Original Research

Geomatics-Based Soil Mapping and Degradation Risk Assessment of Nile Delta Soils

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Abstract

The aim of this study is to apply the powerful capabilities of advanced remote sensing (RS) and geographic information system (GIS) techniques to identify the geomorphological units and degradation risk assessment of some soils east of the Nile Delta. Landsat ETM images and digital elevation model (DEM) were used to produce the physiographic map of the studied area at the landform level. The obtained map showed that the area comprised three distinct landscapes: coastal, flood and Aeolian plains, plus the urban area and water bodies. The major landforms of the studied area were described as clay flats, gypsiferrous flats, recent river terraces, decantation basins, overflow basins, old river terraces, turtle back, sand flats, and sand sheets. The study also demonstrated that the salinization, sodication, and physical degradation of the studied area were about 14.82, 35.86, and 83.04%, respectively. The hazard types were defined as low, moderate, high, and very high. The obtained data showed also that salinity, alkalinity, and water logging are the main encountered degradation hazard. These results were a great help and served as basic sources for the planners and decision makers in sustainable planning.

Keywords: remote sensing, geographic information system, hazards, land degradation risk, soil map

Introduction

Soil degradation phenomena are the result of a complex interaction between natural (e.g. soil properties and climate conditions) and human factors (e.g. over-grazing, over-cultivation, and deforestation) [1]. In the dry lands, degradation by water logging, salinization, and alkalinization of 43 million hectares of irrigated croplands amounted to nearly 30% of the total area [2].

Remote sensing techniques were used extensively for understanding soil degradation processes and modeling soil loss and degradation risk [3-5].

The studied area occupies the southern part of EI-Salam canal, which extends toward the northern edge of Ismaillia Governorate on the western side of the Suez Canal. It is bound by longitudes 32° 17¯00" E and latitudes 30° 41¯31" N, (Fig. 1). A great part of this area is under reclamation and is still suffering from inadequate land use. The climatic data of the studied area indicate that total annual rainfall in Ismaillia was 33.3 mm and the precipitation is not equally distributed throughout the rainy season. The average annual mean temperature was 21.77ºC with a wide difference between summer and winter months. The soil temperature regime of the studied area could be defined as thermic and the soil moisture regime as torric, except for the soil, which has a high water table, the soil moisture regime could be considered aquic. [6] revealed that the units of geology of the investigated area are briefed into: Nile silt, Nile deposits, Quaternary deposits, Sabkha deposits, sand dunes, stabilized dunes, and wadi deposits. The main geomorphological units in the studied area after [7] are coastal plain, flood plain, and Aeolian plain.

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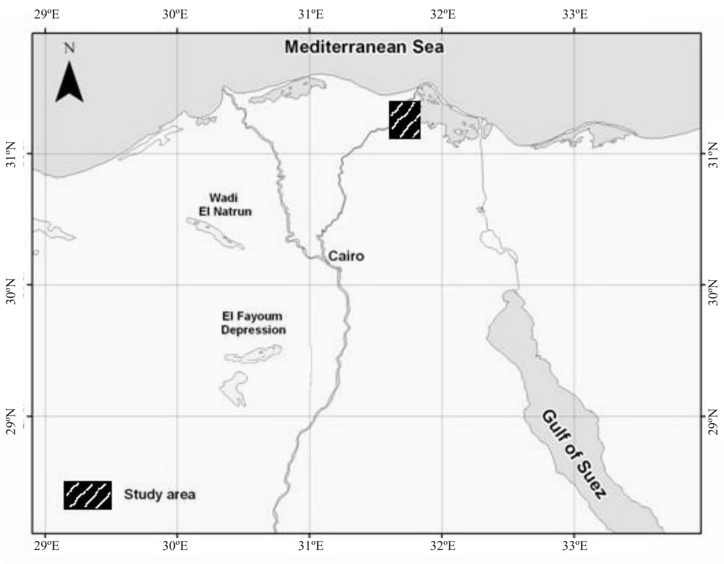

Fig. 1. Location of the studied area.

