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Assessing Degradation of Flood Plain Soils in North East Nile Delta, Egypt

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EVALUATING degradation of fertile soils is the key factor to attain sustainable crop production. An assessment of human-induced soil degradation as well as degradation risk was executed in an area in the north part of Nile Delta. Eight soil profiles were dug and samples were collected. The soils are affected by slight salinity and sodicity hazards. Slight to moderate compaction and moderate waterlogging hazards are noted. The GIS spatial model show that 47.8% of the soils are affected by slight degradation hazards, while the remaining 52.2% are affected by strong (26.1%) and moderate (26.1%) hazards. Excessive irrigation, the lake of conservation measures, improper use of heavy machinery and inadequate drainage are main anthropogenic cause factors for soil degradation. The rate of soil degradation during the last four decades was none to slight since little changes in EC, ESP, bulk density and water table depth were shown. The area is affected by low chemical degradation risks, while the physical risks are very high. Achieving sustainable land use in the area requires proper management practices.

Keywords: Soil degradation, North east Nile Delta; GIS, Modeling

Land degradation has been a milestone of national and international environmental and development programs (Zdruli et al., 2010). This is mainly due to the destructive impacts on stability of land-bases ecosystem, which finally lead to declining land services (Smiraglia et al., 2016). Land degradation can undermine the livelihoods of billions of people, especially the poor rural inhabitants in low and middle-income countries (Reed et al., 2015 and Barbier & Hochard, 2016). Land degradation from the agricultural perspective is the progressive decline in soil capacity to produce biomass for humans and animals (Mainuri and Owino, 2014). Therefore, it poses a threat to food security in many countries since it needs efficient management and high costs, which may eventually obligate farmers to abandon the soils (Uchida, 2015). Soil degradation is a complex phenomenon that results from wide changes in soil properties due to natural and/ or anthropic factors (Shoba and Ramakrishnan, 2016). Soil degradation due to anthropic actions is a result of hazards caused by human activities (El-Baroudy and Moghanm, 2014). Human-induced soil degradation results from the overexploitation of soil, a situation caused by poverty, ignorance, and inability to adopt a proper system for sustainable agriculture (Bridges and Oldeman et al., 1999). It occurs either through the constant displacement of soil materials by the actions of wind and/or water erosion or through the *in-situ* deterioration of soil quality. The processes contribute to such negative effects are physical (compaction, waterlogging, sealing and crusting of topsoil), chemical (salinization, alkalinization, acidification, nutrient decline) and/ or biological (loss of organic matter, land cover and biodiversity) in nature (Oldeman et al., 1991 and Gomiero, 2016). Natural degradation risks are dimensional factors for current and potential soil productivity caused mainly by natural factors including climate, soil, and topography rather than the human intervention (Ali and Abdel-Kawy, 2013).

The situation of soil degradation is more complicated in Egypt, where arable lands (about 3.6 million ha) are not enough to feed the growing population (El-Ramady et al., 2013). Although the fertile lands in the Nile Delta account for about 67% of Egypt's agricultural lands, they undergo degradation, limiting their current and potential productivity (Mohamed, 2017). The main types of land degradation in the floodplain soils in the northern parts of the Nile Delta region are salinity, sodicity, compaction, and waterlogging (Darwish & Abdel-Kawy, 2008 and Wahab et al., 2010) as well as water erosion due to Mediterranean Sea

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level rise (Nahry et al., 2015). Assessing land degradation is important to provide appropriate prevention measures to keep the soil healthy and to attain sustainable land use (El Baroudy, 2011and Huang & Kong, 2016). Hence, the current work aims at evaluating land degradation at an area in north Nile Delta.

Materials and Methods

Site description

The studied area covers 812.92 km^2 ,*i.e.* 81292 ha (1 ha = 2.38 Egyptian feddans) of the floodplain soils in Dakahlia Governorate, north Nile Delta (Fig. 1) between longitude 31° 12′ 10″ to 31° 40′ 42″ E and latitude 31° 00′ 52″ to 31° 21′ 26″ N. The climatic data (Mansura station) indicate hot arid summer and little rainy winter in the area. The mean annual temperature is 20.8 °C (the minimum value is 17.4 °C in August, while the maximum is 17.4 °C in January). The total annual rainfall is 56.0 mm and the maximum value occurs during January. The potential evapotranspiration (PET) is 4.2 mm day^{-1}. Based on Soil Survey Staff (2014), the soil temperature regime is “Thermic” and the soil moisture regime is “Torric”.

Field work and laboratory analysis

The main landforms in the area are overflow mantle, decantation basin, overflow basin, and river terraces (Abdel-Kawy and Ali, 2012). Eight soil profiles were dug to represent the different geomorphic units (Fig. 2). The profiles were dug to a depth of 150 cm or the ground water table depth (Profile No. 8) and were described according to FAO (2006). Twenty-four soil samples were collected from the profiles and analyzed. The chemical analyses were performed according to Sparks et al. (1996), and the physical analyses were carried out based on the methods of Klute (1986).

Assessment of land degradation

This procedure was performed according to FAO/UNEP (1979). The human-induced land degradation was assessed considering the type, degree, causative factors and rate using the criteria presented in Tables 1 and 2. The rate of soil degradation during the last four decades was described based on the comparison between the data extracted from a report of Soil, Water and Environment Research Institute (SWERI, 1976) and the data obtained from the current study. The degradation risk was estimated according to the equations illustrated in Fig. 3. The classes of degradation hazards are low (risk < 2), moderate (risk = 2-4), high (risk = 4-6) and very high (risk > 6).

