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ORIGINAL ARTICLE

Soil resilience mapping in selective wetlands, West Suez Canal, Egypt

W.A. Abdel Kawy [a,*], Abdel-Aziz Belal [b]

[a] *Soils Science Department, Faculty of Agriculture, Cairo University, Giza, Egypt*
[b] *National Authority for Remote Sensing and Space Sciences, Cairo, Egypt*

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Abstract The aims of this study are: (1) producing a geometrically corrected physiographic-soil map scale 1:50,000 reduced to the attached map; (2) detecting some soil characteristics as (effective soil depth, salinity and alkalinity) of the investigated area during the last 28 years to produce the soil resilience maps.

To fulfill the first aim, eight soil profiles were selected from 30 profiles to represent the different mapping units. Morphological description was carried out and soil samples were collected for physical and chemical analyses. Based on ETM+ images and the geographic information system, coupled with the field work and laboratory analysis data, the physiographic-soil map was produced.

The following main landscape units can be identified: (1) coastal plain (the fluvio-marine deposits) and (2) young sub-deltaic deposits.

With respect to the second aim except some environmental processes which occur without human interference, the soil resilience resulted when soils are used and managed in the right way. Land use and management have a direct effect on soil resilience. It can decrease soil degradation and increase soil restoration and accordingly increase soil resilience. The main types of human activities included

* Corresponding author.
E-mail address: dr_wael_kawy@yahoo.com (W.A. Abdel Kawy).

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soil resilience in the investigated area are soil resilience against salinization, soil resilience against alkalinization and soil resilience against water logging.

The human action on soil resilience could be recognized through the man-action as good and proper land management, introducing proper land modern irrigation and drainage styles, in addition to adequate fertilizing programs.

1. Introduction

Land degradation can be observed in all agro-climatic regions on all continents. Although climatic conditions, such as drought and floods, contribute to degradation, the main causes are human activities. The developing countries of the world, and particularly those in the arid and semi-arid zones, are the most seriously affected (UNEP, 1991). Land degradation is a global problem. The Global Assessment of Land Degradation and Improvement (GLADA) under the FAO Land Degradation Assessment in Dry lands indicates that, over the period of 1981–2003, a quarter of the land surface has been degrading, on top of the historical legacy of degradation.

In Egypt, the degradation of land resources is the main constraint to the development of agricultural sector, where the ratio between land and human resources is now the most critical problem. The main land degradation types in irrigated agriculture in Egypt are salinization, alkalization and water logging (El-Kassas, 1999). The resistance of soils to degradation processes by human positive actions is known as soil resilience. Soil resilience has been defined as the capacity of a soil to recover its functional and structural integrity after a disturbance (Pimm, 1984; Eswaran, 1994; Lal, 1997; NRCS, 2005). The rate of soil degradation depends on both soil properties, and land management practices (Shepherd and Soule, 1998), land with low resilience is permanently damaged by degradation (Eswaran et al., 1999). So the soil resilience may be the way that can be used as an operational basis for combating soil degradation (Blum, 1994). The factors of climate, topography, land use, soil type, technological innovations and input management have a direct effect on soil resilience (FAO, 2006; Seybold et al., 1999; Herrick et al., 1997; Greenland and Szabolcs, 1994). The effect of land use on soil resilience is demonstrated by the data from dryland, the proportion of highly resilience soils in the world's dryland areas is about 28% in rangelands, 54% in rainfed crop lands, and 70% in irrigated crop lands. It can therefore be inferred that the soil resilience in dry lands is enhanced by the intensive agricultural land use and technological input, and ecologically appropriate land use to alleviate ecological stresses (Rozanov, 1994). Also the soil resilience is affected by both inherent and dynamic soil characteristics and, thus, will vary substantially from one area to another (MacEwan, 1997), e.g. under similar climate conditions, clayey soils are more resilient than sandy (Prasad and Power, 1997). A close relationship exists between climate and soil resilience. The drier the climate, the less resilient soil systems are following various disturbances (Lal, 1997). Human activity is an important driving factor behind soil formation that may have either positive or negative effects on soil productivity; soils can develop a self-regenerating system against degradative processes through adoption of restorative management systems. Practices leading to soil degradation should be systematically matched with practices leading to improvement in soil resilience. The key to improving the resilience of soils is the adoption of practices that increase the input of soil organic matter. Organic matter improves the soil pore structure, increases water infiltration, and reduces soil compaction and runoff and soil erosion. Improvements in micro-porosity and pore structure are essential to water retention and transmission properties of the soil. High quantities of soil organic matter act like a sponge, lowering the compressibility of the soil but enhancing resilience upon release of stresses. Restoration of degraded soils requires the transformation in farming practices, land use, and human attitude (John et al., 2006).

In general, cropping systems that enhance soil resilience are associated with conservation tillage. Systems that incorporate legumes and high residue producing crops are beneficial to improving soil resilience. Restoration of soil is commensurate with the quantity and quality of crop residue input on the soil surface. Cropping systems that leave large amounts (>5 Mgha^{-1}) of crop residue increase soil organic matter content and percent of water-stable aggregates in the surface horizons. Complex and diverse crop rotations integrated with cover crops are preferable over monocultures to enhance soil resilience. Soil resilience is usually higher under pastures and planted fallow systems than under annual crops. Soil microbiological processes with positive influence on soil resilience are prominent under the improved fallow systems (Wick et al., 1998).

The aims of this study are: (1) producing a geometrically corrected physiographic-soil map scale 1:50,000 using ETM+ images reduced to the attached map scale for the studied area and (2) detecting some soil characteristics as (effective soil depth, salinity, and alkalinity) of the investigated are during the last 28 years to produce the soil resilience maps.

2. Materials and methods

2.1. Study area

The study area is located in the eastern part of the Nile Delta, it is extended between longitudes, 32°02′00″ and 32°09′30″E and latitudes, 30°49′20″ and 30°58′25″N (Fig. 1). Based on the American soil taxonomy (USDA, 2010) the soil temperature regime of this area could be defined as thermic and the soil moisture regime as torric, where the arid climatic conditions dominate the area (Climatologically Normal for Egypt, 2011; EMA, 1996). This area has a good agricultural potentiality and the major constraints determining the present low production capacity of the soil are salinity, sodicity, poor internal