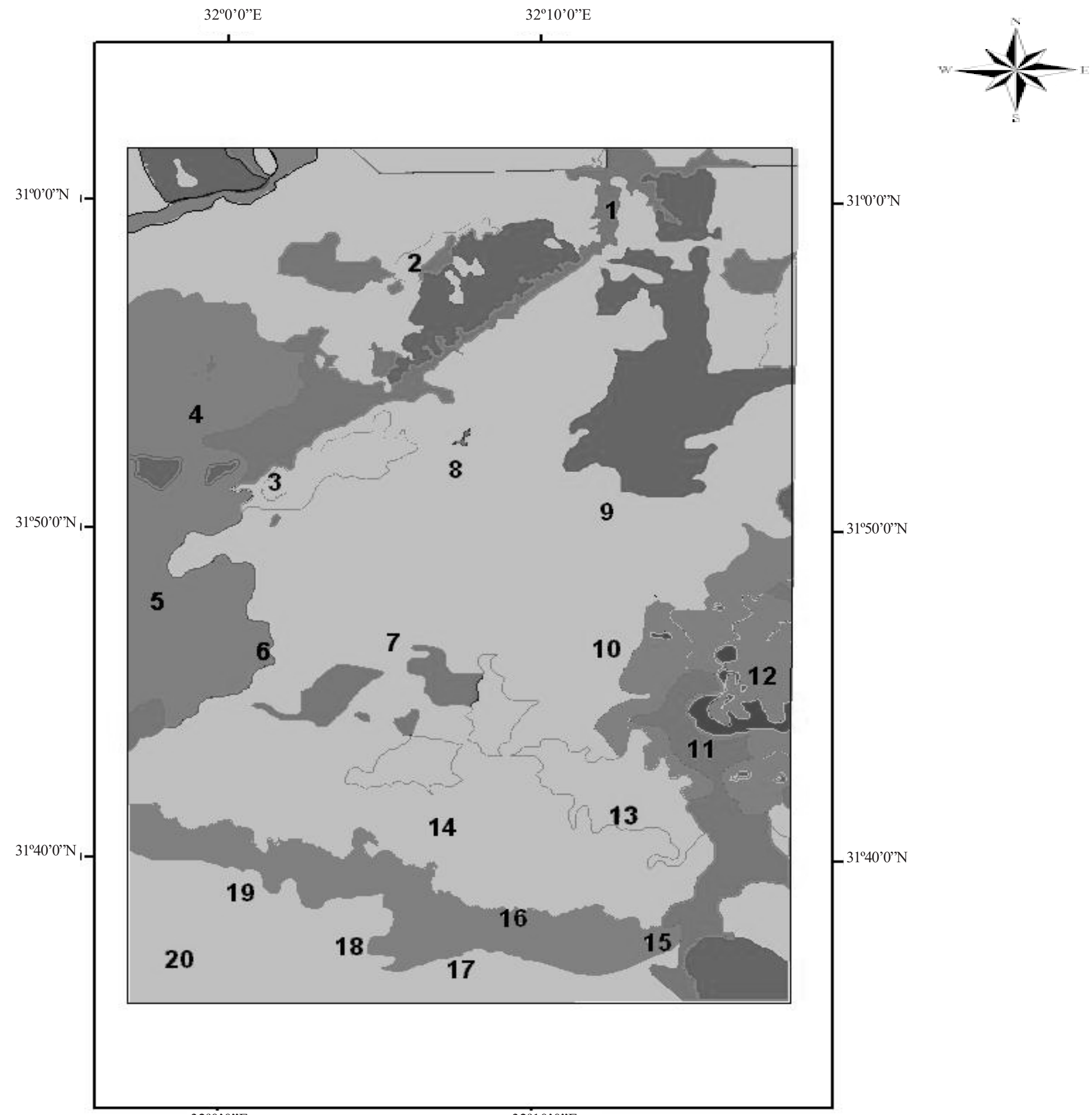

Fig. 2. Location of the studied soil profiles.

The geology of El Ismaillia comprises Mesozoic (Cretaceous) and Cenozoic sediments. It shows mainly the Suez Canal, the Bitter Lakes, and the eastern part of the Nile Delta and El Ismaillia Governorate. The Suez Canal separates western Sinai from the Eastern Desert and the Nile Delta. The Quaternary deposits cover an extensive part of the area. They are mostly composed of sand sheets and dunes. Fluvial sands and silts cover the strip parallel to the Suez Canal. These kinds of deposits are most probably formed by the old branch of the Nile known as the Pelusium Nile [8].