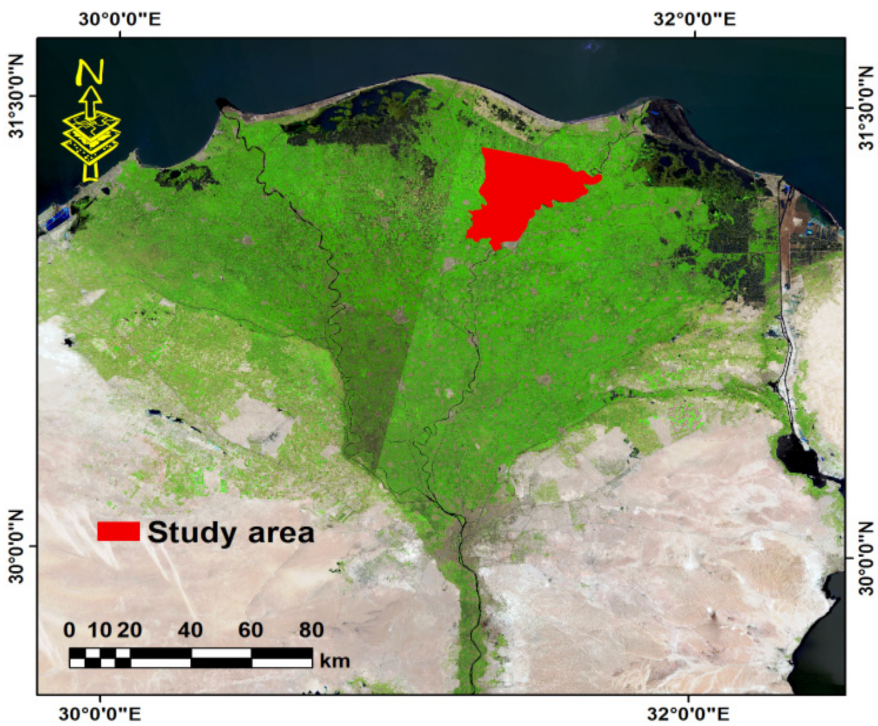


Fig. 1. Location map of the studied area

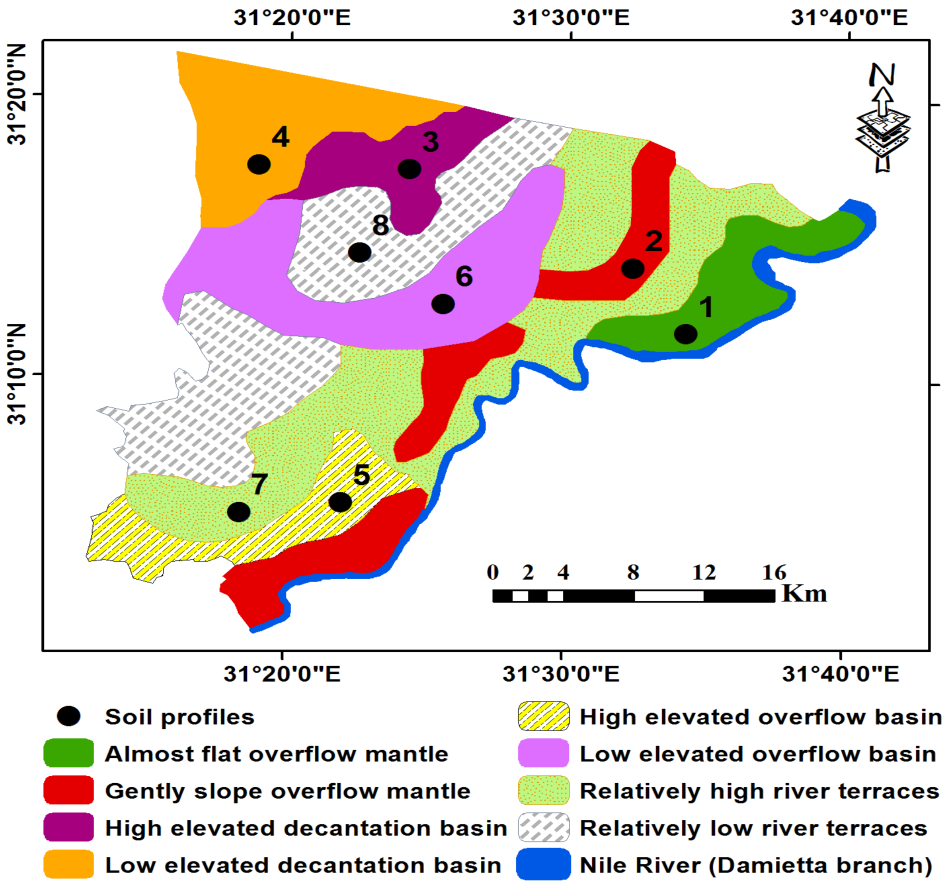


Fig. 2. Geomorphology of the area (After Abdel-Kawy and Ali, 2010) and profiles location

TABLE 1. Criteria used to determine the degree of different degradation types

Criteria/ Hazard type	Indicator	Unit	Hazard class				
			None	Slight	Moderate	Strong	Extreme
Salinization	EC	dS m^{-1}	< 4	4 - 8	8 - 16	16 - 32	> 32
Alkalinization	ESP	%	< 10	10 - 15	15 - 30	30 - 50	> 50
Compaction	Bulk density	Mg m^{-3}	< 1.2	1.2 - 1.4	1.4 - 1.6	1.6 - 1.8	> 1.8
Waterlogging	Water table depth	cm	> 150	150 - 100	100 - 50	50 - 30	< 30