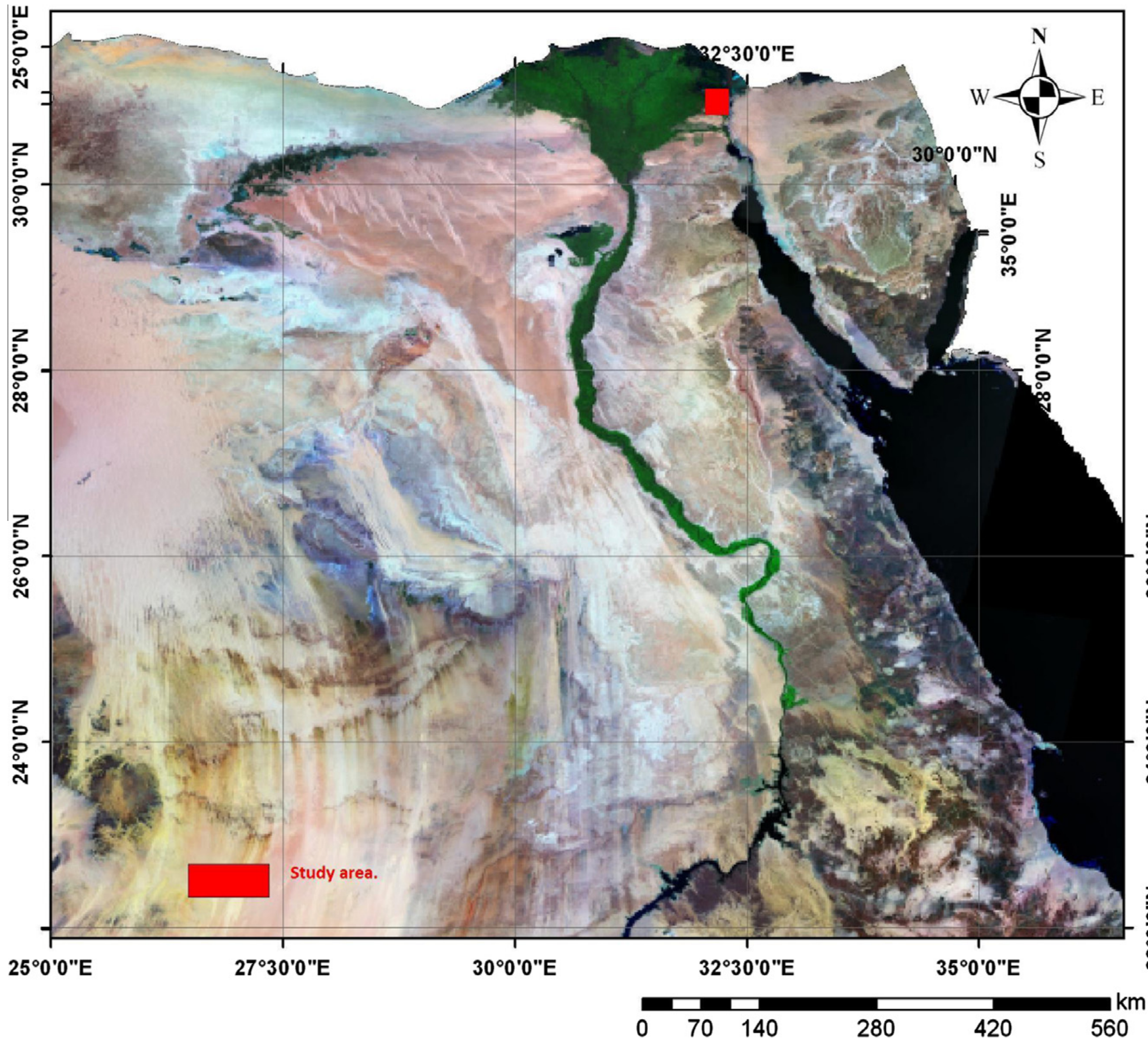

Figure 1 Location map of the studied area.

drainage and impervious compact soil structure (Ismaell, 1988). Two main landscapes characterize this area, the fluvio-marine plain and the river terraces, where both of them originated from fluvial and deltaic origin. Between these two landscapes, there is a wide transitional zone, strongly affected by wind action and consisting of nearly flat plains, gypsiferous sandy soils, wind blown sand soils, with dunes or hummocky relief and small strip of transitional soils. The area in general has fairly flat relief except the river terraces and sand dunes, which have an undulating or hummocky relief (ASRT, 1978). The northern and eastern parts of the study area include young fluvio-marine deposits, which were originally transported and deposited by both the river and the sea, and are composed of clay and silty clay inter-layered with lenses of quartz sand, and highly enriched with salts. The southern parts of the area include young eolian deposits, which are distributed as sand sheets developed into hummocks or sand dunes of variable size. On the other hand, the western parts include sub-deltaic deposits that are composed of medium and fine quartz sand (Said, 1993).

2.2. Field work and laboratory analyses

A semi detailed survey was done throughout the investigated area in order to gain an appreciation on the soil patterns, the land forms and land use/cover. Eight soil profiles were selected from 30 profiles (Fig. 2) to represent different land forms. The morphological description of these profiles was carried out according to the guidelines edited by (FAO, 2006)

Representative soil profile and disturbed soil samples have been collected and analyzed.

2.2.1. Physical analyses

Particle size distribution was determined according to Klut (1986).

2.2.2. Chemical analyses

Electric conductivity (EC), soluble cations and anions, calcium carbonate ($CaCO_3$), organic matter (O.M.), pH, exchangeable Na^+, macro-nutrients and cation exchange capacity (CEC) were determined according to USDA (2004).