A description of the area, located between northern El Isamillia and southern Port Said governorates, is characterized by a very high water table and heavy saline alkali, low-lying clay, and high values of ESP [9, 10].

The geomatics technique was primarily used in this study for mapping. This technique involves gathering, analyzing, interpreting, and using geographic information. It encompasses a broad range of disciplines that can be brought together to create a detailed picture of the area. These disciplines include land surveying, mapping, remote sensing, geographic information systems (GIS), and global positioning systems [11].

The aim of this study was to use geomatic techniques for degradation hazard assessment on some soils east of the Nile Delta while producing the physiographic and soil maps by scale 1/250,000 and assessing the soil degradation risk in the different soil unites.

Materials and Methods

Digital Image Processing

Digital image processing of an ETM+ satellite image (2001) was executed using ENVI 4.7 software [12]. Image processing included image calibration to reflectance, color enhancement, rectification, and sub-setting.

Digital Elevation Model (DEM)

A digital elevation model of the study area was generated from the elevation points (recorded during the field survey by GPS), and the vector contour lines (using topographic map 1/25,000) with accuracy 89%; ESRI ArcMap v. 9.3 software [13].

Physiographic Mapping, Soil Survey and Soil Analysis Stages

Landsat ETM+ image and digital elevation model (DEM) were used in ENVI 4.7 software to produce the physiographic map of the studied area [14]. Twenty soil profiles representing the different physiographic units were developed in the studied area. A detailed morphological description of soil profiles was carried out according to U.S. Department of Agriculture [15]. The studied soil profiles were taken from three sample areas, typically covering about 10% of the investigated area. These sample areas crossed the different mapping units [16]. The profile distribution is shown in Fig. 2. Sixty-three disturbed soil samples were collected from the studied soil profiles based on the morphological variations. These samples were used for laboratory analyses, which were carried out according to USDA standards [17].

Soil Classification and Degradation Assessment

The soils were classified to the sub great group level on the basis of the key to soil taxonomy [18]. The correlations between physiographic and taxonomic units were carried out in order to produce the physiographic-soil maps of the studied area [19]. Salinization, sodication, and physical degradation risk were calculated using soil and climate rating factors according to FAO guidelines [20].

Results and Discussion

Physiography and Soils of the Studied Area

Field survey data, Landsat ETM images, and digital elevation model (DEM) were used to define the physiographic units in the studied area as shown in Fig. 3 and Table 1. The correlation between physiography and soils were carried out, the produced data reveal that the soils of the main physiographic units in the area could be arranged under the landscape level in the following:

Soils of Aeolian Plain

The Aeolian plain covers an area of about 522.81 km^2. This landscape included soils of sand flats (395.29 km^2) and soils of sand sheets (127.52 km^2). These are represented by soil profiles 7, 10, 14, 15, and 16, and were classified to the sub great group level as Typic Torripsamments, Aquic Torriorthents, Typic Psammaquent, Typic Torripsamments, and Typic Torripsamments, respectively, as shown in Fig. 4. The correlation between physiography and soils indicated that the type of mapping unit in this landscape was complex. The soil depth, salinity, ESP, and $CaCO_3$ of this landscape ranges from 75 to 150 cm, 0.2 to 13 dSm^{-1}, 5.9 to 28.8%, and 0.13 to 5.22%, respectively (Table 2).

Soils of Flood Plain

The total area of flood plain was about 509.48 km^2, including the landforms of recent terraces (144.04 km^2), old terraces (122.49 km^2), basins (240.05 km^2) and turtle back (2.9 km^2). These landforms are represented by soil profiles 1, 2, 3, 4, 5, 6, 11, 13, 17, 18, 19, and 20. The studied profiles of this landscape were classified under Vertic Natrargids, Typic Torrifluvens, Typic Torripsamments, Vertic Argigypsids, Typic Toriorthents, and Typic Torripsamments. The correlation between physiography

Table 1. Physiographic legend and areas of the different mapping units of the studied area.