TABLE 2. Soil degradation rates

Chemical degradation (C)	**Salinization (Cs)/increase in EC (dS m^{-1} $year^{-1}$)**	**Alkalinization (Ca)/ increase in ESP (% $year^{-1}$)**
None to slight	< 0.5	< 0.5
Moderate	0.5 – 3	0.5 – 3
High	3 – 5	3 – 7
Very high	> 5	> 7
Physical degradation (P)	Compaction (Pc)/ increase in bulk density (Mg m^{-1} $year^{-1}$)	Waterlogging (Pw)/ increase in water table depth (cm $year^{-1}$)
None to slight	< 0.1	< 1
Moderate	0.1 – 0.2	1 – 3
High	0.2 – 0.3	3 – 5
Very high	> 0.3	> 5

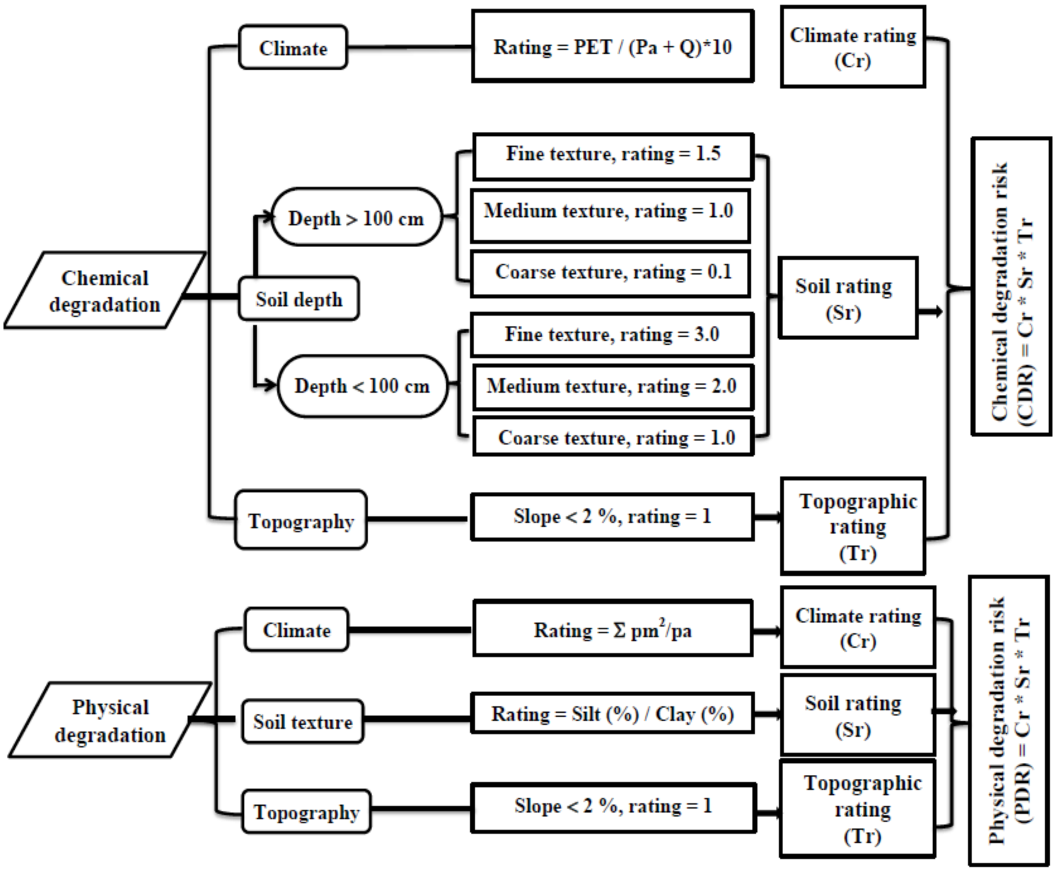


Fig. 3. Degradation risk model (PET, potential evapotranspiration (mm year-1); pa, annual precipitation (mm); pm, monthly precipitation (mm); Q, quantity of irrigation water (mm year-1)

Results and Discussions

Soils of the studied area

The weighted means of the studied soil properties are shown in Table 3. The results indicate that the soils are very deep (> 150 cm), except soils of the relatively high river terraces unit, where the depth is 96 cm, indicating a moderately deep soil (50-100 cm). They are flat to very gently sloping with slopes ranging from 0.10 to 1.91%. According to Soil Science Division Staff (2017), the soils are neutral with a pH range of 7.01-7.26 and very slightly to slightly saline having an EC range of 2.15-5.88 dS m^{-1}. Soil organic matter content is low to moderate (Hazelton and Murphy, 2016) with a range of 15.02 to 22.59 g kg^{-1}. The cation exchange capacity (CEC) is high to very high (Hazelton and Murphy, 2016) and differs from 29.91 to 41.89 cmolc kg^{-1} soil due to the high content of clay and organic matter. The exchangeable sodium percentage (ESP) vary from 3.21 to 10.22, indicating none to slight sodicity hazards (FAO, 1988). The contents of calcium carbonate and gypsum range from 4.62 to 14.05 g kg^{-1} for the former and from 5.85 to 8.07 g kg^{-1} for the latter. The soils have a clayey texture, except the clay loam soils in high elevated decantation basin. The soil bulk density varies from 1.21 to 1.51 Mg m^{-3}. According to Soil Survey Staff (2014), the main soil subgroups are Typic Torrifluvents and Vertic Torrifluvents.

Human-induced soil degradation

Type and degree

Results in Table 4 indicate that the soils of overflow mantle are affected by a slight compaction hazard, where the values of soil bulk density (BD) in almost flat overflow mantle and gently slope overflow mantle are 1.24 and 1.28 Mg m^{-3}, respectively. However, the values of EC, ESP and water table depth (WT) are within the safe range. The soils of high elevated decantation basin are affected by slight hazards of salinity, sodicity (alkalinity) and compaction since the values of EC, ESP and Bd are 5.47 dS m^{-1}, 10.22 and 1.23 Mg m^{-3}.