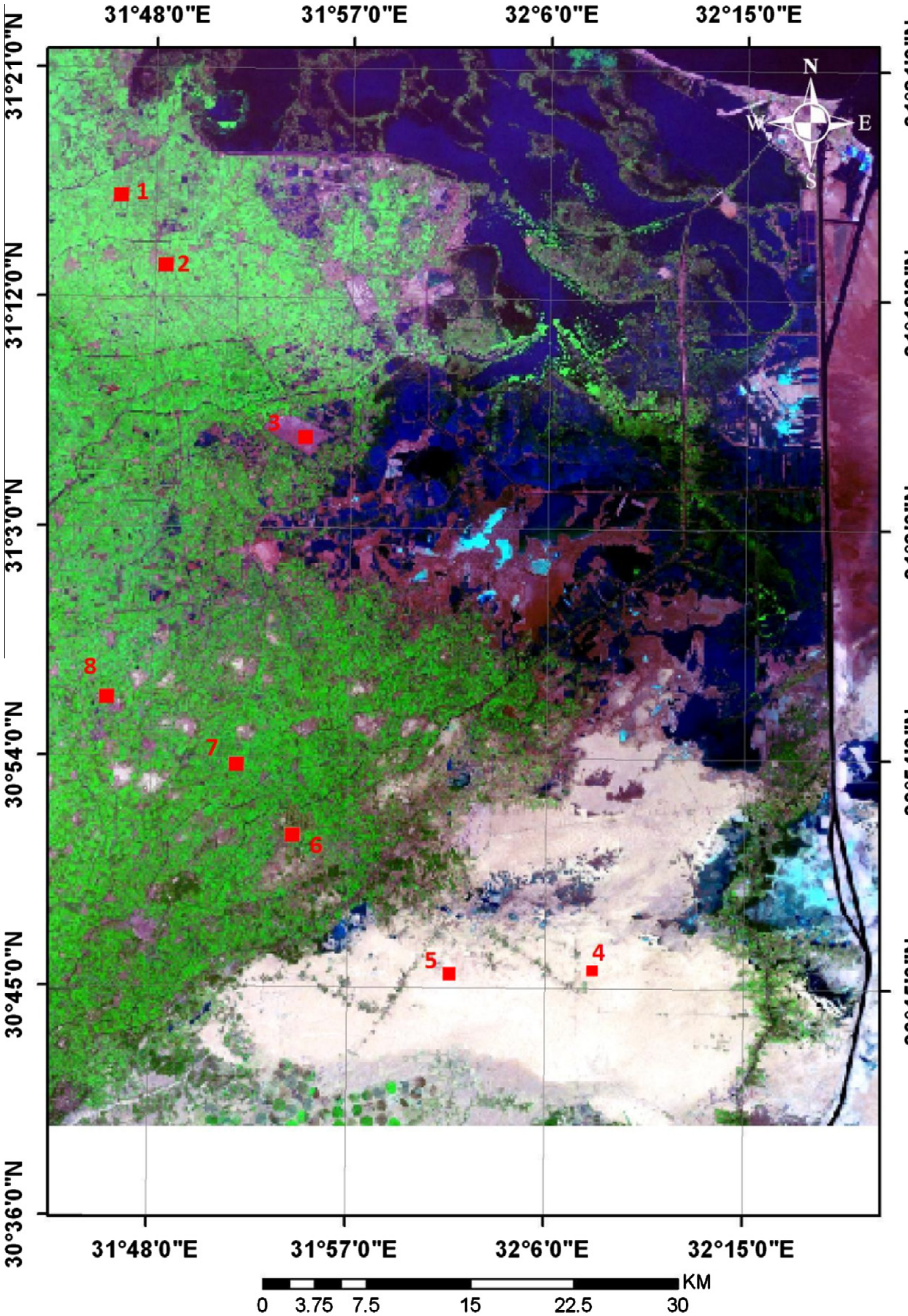

Figure 2 Distribution of the studied soil profiles.

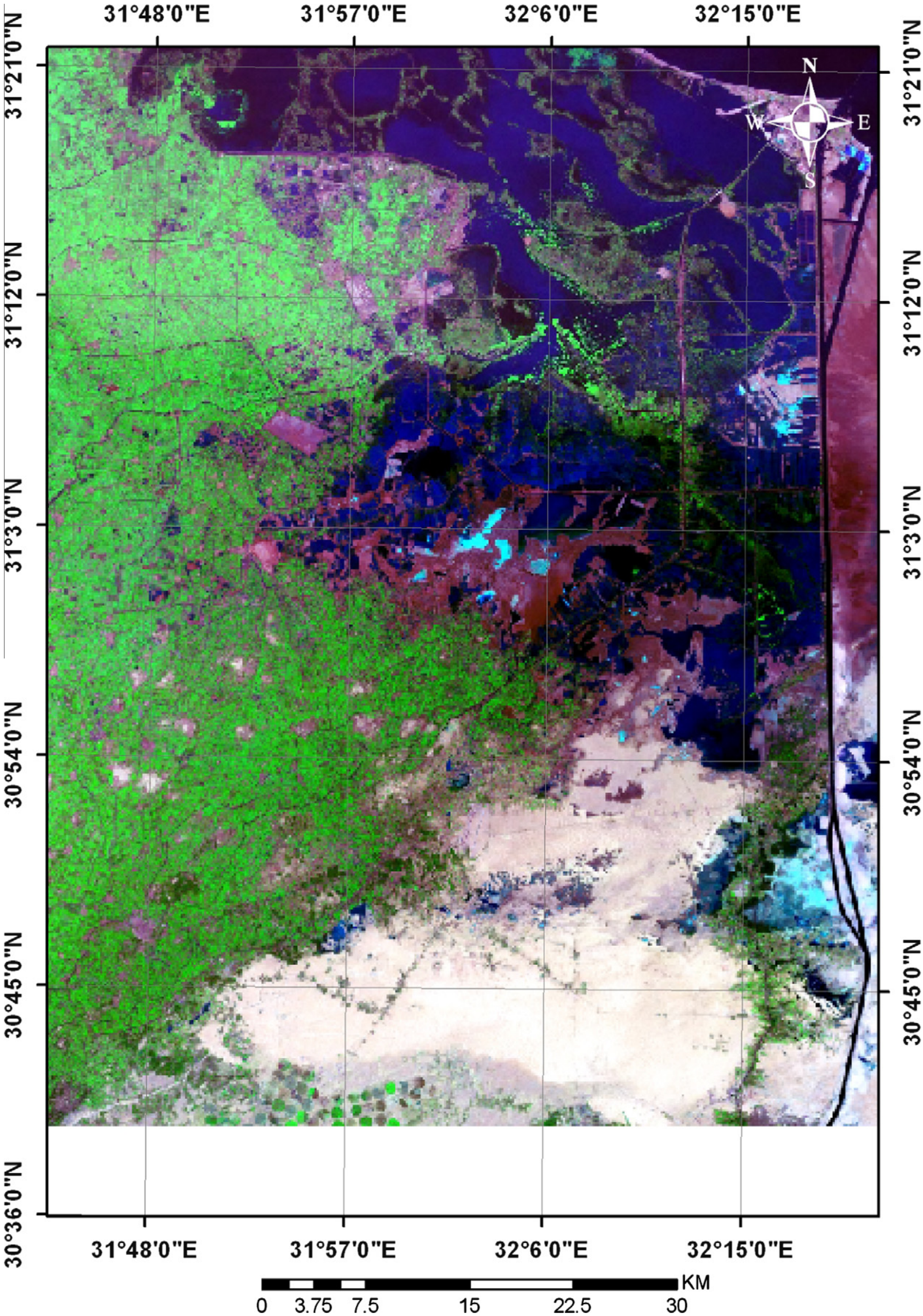

Figure 3 Enhanced Landsat ETM + image of the studied area.

Table 1 Soil quality rating.

Rating	Effective soil depth (cm)	Salinity EC (dS/m)	ESP	Limitation
1	< 150	> 2	> 10	None
2	100–150	2–4	10–15	Slight
3	100–80	4–8	16–20	Moderate
4	80–50	8–15	21–30	Strong
5	> 50	< 15	–	Very strong

Modified by Sys (1985) and Sideruis (1984, 1989).

Table 2 Soil renewal and management rating.

Rating	Soil renewal rate (cm/year)	Management input (Im)	Limitation
1	> 0.1	Chemical fertilizer and organic mater addition with improvement in irrigation and drainage systems	Very high
2	0.06–0.1	Chemical fertilizer and/or organic mater addition with improvement in drainage systems	High
3	0.01–0.05	Chemical fertilizer or organic mater addition	Moderate
4	< 0.01	No management input	Low

Modified after Lal (1994b).

Table 3 Classes and rates of soil degradation.

Rating	Degradation classes	Salinization, increase in EC (dS/m/year)	Alkalinization, increase in ESP/year	Water logging, increase in water table (cm/year)
1	Non to slight	< 0.5	< 0.5	< 1
2	Moderate	0.5–3	0.5–3	1–3
3	High	3–5	3–7	3–5
4	Very high	> 5	> 7	> 5

Modified after FAO (1979).

Table 4 Status and description of soil resilience classes.

Class	Resilience status	Description
0	Highly resilient	Rapid recovery, high buffering
1	Resilient	Recovery with improved management
2	Moderately resilient	Sow recovery with high input
3	Slightly resilient	Slow recovery even with change in land use
4	Non-resilient	No recovery even with change in land use

Modified after Lal (1994a).

2.3. Geomorphology and soil mapping using geographic information system (GIS)

Geomorphologic map was produced using digital image processing of Landsat 7.0 ETM+ image date to 2010 (Fig. 3) executed using ENVI 4.7 software (ITT, 2009). Image was stretched using linear 2%, smoothly filtered, and their histograms were matched according to Lillesand and Kiefer (2007). Image was atmospherically corrected using FLAASH module (ITT, 2009). The different landforms were initially determined from the satellite image and the digital elevation model extracted from the contour map, following the methodology developed by Dobos et al. (2002). Keys of soil taxonomy (USDA, 2010) were used to classify the different soil profiles. ArcGIS 9.3.1 and its Spatial Analyst extension (ESRI, 2009) were used for soil mapping and soil variables.