Landscape	Relief/Molding	Lithology/Origin	Landform	Symbol	Area (km^2)	Area (%)
Aeolian plain E	Almost flat E1	Aeolian deposits E11	Sand flats	E111	395.29	24.81
			Sand sheet	E112	127.52	8.0
Flood plain F	Flat to almost flat F1	Alluvial deposits F11	Recent river terraces	F111	144.04	9.02
			Decantation basins	F112	136.73	8.58
			Overflow basins	F113	103.22	6.48
			Old river terraces	F114	22.49	7.69
	Rolling F2	Aeolian deposits F21	Turtle backs	F211	2.9	0.18
Coastal plain C	Almost flat C1	Fluvio-marine deposits C11	Clay flats	C111	362.75	22.76
			Gypsiferous flat	C112	47.99	3.01
			Clay swamp	C113	59.01	3.7
			Reference terms			
			Gypsiferrous swamps		13	0.82
			Urban area		28.83	1.81
			Water bodies		49.71	3.12
					1593.48	100

and soils showed that the type of mapping unit in this landscape was complex. In this landscape the following soil characteristics range as follows: soil depth (90 to 150 cm), soil salinity (0.25 to 10.92 dSm^{-1}), ESP (0.09 to 20.42%), and $CaCO_3$ content (5.22 to 25.14%).

Soils of Coastal Plain:

The total area of coastal plain was about 469.75 km^2. This landscape included the landforms of clay flats (362.75 km^2), gypsiferrous flats (47.99 km^2), and clay swamp (59.01 km^2). The soils of these landforms are represented by soil profiles 8, 9, and 12. The studied profiles of this landscape were classified under Typic Haplosalids, Typic Haplosalids, and Typic Hapogypsids. The correlation between physiography and soils indicated that the mapping unit in this landscape was complex. The soils of this landscape were characterized by deep soil profiles (140-150 cm), low- to very high salinity (0.43-108.0 dSm^{-1}), high exchangeable sodium percent (17.9-59.4%), and low- to high $CaCO_3$ content (0.89-29.65%) (Table 2).

Degradation Risk and Hazard Assessment

Methodology for assessing soil degradation hazard was used and the results were evaluated and confirmed with the physiographic units [21]. Table 3 showed the information characterizing the landscape, soils (i.e. soil depth, texture, EC, and ESP), and the calculated climatic indices. These data were used in calculating both soil and climatic rating factors. These factors were used in calculating salinization, sodication and physical degradation risks according to [20]. Field data indicated that the slope gradient in the study area ranged between 0.6 and 2.5%, which has a slight effect on natural vulnerability. Thus the topographic effect on the natural vulnerability was considered as 1.0 in different landforms. The climatic factor was calculated by four different formulas adapted to different degradation processes. Evapotranspiration and precipitation rates were included in these formulas. The degradation risk map of the studied area is represented in Fig. 5. The obtained data revealed that turtle back, sand sheet, recent river terraces, and clay flats were characterized by a very high risk of salinization. These soils cover an area of 353.1 km^2 and represent 19.66% of the study area. A bout 1,442.21 km^2, representing 80.34% of the total area, were characterized by a low risk of salinization. The risk of sodication ranged between low and high classes. The areas threatened by high risk values were located in the decantation basin, overflow basin, recent river terraces, clay flat, and sand flat that covered an area of 644 km^2. The areas threatened by moderate and low sodication risk cover an area of 147.6 and 801.88 km^2, respectively.

The risk of physical degradation was moderate in the decantation basin, recent river terraces, and clay flat, while the other units were characterized by high risk of degradation. The areas threatened by moderate and high risks were 264 and 1,531.98 km^2, respectively.

In general, the soil depth of the studied soil profiles changes from 75 to 150 cm, and water table levels from 75 to 140 cm (Table 3).

Table 2. Mean soil properties of the studied profiles.