TABLE 3. Main soil properties of the studied area

Unit	Profile	Area, km^2	Area, %	Slope, %	Depth, cm	pH	EC, $dS\ m^{-1}$	ESP	BD, $g\ cm^{-3}$	Texture	CEC, $cmolc\ kg^{-1}$	OM, $g\ kg^{-1}$	$CaCO_3$, $g\ kg^{-1}$	Gypsum, $g\ kg^{-1}$	Soil Taxonomy
OM1	1	53.68	6.61	0.81	150	7.15	3.75	5.97	1.24	Clay	41.89	20.13	10.45	7.38	Typic Torrifluvents
OM2	2	91.92	11.31	0.61	150	7.01	2.16	9.77	1.28	Clay	36.61	17.06	8.91	7.51	Typic Torrifluvents
DB1	3	47.27	5.82	1.19	150	7.20	5.47	10.22	1.23	Clay loam	29.91	15.02	4.62	6.56	Vertic Torrifluvents
DB2	4	85.94	10.58	0.56	150	7.11	2.15	3.21	1.51	Clay	39.16	15.92	8.86	8.07	Vertic Torrifluvents
OB1	5	55.63	6.85	0.10	150	7.26	5.02	6.05	1.21	Clay	37.81	22.59	8.46	6.01	Typic Torrifluvents
OB2	6	119.96	14.76	0.20	150	7.06	5.88	7.79	1.22	Clay	38.98	15.98	10.47	5.85	Typic Torrifluvents
RT1	7	193.59	23.83	1.91	150	7.26	3.22	6.03	1.41	Clay	41.18	19.01	8.08	6.49	Vertic Torrifluvents
RT2	8	164.49	20.25	0.20	96	7.05	5.07	9.12	1.51	Clay	38.46	18.86	14.95	7.27	Vertic Torrifluvents

OM1, almost flat overflow mantle; OM2, gently slope overflow mantle; DB1, high elevated decantation basin; DB2, Low elevated decantation basin; OB1, high elevated overflow basin, OB2, low elevated overflow basin; RT1, relatively high river terraces; RT2, relatively low river terraces; BD, bulk density; CEC, cation exchange capacity; OM, organic matter

TABLE 4. Human-induced land degradation in the studied area

Unit	Profile	Chemical degradation (C)				Physical degradation (P)				Degradation status (Type/degree/causative factor
		Salinity (s)		Sodicity (a)		Compaction (c)		Waterlogging (w)		
		Degree	Factor	Degree	Factor	Degree	Factor	Degree	Factor	
OM1	1	None	-	None	-	Slight	m	None	-	(Pc/1/m)
OM2	2	None	-	None	-	Slight	m	None	-	(Pc/1/m)
DB1	3	Slight	i, d, o	Slight	i, d, o	Slight	m	None	-	(Cs/1/i, d, o) (Ca/1/i, d, o) (Pc/1/m)
DB2	4	None	-	None	-	Moderate	m	None	-	(Pc/2/m)
OB1	5	Slight	i, d, o	None	-	Slight	m	None	-	(Cs/1/i, d, o) (Pc/1/m)
OB2	6	Slight	i, d, o	None	-	Moderate	m	None	-	(Cs/1/i, d, o) (Pc/1/m)
RT1	7	None	-	None	-	Moderate	m	None	-	(Pc/2/m)
RT2	8	Slight	i, d, o	None	-	Moderate	m	Moderate	i, d, o	(Cs/1/i, d, o) (Pc/2/m) (Pw/2/i, d, o)

i; excessive irrigation; d, imperfect drainage; o, lake of conservation measures; m, improper use of heavy machinery; 1, slight hazard; 2, moderate hazard .

On the other hand, the soils of low elevated decantation basin have a moderate compaction hazard since the value of BD is 1.51 Mg m^{-3}; however, no hazards of salinity, sodicity or water logging are detected. The soils of overflow basin are affected by slight salinity and compaction hazards. The values of EC and BD are 5.02 dS m^{-1} and 1.21 Mg m^{-3}, respectively in the high elevated decantation basin unit and 5.88 dS m^{-1} and 1.22 Mg m^{-3}, respectively in the low elevated decantation basin unit. The soils of relatively high river terraces unit have a moderate compaction hazards with BD of 1.41 Mg m^{-3}, while no hazards are associated with salinity, sodicity or water logging. The highest physical degradation is in the relatively low river terraces unit, where the BD and WT are 1.51 Mg m^{-3} and 96 cm, respectively, indicating moderate compaction and waterlogging hazards. The soils are also affected by a slight salinity hazards with an EC value of 5.07 dS m^{-1}.

Modeling land degradation

This work aimed at utilizing the geographic information system (GIS) to produce degradation map which describes the overall degradation using the inputs of salinity, sodicity, compaction and water logging. The modeling process was executed using ArcGIS 10.2.2 including the following steps (Fig. 4): (1). transforming the features of EC, ESP, BD and water table depth to raster layers, (2). reclassifying the variables to the common scale, (3). assigning a weight to each variable, (4). combining and overlaying variable, (5). using conditional tools to control the output value for each cell, (6). converting raster dataset to polygon features and (7). producing the final degradation map. The result of the spatial model shown in Fig. 5 reveals three degradation classes; strong, moderate and slight. The slightly degraded soils occupy an area of 388.83 km^2, representing 47.83% of the studied area. The strongly and moderately degraded soils cover 212.21 and 211.87 km^2 and represent 26.10 and 26.06% of the total area, respectively.