2.4. Assessment of soil resilience

Quantification of soil resilience has been achieved using the methodology developed by Lal (1994a, 1997)), as the following.

2.4.1. The rate of soil degradative process

Soil resilience can be computed from the rate of change in soil quality, as shown in the following equation

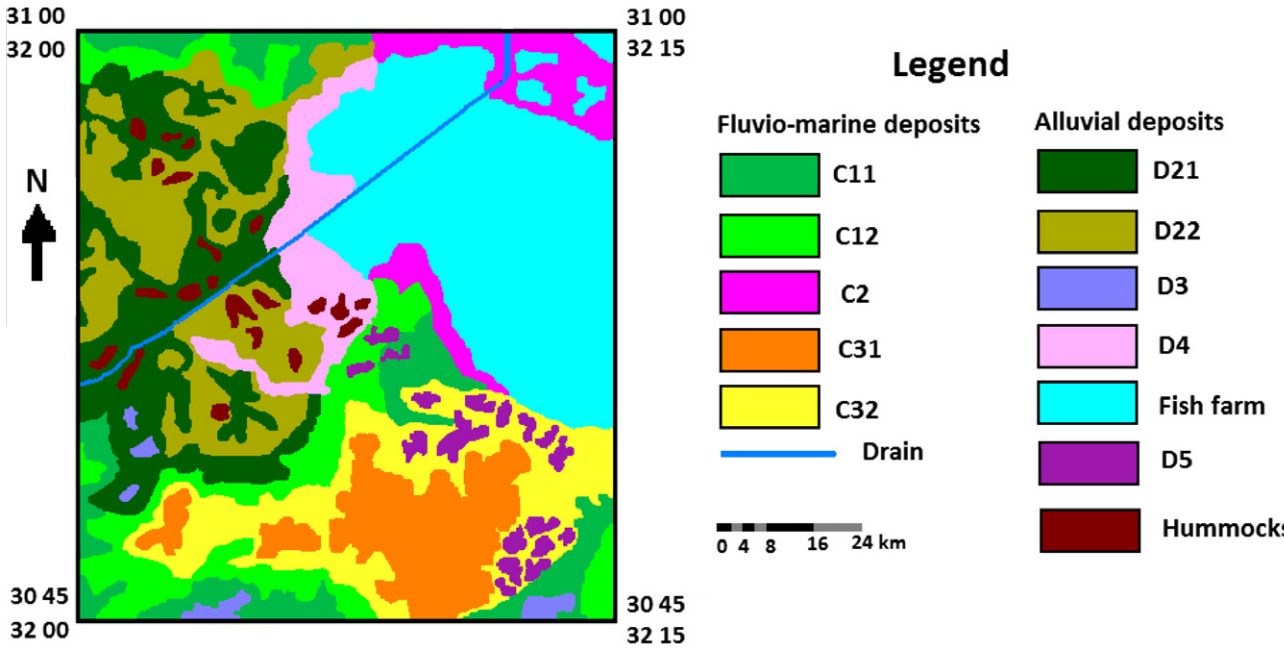

Figure 4 Geomorphology and soil of the investigated area.

Table 5 Physiographic and Soil Map legend of the Investigated Area.

Landscape	Relief	Lithology/origin	Land form	Mapping unit	Rep. profiles	Soil sets	Type of soil sets
Coastal plain	Gently undulating	Fluvio-marine deposits	Clay flats				
			Relatively high	C11	1	Vertic Torrifluvents	Cons.
			Relatively low	C12	2	Vertic Torrifluvents	Cons.
			Clay swamps	C2	3	Typic Aquisalids	Cons.
			Old sandy deposits remnants				
			Relatively high	C31	4	Typic Torripsamments	Cons.
			Relatively law	C32	5	Typic Torripsamments	Cons.
Young sub-deltaic deposits	Flat to almost flat	Alluvial deposits	Scattered small hills (Hummocks)	D1	6	Typic Torrifluvents	Cons.
			Flat plains				
			Relatively high	D21	7	Typic Torrifluvents	Cons.
			Relatively low	D22	8	Typic Torrifluvents	
			Marches	D3	–	–	–
			Intermittent wet land	D4	–	–	–
			Gypsiferous deposits	D5	–	–	–

$$\mathrm{Sr} = -\mathrm{dSq}/\mathrm{d}t$$

where Sq is soil quality and t is time, the negative value of the change refers to degradation.

2.4.2. The rate of soil restoration

In contrast to degradation, the rate of soil restoration can be used to assess soil resilience. It can also be related to changes in soil quality as shown in the following equation

$$\mathrm{Sr} = +\mathrm{dSq}/\mathrm{d}t$$

where the positive value of the change refers to resilience.

2.4.3. Modeling soil resilience

Lal (1994a) proposed the following model:

$$\mathrm{Sr} = \mathrm{Sa} + \int_0^t (\mathrm{Sn} - \mathrm{Sd} + \mathrm{lm})\mathrm{d}t$$

where Sa is the rate of the initial or the antecedent condition, Sn is the rate of soil renewal, Sd is the rate of soil degradation, and Im is the management input rates.

The rate of soil properties changes (salinity, alkalinity and water logging) was estimated using the data extracted from the report of MDNC (1982) and the data of this study. The quantification of soil resilience was worked out using the rating of the antecedent condition of the soil according to soil

Table 6 Soil morphological features' abbreviations of the studied area.

Mapping unit	Rep. profile no.	Depth (cm)	Slope	Color		Texture class	Structure	Consistency	Stickiness	Plasticity	Carbonates	Boundary	Cement	Other
				Dry	Moist									
C11	1	0–35	A	10YR5/3	10YR2/2	C	MG	EFI	VST	VPL	MO	C	M	Shells
		35–110		5YR5/3	5YR3/2	C	MG	EFI	VST	VPL	SL	C	M	Shells
		Water table level												
C2	3	0–20	A	10YR5/2	10YR2/2	C	MM	EFI	VST	VPL	SL	C	M	Shells
		20–45		5YR3/2	5YR2/1	C	MM	EFI	VST	VPL	SL	C	M	Shells
		Water table level												
C32	5	0–45	G	5YR5/2	5YR3/2	SCL	SG	VFI	ST	PL	MO	G	W	Shells
		45–80		5YR3/2	5YR2/1	S	SG	VFI	ST	PL	MO	G	W	Shells
		Water table level												
D1	6	0–40	A	10YR5/3	10YR2/2	C	MM	VFI	ST	PL	MO	G	W	Shells
		40–100		10YR5/3	10YR2/2	C	MM	VFI	ST	PL	MO	G	W	Shells
		Water table level												
D22	8	0–30	A	5YR3/2	5YR1/1	C	MW	VFI	ST	PL	MO	C	M	Shells
		30–75		10YR5/2	10YR2/2	C	MW	VFI	ST	PL	MO	C	M	Shells
		Water table level												
C12	2	0–30	A	10YR5/3	10YR2/2	C	MG	EFI	VST	VPL	MO	C	M	Shells
		30–100		5YR5/3	5YR3/2	C	MG	EFI	VST	VPL	SL	C	M	–
		Water table level												
C31	4	0–30	G	5YR5/2	5YR3/2	SCL	SG	FI	ST	PL	MO	G	W	–
		30–60		5YR3/2	5YR2/1	S	SG	FI	ST	PL	MO	G	W	Shells
		Water table level												
D21	7	0–40	A	5YR3/2	5YR 1/1	C	MW	VFI	ST	PL	MO	C	M	Shells
		40–80		10YR 5/2	10 YR 2/2	C	MW	VFI	ST	PL	MO	C	M	Shells
		Water table level												

