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A Time Series Investigation to Assess Climate Change and Anthropogenic Impacts on Quantitative Land Degradation in the North Delta, Egypt

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Abstract: In the current study the processes of soil deterioration over the past five decades was evaluated. Land degradation risk, status, and rate were assessed in Kafr El-Sheikh Governorate, Egypt, in 2016 using OLI and ETM (2002) remote sensing data, and soil data from 1961.A quantitative deterioration was produced based on the comparative study approach in the integrated weighted sum, weighted overlay, and fuzzy model. The parameters used were soil depth, texture, pH, EC, OM, SAR, ESP, CEC, $CaCO_3$, BD, N, P, K. The variables were based on the measurements derived from the Universal Soil Loss Equation (USLE). The results of the implemented USLE in the GIS model-builder revealed the prevalence of severe soil deterioration processes in the region, and include four main deterioration risks: water-logging, soil compaction, salinization, and alkalization. During 2002–2016, soil sealing took place on 36,297.87 ha of the study area (9.7% of the total area). Urban sprawl was one of the most noticed problems that became apparent during the fieldwork during the inventory of land resources in the investigation area. Soil sealing is one of the hidden manifestations of desertification, and it is the implicit explanation for the lost land for the agricultural production process. The study showed that the investigated soil, as a part of north Nile Delta, is a very fragile system that needs to be protected, especially under the effect of climate change in areas overloaded with population, and because of their negative effects on soil properties. According to the results of this study, it is recommended that the same approach be applied to similar agricultural semi-arid regions to help in building a database of land resources for agricultural use that will be very useful for the decision-maker to monitor changes on agricultural lands.

Keywords: climate changes; dynamic land degradation; ArcGIS model builder; remote sensing

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1. Introduction

Soil is the product of interacting effects of multiple environmental controls, combined in specific geographical/historical backgrounds to produce highly improbable (i.e., unlikely to be duplicated) outcomes. Consequently, soil degradation represents a global environmental and developmental concern [1]. Up-to-date, quantitative information is required to provide policy recommendations and to properly plan action to increase food security and food safety, stimulate economic development, ensure water security, maintain environmental integrity and conserve resources [1]. Therefore, land degradation is defined as a long-term deterioration in ecosystem services in terms of net primary productivity. The main land degradation processes are degradation of vegetative cover, wind and rainfall-induced erosion, salinization, reduction of soil organic matter content, soil crusting and compaction, and presence of toxic substances [2]. In addition, they differentiate between factors (variables) and processes (forms) of degradation in soils. Degradation processes of