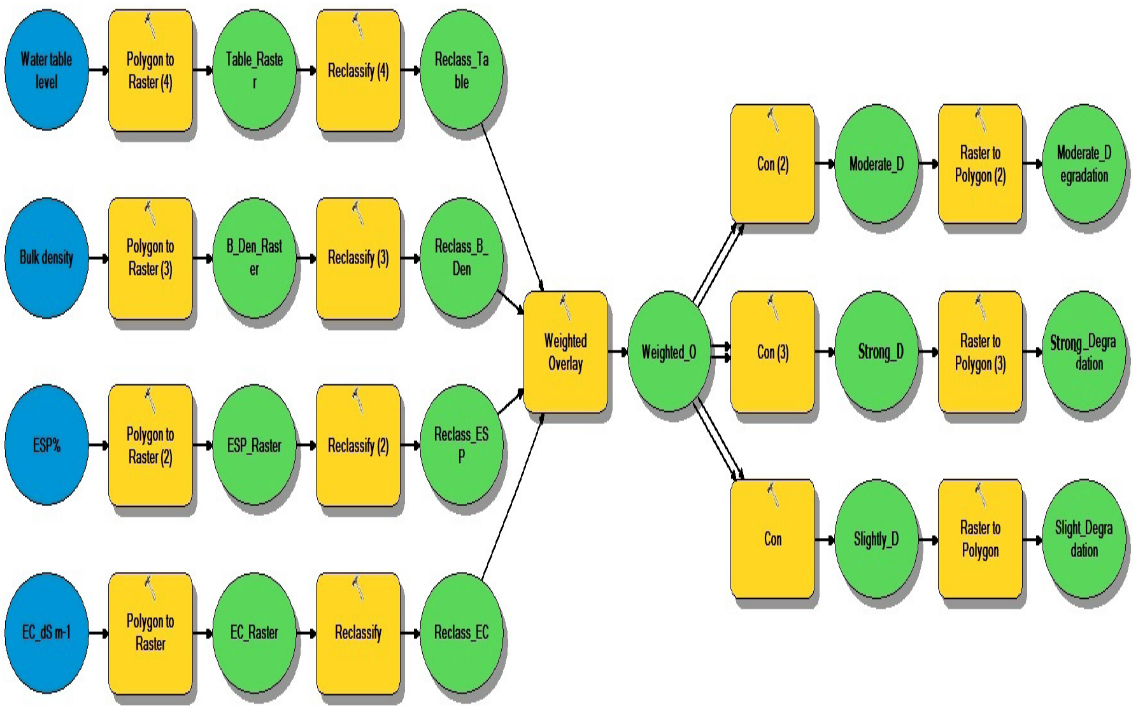


Fig. 4. Flowchart of the designed soil degradation model

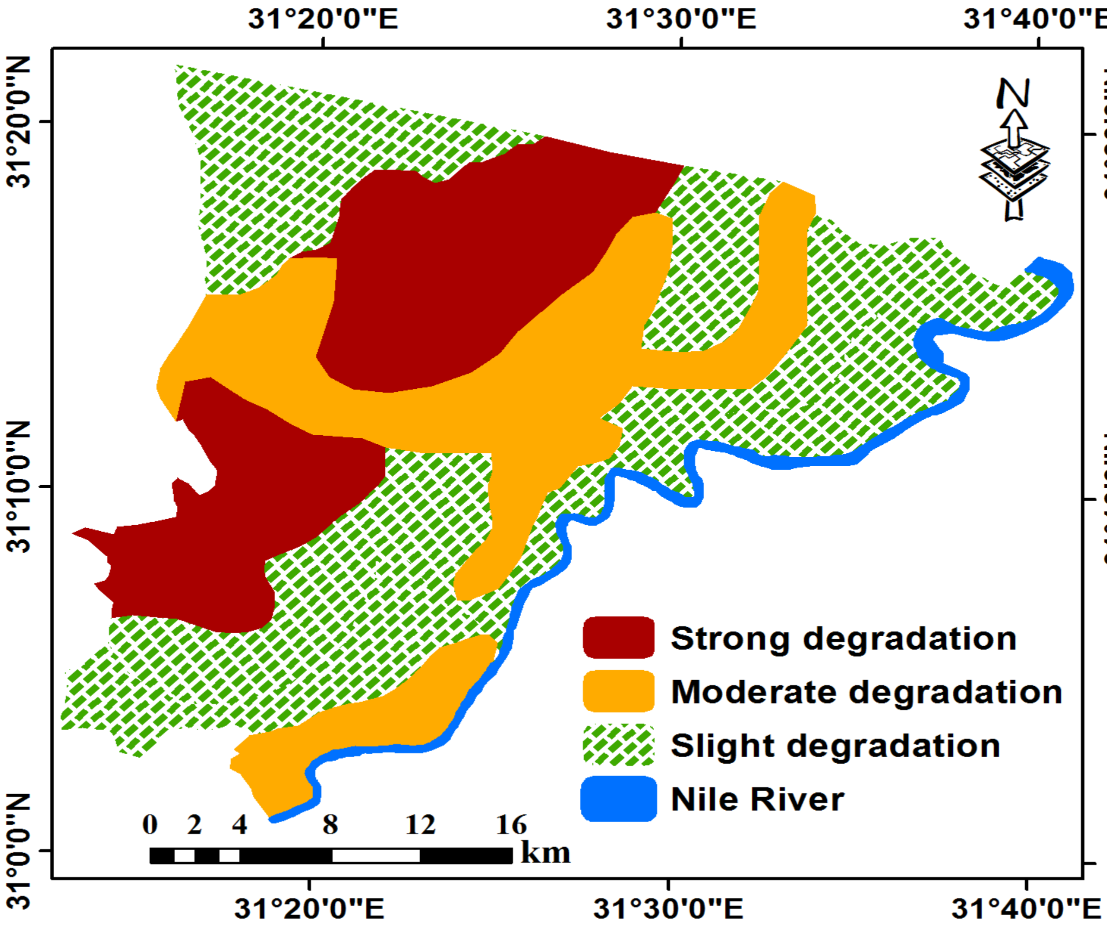


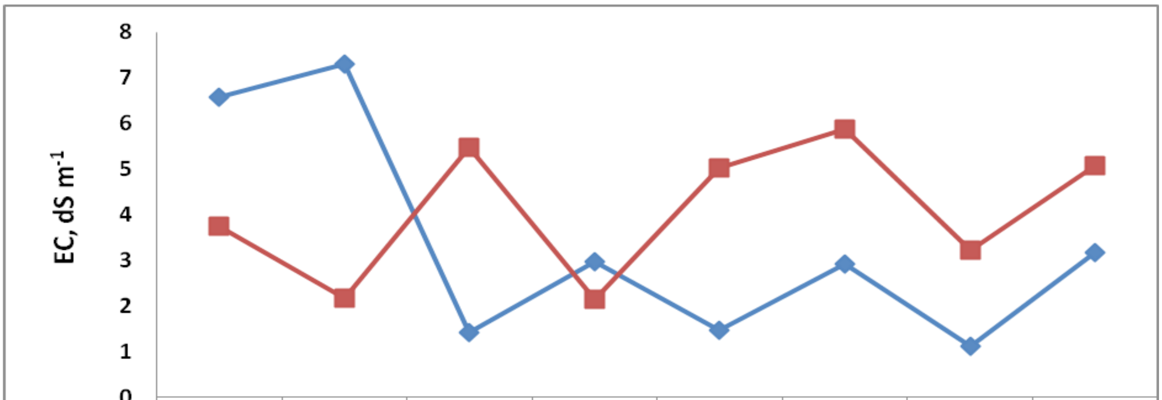
Fig. 5. Soil degradation degree of the studied area

Causative factors

The main causative factors involved in soil degradation in the area of study are related mainly to agricultural practices, which are similar in different units. The chemical degradation processes; salinity and sodicity usually result from excessive irrigation due to the use of the traditional flood irrigation (Gao et al., 2015), absence of conservation measures such as leaching requirements, and using brackish water in irrigation due to fresh water scarcity (Ali, 2011). Salinity has negative effects on crops in different ways, including reducing water availability due to osmotic effects, specific ion toxicity and/or nutritional disorders. Sodicity, on the other hand, adversely affects soil physical conditions, which leads to decreased oxygen diffusion and increased soil strength (Läuchli and Grattan, 2007). Regarding the main two types of physical degradation, soil compaction is caused mainly by the improper use