37			Strong	Frequent	21%	(3,3)	High
Lacustrine plain (L)	696	1021	33%	Slight	Dominant	68%	(1,5)	High
	181			Moderate	Frequent	18%	(2,3)	High
	108			Strong	Common	11%	(3,2)	High
	37			Extreme	Infrequent	4%	(4,1)	Medium
Pediment plain (P)	118	118	4%	Slight	Dominant	100%	(1,5)	High
Plateau (U)	47	47	2%	Slight	Dominant	100%	(1,5)	High
	3077	**3077**	**100%**					

The severity types are two numbers. The first number refers to degrees including Slight (1), Moderate (2), Strong (3), Extreme (4), Salinization, the second number refers to the relative



extent involved Infrequent (1), Common (2), Frequent (3), Very frequent (4), Dominant (5). The Severity level includes Low (L), Medium (M), High (H), Very high (VH).

Figure 8. Degree, Extent and Severity of alkalinization of study area.

3.2.3. Compaction

As illustrated in Table 9 and Figure 8, the Aeolian Plain unit encountered severity classes high (163 km^2) and very high (1018 km^2). The coastal plain unit was divided into two distinct severity classes: very high (2.5%) and (3.4%), covering 532 km^2. The Deltaic plain unit consisted of high (3.4%), covering 35 km^2, and very high (2.5%), covering 144 km^2. The lacustrine plain unit was categorized into high (2.4%) and very high (3.5%), covering an area of 267 km^2 and 754 km^2 respectively. The pediment plain unit embraced high (2.4%), covering 38 km^2, and very high (3.5%), covering

Table 9. **Degree, extent and severity level of Compaction**

Landscape	Area (km^2)	Area (km^2)	Percent	Degree	Extent	Percent of mapping unit	Severity Coode	Severity class
Aeolian Plain (A)	163	1180	38%	Moderate	Frequent	14%	(2,3)	High
	1018			Strong	Dominant	86%	(3,5)	Very high
Coastal Plain (C)	364	532	17%	Moderate	Dominant	68%	(2,5)	Very high
	168			Strong	Very frequent	32%	(3,4)	Very high
Deltaic plain (D)	144	179	6%	Moderate	Dominant	81%	(2,5)	Very high
	35			Strong	Frequent	19%	(3,4)	High
Lacustrine plain (L)	267	1021	33%	Moderate	Very frequent	26%	(2,4)	High
	754			Strong	Dominant	74%	(3,5)	Very high
Pediment plain (P)	38	118	4%	Moderate	Very frequent	32%	(2,4)	High
	81			Strong	Dominant	68%	(3,5)	Very high
Plateau (U)	24	47	2%	Moderate	Very frequent	51%	(2,4)	High
	23			Strong	Very frequent	49%	(3,4)	Very high
	3077	**3077**	**100%**					

The severity types are two numbers. The first number refers to degrees including Slight (1), Moderate (2), Strong (3), Extreme (4), Salinization, the second number refers to the relative extent involved Infrequent (1), Common (2), Frequent (3), Very frequent (4), Dominant (5). The Severity level includes Low (L), Medium (M), High (H), Very high (VH).

81 km^2. The plateau unit was divided into two distinct severity classes: high (2.4%), covering 24 km^2, and very high (3.5%), covering 23 km^2. The

study area was greatly affected by soil compaction, which appeared in lands far from the lake in sandy lands, and the reason was an increase in calcium carbonate content. Soil compaction mitigation techniques encompass soil ventilation, incorporation of organic substances, utilization of cover crops, and meticulous employment of machinery.

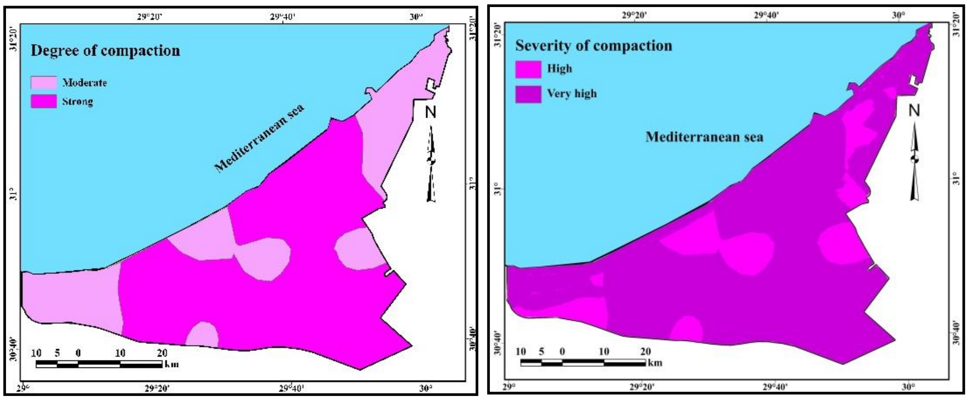


Figure 9. Degree, Extent and Severity of compaction of the study area.

3.2.4. Waterlogging

Waterlogging is the rise of groundwater to the surface of the land and sometimes takes the shape of streams. Salinity occurs when the groundwater is slightly below the surface of the ground, and the evaporation of this water results in the accumulation of salts near the roots of the plants.