soils incorporate forms of biological, physical and chemical inter-actions, which influence the soil's capacity for self-regulation and its production efficiency. Whereas degradation factors (variables) of soils are components of human-induced, natural agents, and catalysts that set those forms in motion and movement, driving to changes in soil characteristics and its life-support properties. Changes in soil properties resulting from physical degradation include hydrological or physical characteristics which lead to changes in soil physical properties, which have negative effects on environmental quality, crop growth, and animal production, which in turn negatively affect farm income. Soil degradation is defined as a quality reduction of soil, whereby its actual and/or potential productivity and/or capability decrease in uses as a multi-purpose resource, as a consequence of both human-induced and natural causes [3–8]. Many studies have indicated that the most important natural processes of land degradation are fragipan and clay pan formation, laterization, and hard-setting [4]. The processes and effects on soil for increasing the production determination are soil compaction, salt accumulation and nutrient leaching, accelerated erosion, desertification, and acidification. During the last fifty years, the quick populace development in Egypt has caused an extraordinary request for nourishment and other agrarian items. Since 50% of the food needs were generated locally, much attention has been paid to expanding the production from agriculture in Egypt. This can be achieved through two main strategies, which comprise reclamation of vast desert areas to be productive land, and the intensive cultivation of productive land using high technology management. In both cases it is of paramount importance to obtain information on soil properties and the distribution of these properties in these areas. Therefore, there is a need to build a framework that can provide accurate, valuable and timely data on soil and water to decision makers and policy planners. In Egypt, the problems caused by soil deterioration are not only serious but also far-reaching in terms of the affected regions and the millions of individuals who suffer from its consequences [3,5–20] related to climate changes and also to the conditions under which the small Egyptian farmers have to live and work. Land degradation severity can be efficiently monitored from multi-temporal satellite images. Environmental sensitivity could assess the response of the environment to any change in one or more external factors. The Mediterranean Desertification and Land Use (MEDALUS) model focuses on recognizing environmentally sensitive areas (ESAs) that reveal different sensitivity to desertification through multi-factor approaches. To define the ESA index (ESAI) four qualities are evaluated: soil, climate, vegetation, and management. Through this model, more attention can be given to areas which are most vulnerable to degradation. This model is simple, robust, adaptable, and widely applicable in the Mediterranean region [21]. Three general types of ESAs to desertification can be distinguished: critical, fragile, potential ESAs—besides the non-sensitive areas. The northern part of the Nile Delta, located between the Rosetta and Damietta branches, is formed from coastal, alluvial and lacustrine deposits. Most of this area is affected by much soil degradation, i.e., salinity, alkalinity, poor drainage, wind and water erosion and compactions. On the other hand, there are many on-land reclamation processes and soil conservation performance as addition of amendments (gypsum, super phosphate, sulphur), tile drainage, sub-soiling, etc. The satellite images and Geographic Information System (GIS) are tools developed to save time and money in soil studies and to give more accurate results for soil mapping. Consequently, different remote sensing and GIS data were used in this study to investigate and to evaluate the soils of the studied area and monitor soil degradation.

The effect of climate change on soil is a complex and slow process because the soil is severely influenced not only by direct climate change (e.g., the effect of temperatures on the decay of soil organisms) [22]. Soil organic matter (OM) was subjected to decay as a result of climate change, resulting in a reduction in the stability of the soil layer and the rate of water infiltration, and in an increase in the danger of congestion, water flow, and erosion [23]. The fastest chemical or mineral changes caused by climate change might include salt loss and nutrient intake as leakage rises, and salinity in water when total water movement occurs owing to greater evaporation or less rainfall or irrigation water. The composition of

the mineral clay, according to the mineralogy of the coarse particles, will usually change slightly over time. Changes in the surface characteristics of the clay particle are often slower than changes in pile formation or crystalline structure, which occur significantly more quickly. Such environmental changes have a significant impact on the physical and chemical characteristics of the soil [24–26].

Determination of the land degradation status could be considered the cornerstone of any agricultural development program, in which recognizing its various types is a necessity for taking sound scientific and practical measures to combat it and preserve the agricultural soil in a proper and maintainable manner. The current work aims to assess soil degradation in the last five decades from 1961 to 2016. This was achieved by building a database of land resources for agricultural use and building a new land degradation assessment model.

2. Materials and Methods

2.1. Study Area

The study area is located in the administrative borders of Kafr El-Sheikh Governorate (Figure 1), which is famous for agriculture, especially rice in the north part of the governorate. The entire area (3.748 km^2) is located in the north of the Nile delta and overlooks the Mediterranean Sea. It extends a distance of 100 km between the two branches of the Nile on the coast of the Mediterranean Sea, and is bordered by the Rashid River branch on the western side with a length of 85 km. It is bounded on the eastern side by the Dakahlia Governorate, and its borders from the southern side are the Gharbia Governorate. Kafr El-Sheikh Governorate is famous for the cultivation of cotton, rice, corn and wheat crops. These crops are irrigated with water from the lake behind the Zefta Barrage located on the Damietta River branch of the Nile. In the early eighties, sugar beet was introduced to the governorate, and at that time fish farming began. It is also mentioned that the two cities of Desi Bella are among the most important cities whose industries are related to agricultural products, such as the cotton industry, rice milling, and the sugar beet industry. There are also other industries in the capital, Kafr El-Sheikh.