of heavy machinery during tillage and harvest. It deteriorates soil structure due to reduced water and air infiltration and hindering root penetration in the soil. (Nawaz et al., 2013; Colombi and Walter, 2017). Waterlogging is abiotic stress which causes changes in soil environment due to decreased O_2 and increased levels of CO_2, NH_4, and C_2H_4. These changes reduce root respiration that inhibits root growth and limits nutrient uptake and transport to shoots, and consequently reduce the potential yield of crops (Gomathi et al., 2015). Inadequate drainage is the key factor for waterlogging in the studied area.

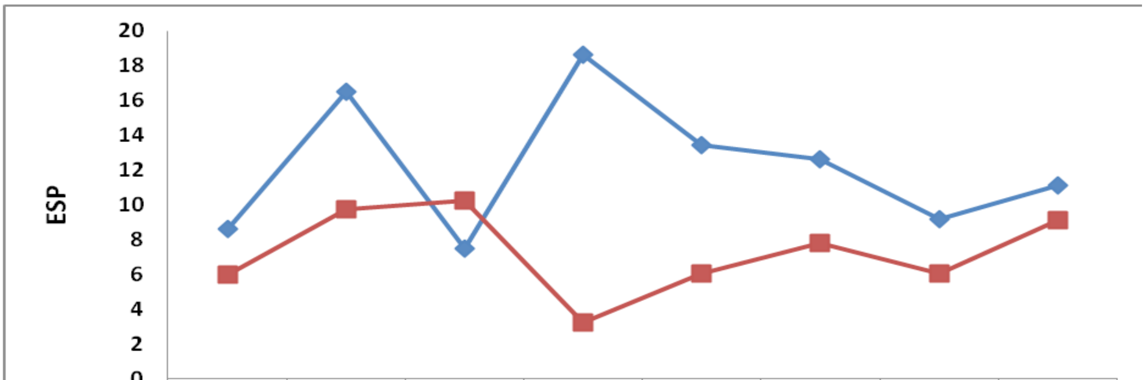
Monitoring soil degradation

The changes of EC, ESP, BD, and WT between 1976 and 2017 are shown in Fig. 6-9. The results indicate that finite changes in soil properties occurred during the last four decades. As a result, the rate of salinization, alkalinization, compaction and waterlogging is none to slight since the annual increases of EC, ESP, BD and WT do not exceed 0.5 dS m^{-1}, 0.5, 0.1 Mg m^{-3} and 1 cm per year, respectively. The data of areas affected by different degradation types are shown in Table 5.