Soil properties	Coastal plain	Flood plain	Aeolian plain
EC (dSm^{-1})	0.4-108.0	0.3-10.9	0.2-13
pH	7.5-8.4	7.6-8.4	7.5-8.4
ESP	17.9-59.4	0.1-20.4	5.9-28.8
CEC meq/100g	3.9-52.6	2.9-53.0	3.4-11.2
$CaCO_3$ (%)	0.9-29.65	5.2-25.1	0.13-5.2
Gypsum. (%)	0.1-50.60	0.01-13.1	0.2-4
Soil depth (cm)	140-150	90-150	75-150
Soil texture	Sandy and clay	between sandy and clay	between sandy and loamy sand

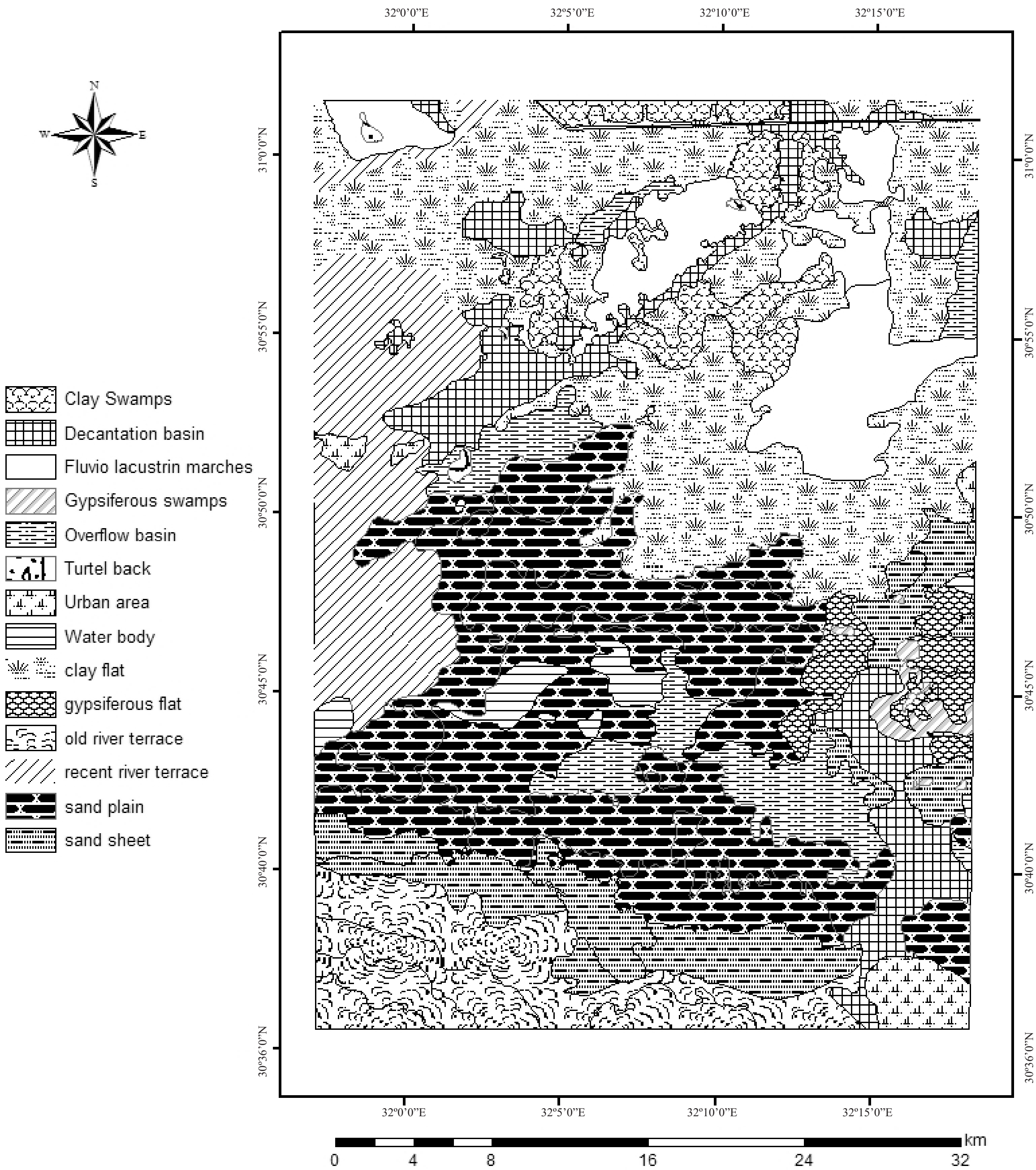

Fig. 3. Geomorphology of the investigated area.

Table 3. Soil characteristics and climatic index of the different landforms in the studied area.