Abbreviations according to FAO (2006). S: sandy; SCL: sandy clay loam; C: clay; SG: single grained; MW: massive, weakly coherent; MM: massive, mod. coherent; MG: massive, strongly coherent; VFI: very firm; EFI: extremely firm; SL: slightly calcareous; MO: mod.; ST: strong; ST: sticky; VST: very stick; PL: plastic; VPL: very plastic; C: clear; G: gradual; A: almost flat; G: gently undulating; Y: compacted; W: weakly cemented; M: mod. cemented.

quality rating (effective soil depth, salinity and alkalinity) after Sys (1985) and Sideruis (1984, 1989), the rate of soil renewal and management input after Lal (1994b) and the rate of soil degradation (salinization, alkalinization, and water logging), after FAO (1979), as shown in Tables 1–3. The soils have been grouped into different classes according to their degree of soil resilience as shown in Table 4.

3. Results and discussion

3.1. Landforms of the studied area

The landforms of the studied area were delineated by using the digital elevation model, Landsat ETM+, and ground truth data (Fig. 4). The obtained data represent the main landforms of the study area as shown in (Table 5). The obtained data indicate that the western side of the area includes the landforms of flat plains (55.19 km^2) and hummocks (1.88 km^2). These landforms are exhibited by alluvial deposits of the river Nile. The eastern side is dominated by fluvio-marine deposits including the landforms of clay flats (43.62 km^2), clay swamps (7.86 km^2), marches (3.01 km^2), intermittent wet land (4.83 km^2), gypsiferous deposits (2.12 km^2), and fish pond (80.15 km^2). The south east corner of the area is occupied by the eolian deposits which include old sand deposits (37.45 km^2) landforms.

3.2. Soils of the studied area

The obtained results as shown in Tables 6 and 7 indicate the following.

3.2.1. Soils of coastal plain (fluvio-marine deposits)

This plain is low lying, almost flat. It was originally affected by the Nile then the sea and later by the wind as soil forming factors. Soils of this landscape mainly occur on three main subland types, i.e. clay flats, clay swamps, and old sand deposits. These soils are found in mapping units (C11, C12, C2, C31, and C32) and are represented by profiles 1–5. The particle size distribution is characterized by alternative pattern of sedimentation as the texture is clayey for the different layers of profiles 1–3 and sandy clay loam in the upper layer, sandy in the second layer of profiles 4 and 5. The structure ranges from single grains to massive. The consistence is firm to extremely firm, sticky to very sticky, and plastic to very plastic. There are few to many shells along the profile depths. The compaction in the second horizon is slight to high. There are common fine to medium pores. The effervescence with HCl is slight to mod-

Table 7 Main physical and chemical characteristics of the representative soil profiles.

Mapping unit	Rep. profile no.	Depth (cm)	Particle size distribution (%)					Texture class	pH	O.M. (%)	$CaCO_3$ (%)	EC (dS/m)	CEC (cmolc/kg)	ESP (%)	Available macro-nutrients (mg/L)		
			Gravel	C. sand	F. sand	Silt	Clay								N	P	K
C11	1	0–35	0.0	0.64	2.17	25.56	71.63	Clay	8.6	1.8	10.2	17.6	68.2	16.4	91.1	31.4	290.2
		35–110	0.0	0.79	3.24	22.36	73.61	Clay	8.7	1.5	9.6	15.3	68.9	17.6	–	–	–
		Water table level															
C2	3	0–20	0.0	0.71	1.86	30.02	67.41	Clay	8.8	1.9	9.7	19.1	60.3	20.2	83.3	30.2	245.8
		20–45	0.0	0.43	2.19	25.56	71.82	Clay	8.7	1.4	6.8	16.2	60.8	18.7	–	–	–
		Water table level															
C32	5	0–45	0.0	4.83	55.55	16.31	23.31	SCL	8.7	1.7	11.7	18.2	13.1	18.3	21.3	24.6	100.2
		45–80	0.0	11.72	78.40	3.72	6.16	Sandy	8.6	1.2	10.3	15.4	2.2	16.9	–	–	–
		Water table level															
D1	6	0–40	0.0	0.57	3.31	42.38	53.92	Clay	8.5	1.6	12.6	10.6	47.8	15.8	81.6	27.8	210.4
		40–100	0.0	0.16	2.68	37.25	59.64	Clay	8.5	1.2	10.4	9.2	51.1	16.3	–	–	–
		Water table level															
D22	8	0–30	0.0	0.18	2.36	37.25	60.21	Clay	8.8	1.8	13.5	11.3	54.2	16.4	91.4	26.7	208.6
		30–75	0.0	0.27	2.11	32.7	64.92	Clay	8.6	1.1	11.2	8.7	56.3	15.5	–	–	–
		Water table level															
C12	2	0–30	0.0	0.64	4.17	28.56	66.63	Clay	8.5	1.6	11.3	16.8	61.2	16.4	90.0	30.1	280.2
		30–100	0.0	0.79	6.24	26.97	66.00	Clay	8.6	1.3	9.0	14.2	62.5	17.8	–	–	–
		Water table level															
C31	4	0–30	0.0	6.38	54.00	16.62	23.00	SCL	8.3	1.6	11.2	16.9	15.4	18.0	19.3	21.7	90.6
		30–60	0.0	14.56	75.00	3.72	6.72	Sandy	8.5	1.1	9.7	14.1	3.5	16.1	–	–	–
		Water table level															
D21	7	0–40	0.0	0.18	7.82	35.00	57.00	Clay	8.5	1.6	12.8	10.1	51.2	16.1	86.4	23.4	200.5
		40–80	0.0	0.20	4.00	34.80	60.00	Clay	8.5	1.0	8.9	7.6	52.3	15.0	–	–	–
		Water table level															

Table 8 Monitoring of EC, ESP and effective soil depth between the years (1982–2010).