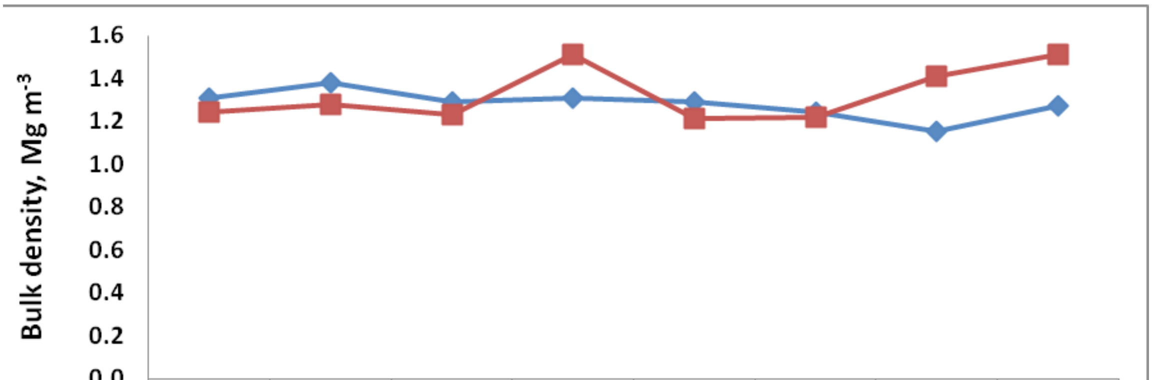
	OM1	OM2	BD1	DB2	OB1	OB2	RT1	RT2
1976	6.58	7.29	1.41	2.98	1.46	2.91	1.11	3.17
2017	3.75	2.16	5.47	2.15	5.02	5.88	3.22	5.07

Fig. 6. Changes of EC values over the mapping unit between 1976 and 2017



	OM1	OM2	BD1	DB2	OB1	OB2	RT1	RT2
1976	8.62	16.51	7.51	18.62	13.41	12.62	9.18	11.15
2017	5.97	9.77	10.22	3.21	6.05	7.79	6.03	9.12

Fig. 7. Changes of ESP values over the mapping unit between 1976 and 2017



	OM1	OM2	BD1	DB2	OB1	OB2	RT1	RT2
1976	1.31	1.38	1.29	1.31	1.29	1.24	1.15	1.27
2017	1.24	1.28	1.23	1.51	1.21	1.22	1.41	1.51

Fig. 8. Changes of bulk density over the mapping unit between 1976 and 2017

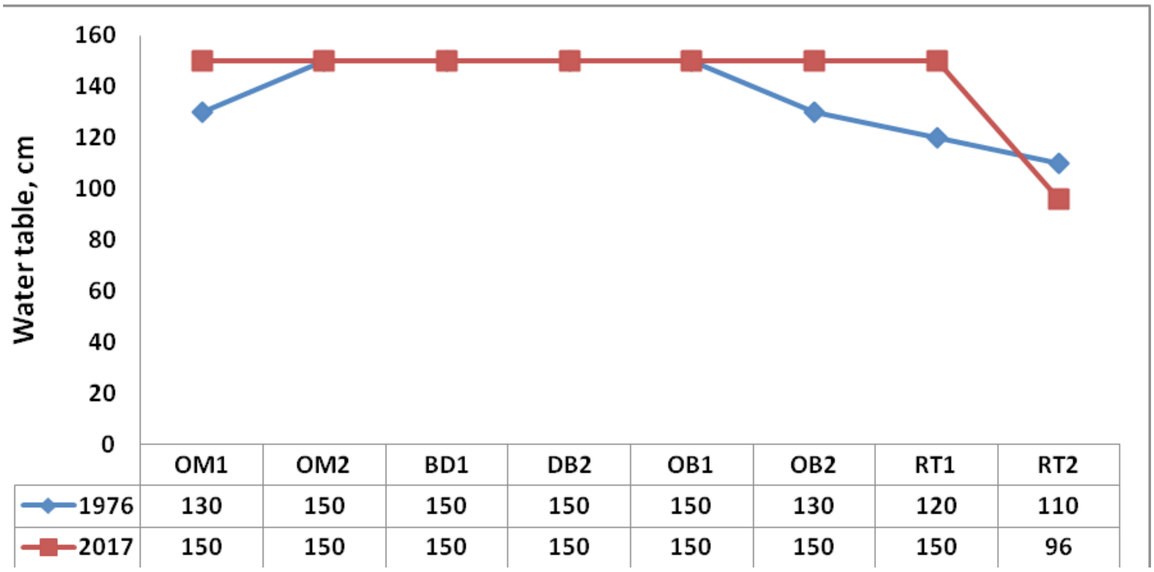


Fig. 9. Changes of soil water table depth over the mapping unit between 1976 and 2017.

TABLE 5. Changes in land degradation between 1976 and 2017 .

Type	Criteria	Indicator	Range	Area in 1976		Area in 2017		Differences	
				km²	%	km²	%	km²	%
Chemical degradation	Salinization	EC, dS m^{-1}	< 4	666.87	82.08	425.13	52.33	241.74	29.75
			4--8	145.60	17.92	387.34	47.67	-241.74	29.75
			8--16	0.00	0.00	0.00	0.00	0.00	0.00
			16--32	0.00	0.00	0.00	0.00	0.00	0.00
			> 32	0.00	0.00	0.00	0.00	0.00	0.00
	Alkalinization	ESP	< 10	294.53	36.25	765.20	94.18	-470.67	57.93
			10--15	517.93	63.75	47.27	5.82	470.67	57.93
			15--30	0.00	0.00	0.00	0.00	0.00	0.00
			30--50	0.00	0.00	0.00	0.00	0.00	0.00
			> 50	0.00	0.00	0.00	0.00	0.00	0.00
Physical degradation	Compaction	Bulk density, Mg m^{-3}	< 1.2	193.59	23.83	0.00	0.00	193.59	23.83
			1.2--1.4	618.88	76.17	368.45	45.35	250.43	30.82
			1.4--1.6	0.00	0.00	444.02	54.65	-444.02	54.65
			1.6--1.8	0.00	0.00	0.00	0.00	0.00	0.00
			> 1.8	0.00	0.00	0.00	0.00	0.00	0.00
	Water logging	Water table depth, cm	> 150	280.75	34.56	647.98	79.75	-367.23	45.20
			150--100	531.72	65.44	0.00	0.00	531.72	65.44
			100--50	0.00	0.00	164.49	20.25	-164.49	20.25
			50--30	0.00	0.00	0.00	0.00	0.00	0.00
			< 30	0.00	0.00	0.00	0.00	0.00	0.00