Profile No.	Landform	Slope	Soil characteristics						Climatic index			
			De	T	Si/C	ECs	ECg	ESP	A	B	C	D
1	F112	1.5	150	C	0.37	2.84	1.95	19.19	5.64	4.5	–	0.27
2	F113	1.6	90	CL	1.20	10.11	5.2	34.14	5.64	11.9	–	0.18
3	F211	1.9	100	L	1.26	1.97	3.2	12.83	5.64	7.4	3.8	–
4	F111	1.7	150	C	0.37	2.02	3.1	13.88	5.64	7.2	–	0.27
5	F111	1.2	115	C	0.41	3.42	5.23	22.61	5.64	12	–	0.19
6	F111	1.0	150	C	0.70	4.75	16.4	23.83	5.64	37.7	3.8	–
7	E111	0.9	150	S	2.82	11.27	18.3	11.98	5.64	42.9	3.8	–
8	C111	0.9	140	C	0.68	54.86	12.2	43.56	5.64	28.7	3.8	–
9	C111	0.6	150	C	0.34	29.85	10.3	42.79	5.64	23.6	3.8	–
10	E111	0.7	90	LS	2.7	0.77	1.3	14.32	5.64	2.9	–	0.43
11	F112	0.6	150	LS	0.56	3.56	3.5	9.29	5.64	8.1	–	0.12
12	C112	1.6	150	S	3.32	4.74	3.8	19.97	5.64	8.7	–	0.25
13	F113	2.1	150	SL	0.96	2.16	2.4	17.88	5.64	5.5	–	0.12
14	E111	1.0	75	S	2.32	1.27	7.1	18.11	5.64	16.3	–	0.43
15	E112	1.4	150	S	1.85	0.95	3.4	12.74	5.64	7.8	–	0.43
16	E112	1.9	150	S	1.61	1.72	2.6	14.31	5.64	6.0	–	0.43
17	F114	2.2	150	S	1.30	7.31	3.84	6.07	5.64	8.8	3.8	–
18	F114	1.8	150	S	2.10	0.37	3.45	16.32	5.64	7.9	–	0.43
19	F114	2.4	150	S	2.37	0.41	2.5	13.45	5.64	5.8	–	0.43
20	F114	2.5	150	S	0.65	0.29	12.5	9.33	5.64	28.8	3.8	–

$A=\sum(Pm)^2/(Pa)$; $B= PET\cdot ECg$; $C=PET/(Pa)\ 10$; $D=PET/(Pa+Q)\ 10$
S=slope (%), De=soil depth (cm), T=soil texture (class), Si=silt (%), C=clay (%), ECg= groundwater salinity (dS/m), ECs=soil salinity (dS/m), ESP=exchangeable sodium percent (%), Pm=monthly precipitation (mm), Pa=annual precipitation (mm), PET=potential evapotranspiration (mm), Q=irrigation water (mm/season).

Data revealed that salinity, sodicity, and water logging are the main degradation hazards in the studied area. They were defined in relation to the present value of electric conductivity (EC), exchangeable sodium percentage (ESP) and the depth of the water table, respectively. Accordingly, the very high hazard of salinity and sodicity were facing 12.26 and 12.26% of the total area, respectively. The soils affected by a high hazard of salinity, sodicity, and water logging in the studied area represented 8.3, 21.37, and 16.75% of the total area, respectively. A moderate hazard of salinity, sodicity and water logging was found in different landforms representing 6.67, 26.35, and 83.25% of the total area, respectively.

As to the effect of human activities, it is obvious that induced land degradation by salinization, alkalinization, soil compaction, and water logging. Human-induced salinization and alkalinization can result from two causes: poor management of irrigation schemes, and high salt content of the irrigation water or too little attention given to the drainage of irrigated fields. This type of salt accumulation mainly occurs under arid and semi-arid conditions. A second type occurs where human activities lead to an increase in evapo-transpiration of soil moisture in areas of high salt-containing parent materials or with saline ground water.

A similar finding was obtained by [22], who found that the main types of land degradation identified in an area located between northern Isamillia and southern Port Said Governorates are salinity, sodicity, compaction, and water logging as a result of human activities, inadequate soil management, using heavy machinery, and human intervention in natural drainage systems.