Mapping unit	Profile No.	EC (dS/m)		ESP (%)		Depth (cm)	
		1982	2010	1982	2010	1982	2010
D22	8	8.6	10.0	16.4	15.9	75	75
D21	7	6.5	4.2	15.1	16.2	100	100
C11	1	23.6	16.4	19.2	17	110	110
C31	4	7.2	7.9	15	16.2	120	120
C12	2	17.8	6.5	18.2	15.6	120	120
C2	3	24.1	20.6	21.3	19.8	At 100	At 45
C32	5	12.6	16.8	18.2	17.6	At 120	At 80
D1	6	11.8	9.9	15.4	16.1	100	100

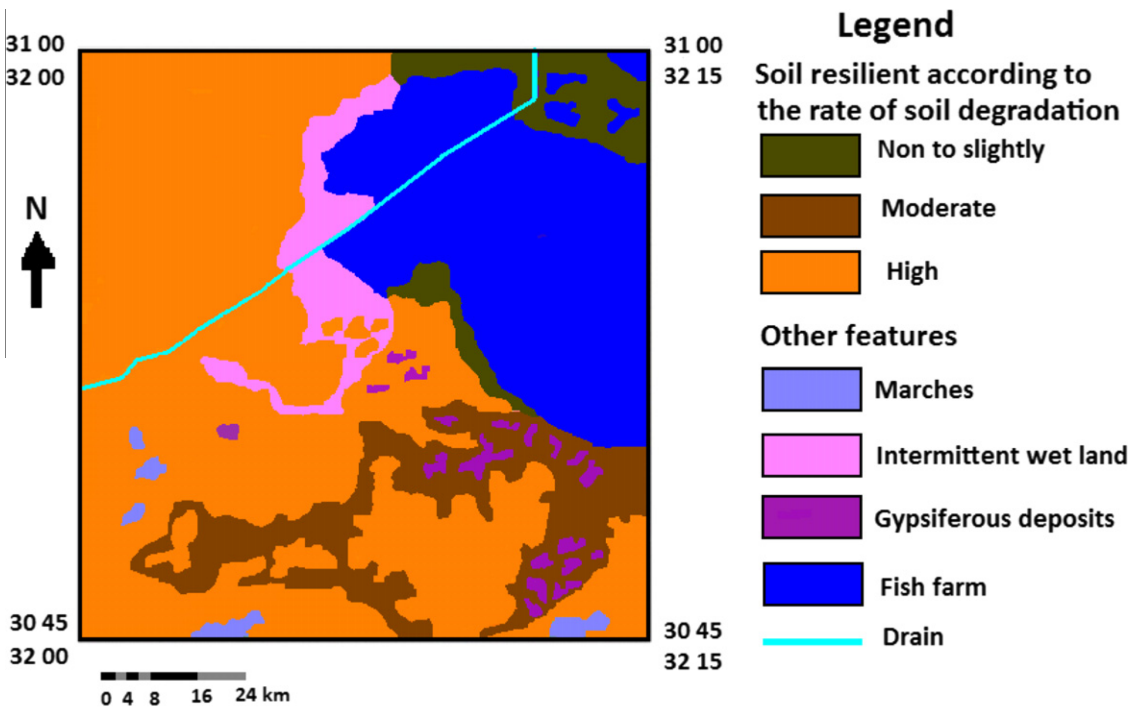

Figure 5 Soil resilience according to the rate of soil degradation.

Table 9 Soil resilient according to the rate of soil degradation.

Mapping unit	Profile no.	dSd/d*t*	dSz/d*t*	dSa/d*t*	Limiting factor	−dSq/d*t*	Sr.deg.
D22	8	0	0	0	–	0	High
D21	7	0	0	0	–	0	High
C11	1	0	0	0	–	0	High
C31	4	0	0	0	–	0	High
C12	2	0	0	0	–	0	High
C2	3	−2	−2	0	*d*, *a*, *z*	2	Non to slight
C32	5	−1	−1	0	*d*, *z*	1	Mod
D1	6	0	0	0	–	0	High

High = 0, mod = 1, non to slight = 2. Sq is soil quality (*d* is the effective soil depth, *z* is salinity, *a* is alkalinity), *t* is time, and Sr.deg. is the soil resilient according to the rate of soil degradation. The negative value of the change refers to degradation.

erate; the nature of boundary is gradual to clear. EC soil paste varies between 14.1 and 18.2 dS/m; pH value is 8.2–8.8; organic matter content ranges between 1.2% and 1.8%, the high values of O.M. content may be due to the common humified and fresh residuals of organic materials (fish ponds), and irrigation water which is very rich in decomposed organic residuals. Calcium carbonate varies between 6.8% and 11.7%; the high percentage of $CaCO_3$ is due to shells' fragments. CEC ranges

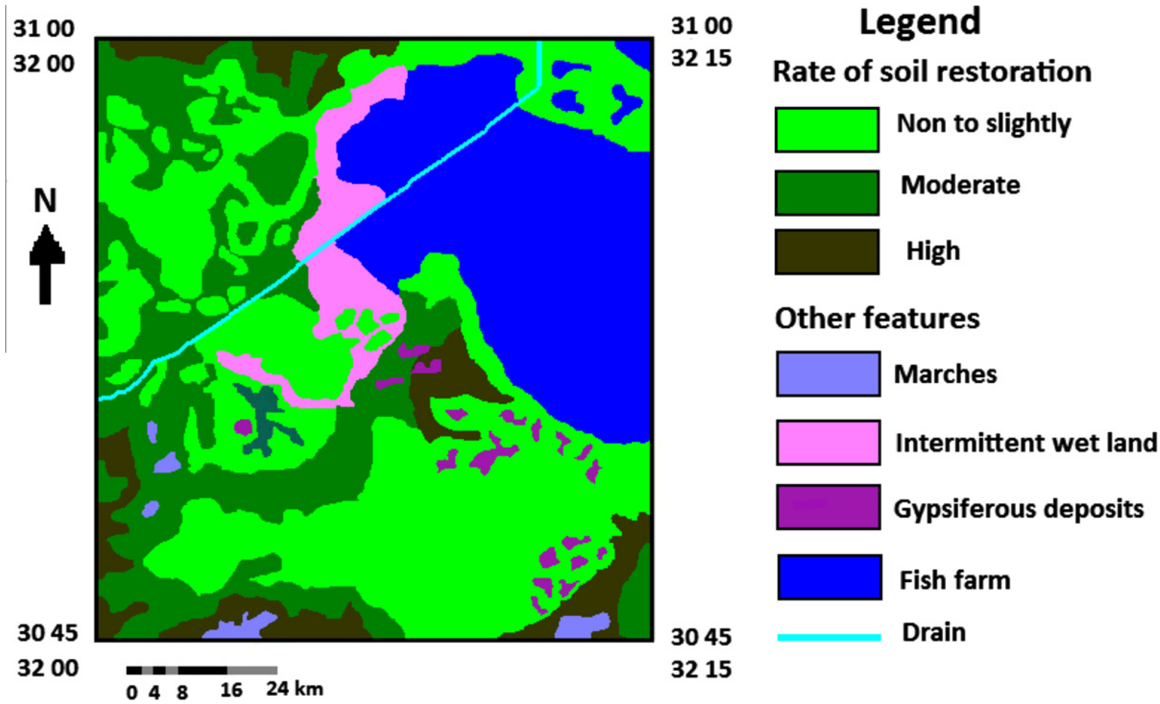

Figure 6 Soil resilience according to the rate of soil restoration.

Table 10 Soil resilient according to the rate of soil restoration.

Mapping unit	Profile no.	dSd/d*t*	dSz/d*t*	dSa/d*t*	Limiting factor	+ dSq/d*t*	Sr.rest.
D22	8	0	0	0	–	0	Non to slight
D21	7	0	1	0	*z*	1	Mod
C11	1	0	2	0	*z*	2	High
C31	4	0	0	0	–	0	Non to slight
C12	2	0	1	1	z, *a*	1	Mod
C2	3	0	0	0	–	0	Non to slight
C32	5	0	0	0	–	0	Non to slight
D1	6	0	0	0	–	0	Non to slight

High = 2, mod = 1, non to slight = 0. Sq is soil quality (*d* is the effective soil depth, *z* is salinity, *a* is alkalinity), *t* is time and Sr.rest. is the soil resilient according to the rate of soil restoration. The positive value of the change refers to resilience.

between 2.2 and 68.9 cmolc/kg, ESP ranges between 16.1% and 20.2%. The macro-nutrient analysis indicates that available nitrogen is 19.3–91.1 mg/L; available phosphors is 21.7–31.4 mg/L, and available potassium is 90.6–290.2 mg/L.