Results reveal that soils having no salinity hazards (EC < 4 dS m^{-1}) decreased by 29.75%, while soils with slight hazards (EC of 4-8 dS m^{-1}) increased by 29.75% due to improper irrigation practices. Soils having ESP lower than 10 (no hazard) increased by 57.93%, while those with slight hazards (ESP of 10-15) decreased by 57.93%. These favorable changes may be attributed to addition of organic amendments and gypsum. The areas of safe compaction limit (Bd less than 1.2 Mg m^{-3}) decreased by 23.83%. The soils affected by slight hazards (Bd of 1.2-1.4 Mg m^{-3}) decreased by 30.82%, while those affected by moderate hazards (Bd of 1.4-1.6 Mg m^{-3}) increased by 54.65%. Increased compaction hazards results mainly from the intensive use of heavy machinery. The soils with water table depth of more than 150 cm increased by 45.20%. The soils lying in the range of water table of 150-100 cm (slight waterlogging hazards) decreased by 65.44%, while those lying within the range of 100-50 cm (moderate hazards) increased by 20.25%. Considerable attentions paid to the drainage contribute to alleviating waterlogging hazards.

Degradation risk

The natural vulnerability of soil degradation was assessed considering climatic, topographic and soil (depth and texture) factors as shown in Table 6. The slope gradient in the study area lies between 0.10 and 1.91% that pose a slight impact on the natural vulnerability. Hence, the topographic effect was set as 1.0 in the different unit. The obtained results indicate that the chemical risk ranges from 0.10 to 0.30, indicating low risk. The lowest value is in the high elevated decantation basin unit, where the soils have medium soil texture and very deep profile. The highest value is in the relatively low river terraces, where the soils have a fine texture and moderately deep profile. On the other hand, the area is affected by a very high physical degradation risk sine the risk value varies from 7.26 to 7.88.

TABLE 6. The risk of soil degradation in the studied area

Unit	Profile No.	Chemical degradation					Physical degradation				
		Cr	Sr	Tr	Risk	Class	Cr	Silt/Clay	Tr	Risk	Class
OM1	1	0.10	1.50	1.00	0.15	Low	8.75	0.83	1.00	7.26	Very high
OM2	2	0.10	1.50	1.00	0.15	Low	8.75	0.85	1.00	7.44	Very high
DB1	3	0.10	1.00	1.00	0.10	Low	8.75	0.90	1.00	7.88	Very high
DB2	4	0.10	1.50	1.00	0.15	Low	8.75	0.85	1.00	7.44	Very high
OB1	5	0.10	1.50	1.00	0.15	Low	8.75	0.83	1.00	7.26	Very high
OB2	6	0.10	1.50	1.00	0.15	Low	8.75	0.87	1.00	7.61	Very high
RT1	7	0.10	1.50	1.00	0.15	Low	8.75	0.84	1.00	7.35	Very high
RT2	8	0.10	3.00	1.00	0.30	Low	8.75	0.85	1.00	7.44	Very high

Cr, climatic rating; Sr, soil rating; Tr, topographic rating; chemical risk = Cr*Sr*Tr; physical risk = Cr*(silt/clay)*Tr; risk classes are low (risk < 2), moderate (risk = 2-4), high (risk = 4-6) and very high (risk > 6).

Conclusion

Soils of the studied area are threatened by slight hazards of salinity and alkalinity, slight and moderate hazards of compaction and moderate hazards of waterlogging. The GIS spatial model shows that approximately half of the area is affected by slight degradation hazards, while the other half is affected by strong and moderate hazards. These hazards are attributed mainly to excessive irrigation, absence of conservation measures, improper use of heavy machinery and inadequate drainage. The area is subjected to none to sight rate of human-induced (anthropic) soil degradation during the last four decades. The risk of soil degradation indicates that the soils are affected by a low chemical risk but a very high physical risk. The area needs effective and popper land management practices to attain sustainable agriculture.

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تقييم تدهور أراضي السهل الفيضي في شمال شرق دلتا النيل – مصر

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الهدف من هذه الدراسة هو الوقوف على حالة ومخاطر تدهور التربة في بعض مناطق شمال شرق دلتا النيل - مصر. تم تمثيل الوحدات الأرضية المختلفة بالمنطقة بعدد ٨ قطاعات أرضية جمعت منها عينات التربة وأجريت عليها التحليلات اللازمة. وجد أن المنطقة معرضة لأخطار الملوحة، الصودية، الإنضغاط والغدق المائي بدرجات متفاوتة وأن هذه الأخطار ناتجة عن الممارسات البشرية الغير رشيدة مثل الري الزائد، غياب تدابير الصيانة اللازمة، الإستخدام المفرط للمعدات الزراعية الثقيلة والصرف الغير كافي. أظهر النموذج المكاني لنظم الملعومات الجغرافية أن ٤٧,٨٪ من الأراضي متأثرة بتدهور طفيف في حين أن ٥٢,٨٪ متأثرة بتدهور قوي ومتوسط بالتساوي. لم تتعرض الأراضي المدروسة لتغيرات شديدة في حواص التربة خلال الأربعة عقود الماضية مما أدى إلى إنخفاض معدل التدهور. تشير بيانات خطر التدهور أن حدود التدهور الكيميائي في المنطقة أمنة، ولكن المخاطر الفيزيائية عالية جداً. لتحقيق الزراعة المستدامة في المنطقة يجب إتباع التدابير الوقائية التي ترفع من مقاومة التربة للتدهور.