The Aeolian plain comprises different levels of waterlogging severity, including medium (1.3%) with an area of 134 km^2, and very high (2.5%) and (3.1%), which exhibit 1047 km^2 within the entirety of the area. The coastal plain is categorized as very high, occupying the entire area of the coastal plain. The Deltaic plain is classified as high (3.4%) with an area of 89 km^2

and very high (2.4%) covering an area of 90 km^2. The Lacustrine plain unit is categorized as very high (2.5%), i.e., 534 km^2, and severity classes very high (3.4%), i.e., 487 km^2. The pediment plain and plateau units comprise a very high severity class of waterlogging, covering 118 and 47 km^2 respectively. The results of the study show that waterlogging occurs in lands close to the Mediterranean coast. The phenomenon of waterlogging involves the execution of drainage systems, enhancing the composition of soil, opting for suitable crops, and engaging in efficient water administration. Through the utilization of these approaches, individuals responsible for the oversight of land can ameliorate waterlogging predicaments, foster appropriate soil drainage, and guarantee ideal circumstances for the development of plants. Ultimately, this

Table 10. Degree, extent and severity level of waterlogging

Landscape	Area (km^2)	Area (km^2)	Percent	Degree	Extent	Percent of mapping unit	Severity Code	Severity class
Aeolian Plain (A)	134	1181	38%	Slight	Frequent	11%	(1,3)	Medium
	1004			Moderate	Dominant	85%	(2,5)	Very high
	43			Strong	Infrequent	4%	(3,1)	Very high
Coastal Plain (C)	378	532	17%	Moderate	Dominant	71%	(2,5)	Very high
	153			Strong	Very frequent	29%	(3,4)	Very high
Deltaic plain (D)	90	179	6%	Moderate	Very frequent	50%	(2,4)	High
	89			Strong	Very frequent	50%	(3,4)	Very high
Lacustrine plain (L)	534	1021	33%	Moderate	Dominant	52%	(2,5)	Very high
	487			Strong	Very	48%	(3,4)	Very

					frequent			high
Pediment plain (P)	0.02	118	4%	Slight	Infrequent	0%	(1,1)	Low
	118			Moderate	Dominant	100%	(2,5)	Very high
Plateau (U)	47	47	2%	Moderate	Dominant	100%	(2,5)	Very high
	3077	**3077**	**100%**					

The severity types are two numbers. The first number refers to degrees including Slight (1), Moderate (2), Strong (3), Extreme (4), Salinization, the second number refers to the relative extent involve Infrequent (1), Common (2), Frequent (3), Very frequent (4), Dominant (5). The Severity level includes Low (L), Medium (M), High (H), Very high (VH).

contributes to the upholding of agricultural productivity and sustainability within areas affected by excessive water accumulation. These data are illustrated in Table 10 and Figure 10.

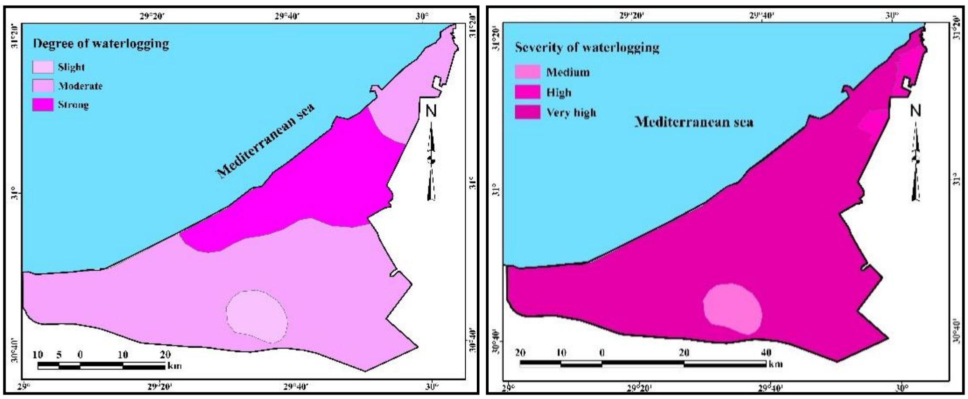


Figure 10. Degree of waterlogging of the study area.

4. Conclusion

In conclusion, using geospatial analysis and GLASOD, FAO schemes of land degradation provide more precise information and offer important insights into the distribution and severity of land degradation within the area of interest. The findings reveal that land degradation varies across trans-physiographic mapping units and within those units at different locations. The study area experiences different levels of land degradation, ranging from slight to extreme. The physiographic units are ordered due to the interaction between marine and continental conditions, aided by geological and climatic factors. The study finds that land degradation in the area has increased due to several factors, such as salinization and soil compaction, which are of great concern in the study area. Salts accumulate near the soil surface when rainfall decreases, and tilling the soil under these conditions has multiple benefits. Sandy soil far from the lake is affected by soil compaction due to a high content of calcium carbonate. Overall, this research emphasizes that soil salinity and alkalinization are the main causes of land degradation on the northwestern coast. Understanding the distribution and severity of these issues within different mapping units is crucial for implementing targeted strategies to mitigate land degradation and effectively manage agricultural practices in arid and semi-arid regions.

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