3.2.2. Soils of recent sub-deltaic deposits (alluvial deposits)

These soils represent the recent sub-deltaic plain, which is of recent age. Throughout the successive periods of the river terraces formation, immense quantities of gravel and sand have been carried by the Nile into the sea, where they spread out around the river's mouth in the form of Delta. As the relative level of the sea fell, the less compacted sandy and gravelly deposits were disintegrated by water action and the materials were again redistributed, where the more resistant portions remained in situ and formed Islands, these soils are called "Turtle backs" or "Hummocks".

These soils are found in mapping units (D1, D21, D22, D3, D4, and D5) and represented by profiles (6–8). The texture is clayey for different layers. The structure is massive. The consistence is extremely firm, very sticky, and very plastic. There are few to many shells along the profiles. The compaction in the second horizon is slightly to highly compacted. There are common fine to medium pores. The effervescence with HCl is slight to moderate; the nature of boundary is gradual to clear. EC (soil paste) varies between 7.60 and 11.3 dS/m; pH value ranges between 8.5 and 8.8; organic matter content ranges between 1.0% and 1.8% and calcium carbonate varies between 8.9% and 13.5%. CEC ranges between 47.8 and 56.3 cmolc/kg; ESP ranges between 15.0% and 16.4%. The macro-nutrient analysis indicates that available nitrogen content is 81.6–91.4 mg/L; available phosphorus is 23.4–27.8 mg/L, and available potassium is 200.5–210.4 mg/L.

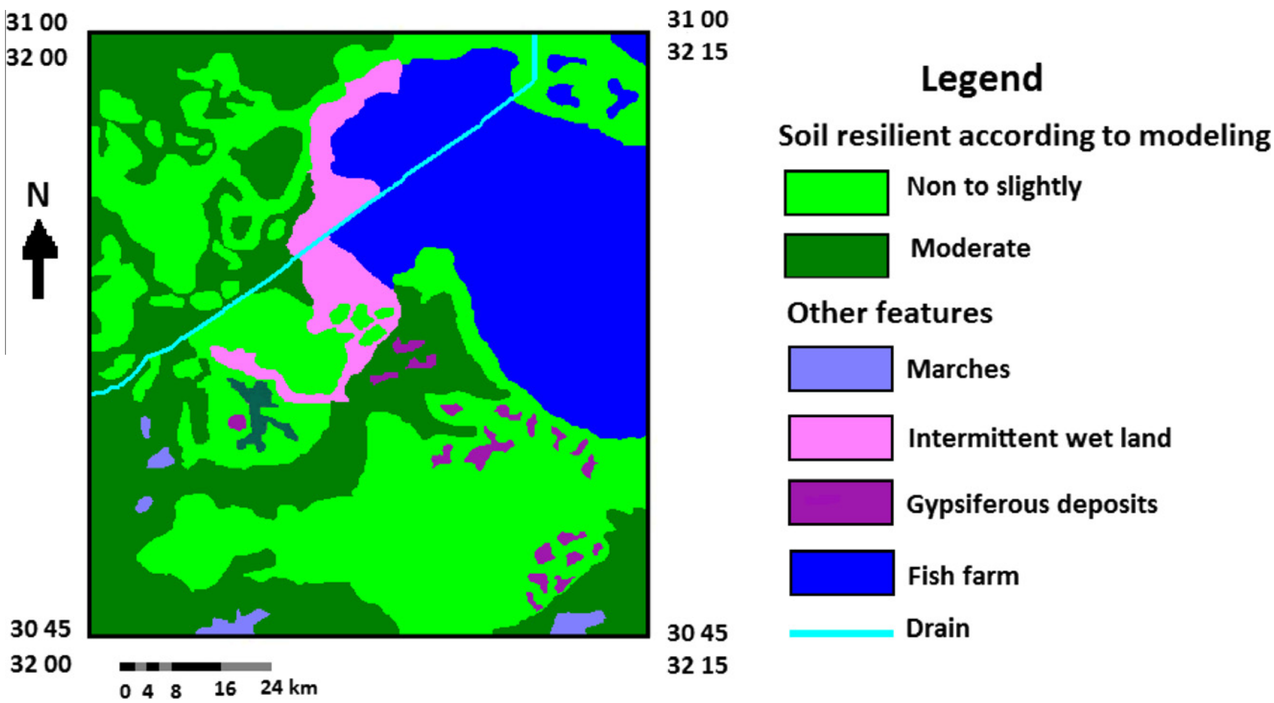

Figure 7 Soil resilience according to modeling.

Table 11 Soil resilient according to modeling.

Mapping unit	Profile no.	Sa	Sn	Sd	Im	Sr.mod.
D22	8	3	3	1	4	Non to slight
D21	7	3	3	1	1	Mod
C11	1	3	3	1	1	Mod
C31	4	2	3	1	2	Non to slight
C12	2	2	3	1	1	Mod
C2	3	2	3	1	3	Non to slight
C32	5	2	3	1	3	Non to slight
D1	6	2	3	1	4	Non to slight

Sa is the rate of the initial or the antecedent condition, Sn is the rate of soil renewal, Sd is the rate of soil degradation, Im is the management input rates and Sr.mod. is the soil resilient according to modeling.

Table 12 Concluded soil resilience classes.

Mapping unit	Profile no.	Sr (degradation)	Sr (rest)	Sr (model)	Sr (class)	Sr concluded
D22	8	High	Non to slight	Non to slight	2	Moderately resilient
D21	7	High	Mod	Mod	1	Resilient
C11	1	High	High	Mod	0	Highly resilient
C31	4	High	Non to slight	Non to slight	2	Moderately resilient
C12	2	High	Mod	Mod	1	Resilient
C2	3	Non to slight	Non to slight	Non to slight	4	Non-resilient
C32	5	Mod	Non to slight	Non to slight	3	Slightly resilient
D1	6	High	Non to slight	Non to slight	2	Moderately resilient

3.3. Soil classification

According to the Recent Keys of soil Taxonomy USDA (2010), the studied soils could be classified as: C11, Vertic Torrifluvents; C12, Vertic Torrifluvent; C2, Typic Aqusalids; C31, Typic Torripsamments; C32, Typic Torripsamments; D1, Typic Torrifluvents; D21, Typic Torrifluvents; D22, Typic Torrifluvents.