Conclusions

The use of Landsat ETM images and digital elevation model (DEM) is very important in elaborating physiographic and soil maps. They facilitate the linkage between the soil unit and physiography on the basis of data extrapolation. The main physiographic units in the area were eolian plain, flood plain, and coastal plain. The arid climate and soil properties have essential impacts on degradation hazards in the studied area. About 14.82, 35.86, and 83.04% of the studied area have a high risk due to salinization, sodication, and physical degradation, respectively. The high hazard of salinity, sodicity, and water logging affect 20.56, 33.63, and 16.75% of the total, respectively. These results will be of great help and basic sources for the planners and decision makers in sustainable planning.

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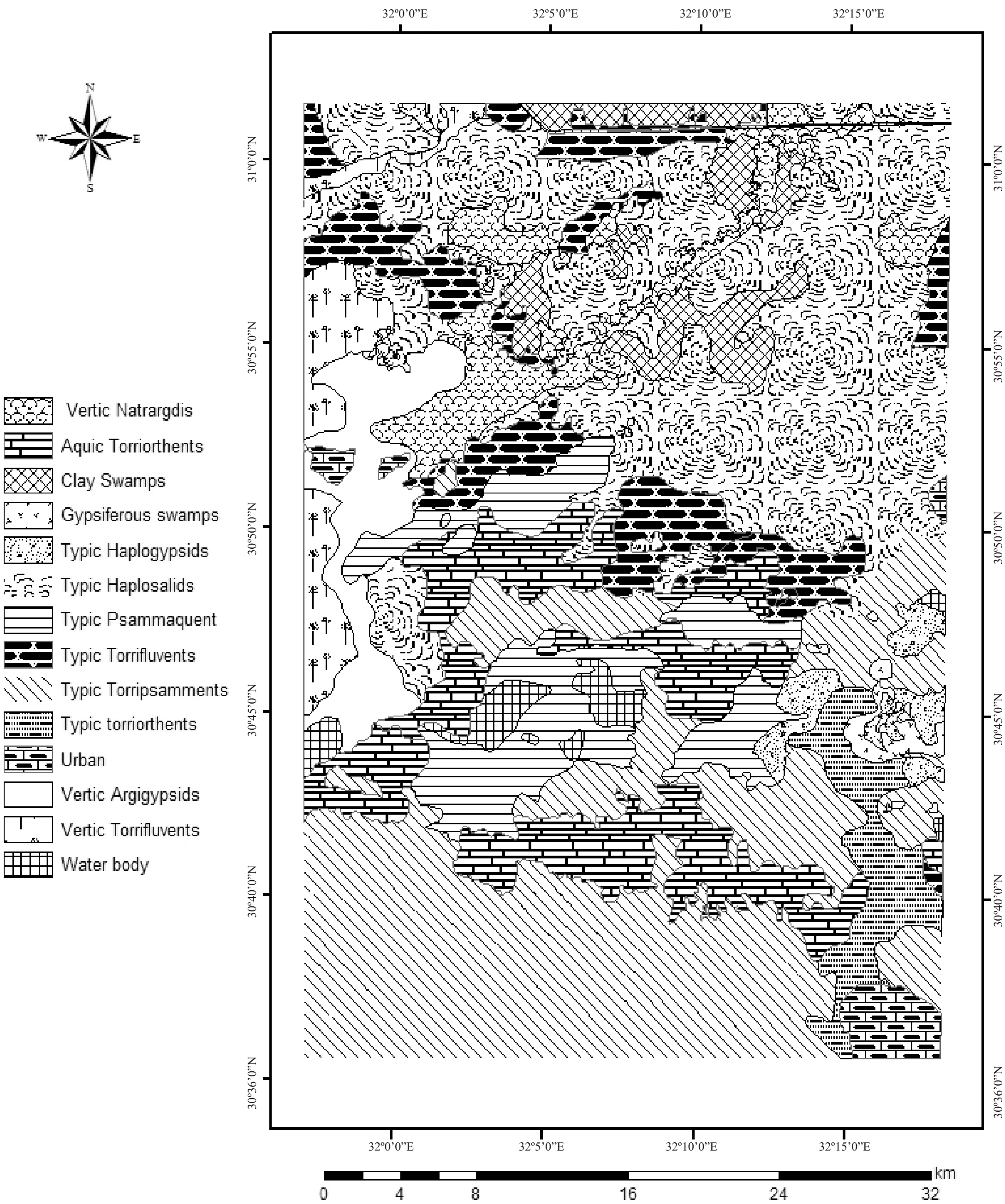

Fig. 4. Soil map of the studied area.

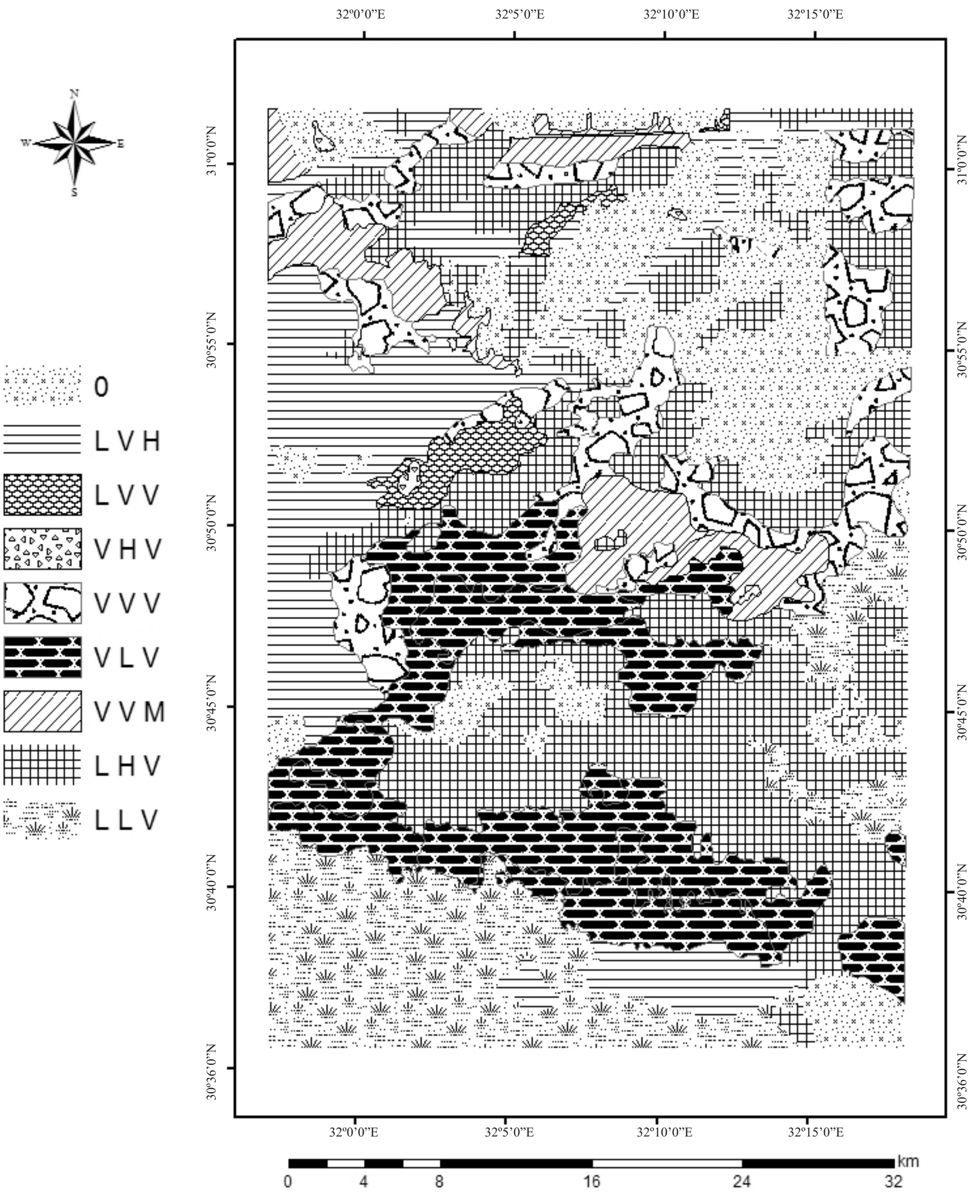

Fig. 5. Degradation risk map of the studied area.
The first letter = salinization risk class, middle letter = sodication risk class, and the last letter = physical degradation risk class where L = low, M = moderate, H = High, and V = very high risk; O= water body, urban, and Gypsiferrous swamp.

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