3.4. Soil resilience assessment

3.4.1. Soil resilience according to the rate of soil degradation

Table 8 represents the monitoring of physical and chemical properties of the studied area. Fig. 5 represents the soil resilience according to the rate of soil degradation in the studied area for the different mapping units. The obtained data are shown in Table 9 reveal that soil resilience classes are high

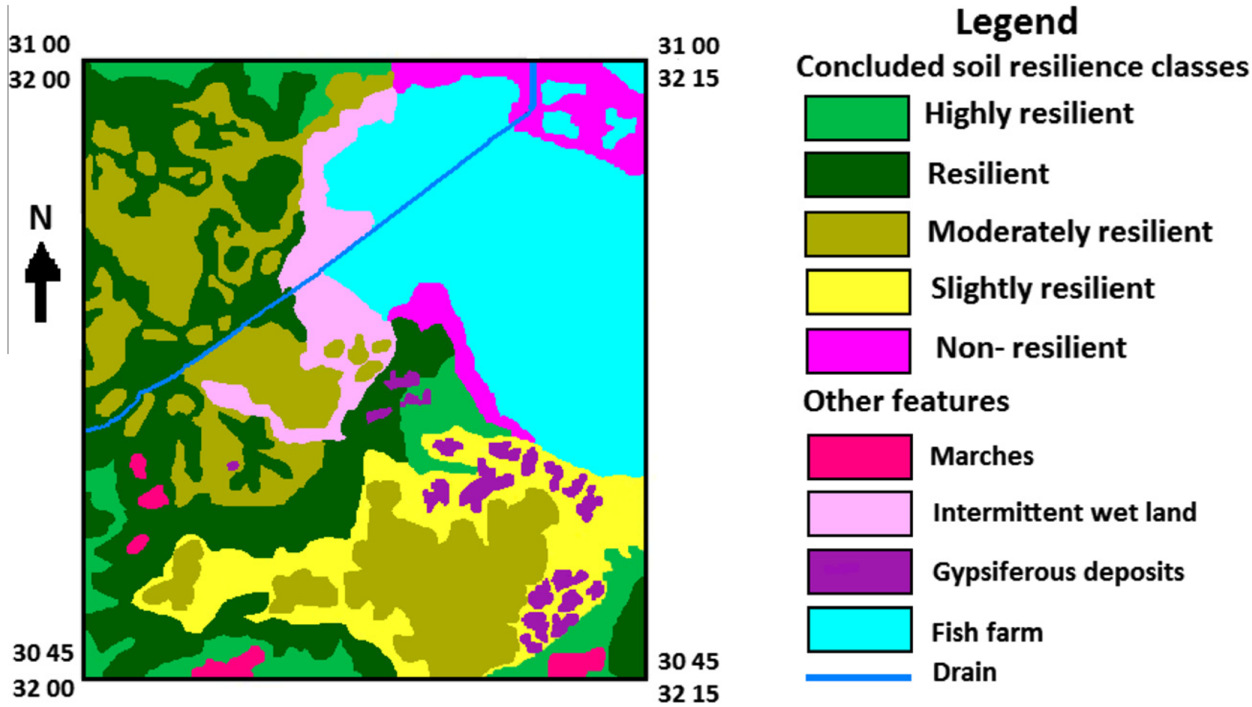

Figure 8 Concluded soil resilience classes.

in the mapping units of D22, D21, C11, C31, C12, and D1 with an area of 120.03 km^2, and moderate in C32 with an area of 18.11 km^2, and non to slight in C2 with an area of 7.86 km^2. The highly resilient soils are non or slightly degraded after continuous use and have high soil quality. Moderately resilient soils are moderately degraded after continuous use and non to slightly resilient are severely degraded after continuous use.

3.4.2. Soil resilience according to the rate of soil restoration

Fig. 6 represents the soil resilience according to the rate of soil restoration in the studied area for the different mapping units. The obtained data (Table 10) reveal that soil resilience class is high in the mapping units of C11 with an area of 18.49 km^2, and moderate in D21 and C12 with an area of 56.68 km^2, and non to slight in D22, C31, C2, C32, and D1 with an area of 70.83 km^2. The highly resilient soils have high improvement in soil quality. Moderately resilient soils have moderate improvement in soil quality and non to slightly resilient soils have no improvement in soil quality, including the uncultivated area.

3.4.3. Soil resilience according to modeling

Fig. 7 represents the soil resilience according to the modeling in the studied area for the different mapping units. The obtained data (Table 11) reveal that soil resilience class is moderated in the mapping units D21, C11, and C12 with an area of 75.17 km^2, and non to slight in D22, C31, C2, C32, and D1 with an area of 70.83 km^2. The moderated resilient soils have high to moderate management input and high soil quality in the antecedent condition, and non to slight resilient soils have non to slight management input and were of low soil quality in the antecedent condition, including the uncultivated area.

3.4.4. Concluded soil resilience classes

The soil resilience classes in the studied area were estimated based on the correlation between the rate of soil degradation (Sr.deg.), the rate of soil restoration (Sr.rest.), and the modeling (Sr.mod.), as shown in Table 12 and Fig. 8. The highly resilient soils, class 0, have high Sr.deg., high Sr.rest., and moderate Sr.mod. It is presented in the mapping unit of C11 with an area of 18.49 km^2, in this mapping unit the water table is deep, the electrical conductivity is about 16.4 dS/m the exchangeable sodium percentage is 17.0%. This mapping unit also has high management input as chemical fertilizer and manure additions. The resilient soils, class 1, have high Sr.deg., moderate Sr.rest., and moderate Sr.mod. It is presented in the mapping units of D21 and C12 with an area of 56.68 km^2. In this mapping unit the water table is deep, the electrical conductivity ranges between 4.2 and 6.5 dS/m and the exchangeable sodium percentage ranges between 15.6% and 16.2%. These mapping units have high management input as chemical fertilizers, manure additions, and improved irrigation systems.

The moderately resilient soils, class 2, have high Sr.deg., slight Sr.rest., and slight Sr.mod. It is presented in the mapping units of D22, C31, and D1 with an area of 44.86 km^2. In these mapping units the water table is deep, the electrical conductivity ranges between 7.9 and 10 dS/m, the exchangeable sodium percentage ranges between 15.6% and 16.1%. These mapping units also have high management input as chemical fertilizer, manure additions, and improved in the irrigation and drainage systems. Some mapping units are new cultivated areas and others are barren. The slight resilient soils, class 3 have moderate Sr.deg., slight Sr.rest., and slight Sr.mod. It is presented in the mapping unit of C32 with an area of 18.11 km^2. In theses mapping units the water tables range from moderately to deep, the electrical conductivity reaches to 16.8 dS/m; the exchangeable sodium percentage reaches to 17.6%. These mapping units also have low management input as chemical fertilizer, some mapping units are new cultivated areas. The non-resilient soils, class 4 have non to slight Sr.deg., non to slight Sr.rest., and non to slight Sr.mod. It is presented in the mapping unit of C2 and with an area of 7.86 km^2. In theses mapping units the water table reaches 45 cm depth from soil surface, the electrical conductivity reaches to 20.6 dS/m and the exchangeable sodium percentage reaches 19.8%. These mapping units have low management input as chemical fertilizers.

4. Conclusion

Except some environmental processes which occur without human interference, the soil resilience is resulted when soils are used and managed in the right way. Land use and management have a direct effect on soil resilience. It can decrease soil degradation and increase soil restoration and accordingly increase soil resilience. The main types of human activities included soil resilience in the investigated area are soil resilience against salinization, soil resilience against alkalinization, and soil resilience against water logging. Human action on soil resilience could be recognized through the man-action as good and proper land management, introducing proper land modern irrigation and drainage styles, in addition to adequate fertilizing programs.

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