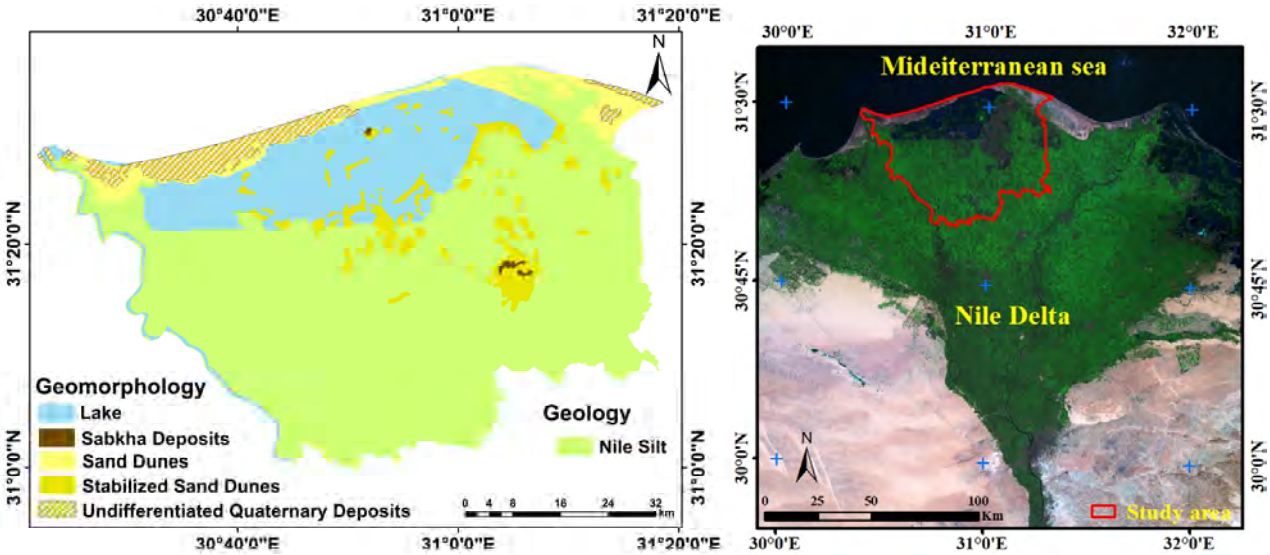

Figure 1. Geomorphology associated with geology (after [27] Conoco (1987)). Location map of the study area.

The study area is located north of the Nile Delta in Egypt. The soil of the Nile River Delta is considered one of the areas rich in nutrients, due to the silt deposits (mud) resulting from the flow of the Nile River [27]. Branches of the Nile River spread to the Mediterranean Sea. In ancient times, the frequent floods of the river led to the spread of silt in the vicinity of the Nile Delta, which led to an increase in its area east and west. It has two main branches: Al-Rashid in the west, and Damietta in the east [27]. Figure 1 shows geomorphology

associated with geology: (1) Nile silt occupies the largest area with fine-grained sediment (silt and clay) deposited from suspension on a flood plain by floodwaters that cannot be contained within the stream channel. (2) Quaternary marine deposits are common on lower parts of the present land surface (such as carbon deposits and gypsum metal) and terrestrial deposits are common on higher parts of the present sea floor. (3) Sabkha deposits are salt-flat soils that are flat and very saline areas of sand or silt lying just above the watertable and often contain soft nodules and enterolithic veins of gypsum or anhydrite. (4) Sand dunes are a ridge of sand created by the wind and are found in deserts or near lakes and oceans. (5) Stabilized dunes are areas where wind moves the dunes inward from the lake. If the sand dune is stabilized by vegetation such as this dune slope, movement is halted.

2.2. Remote Sensing Data and Image Processing

Satellite images for the study area in 2002 and 2016 were used for the visual interpretation of land degradation, while supervised classification was used to extract the land use/land cover (LULC) classes. Both satellite images have a spatial resolution of 30 m and can cover the area with one scene.

The recent administrative boundary of Kafr El-Sheikh Governorate was used to subset the area from the satellite Images. Then supervised classification techniques in ENVI software were applied, using the combination of selected bands that accurately help to visually separate the targeted LULC classes. The ETM 2002 satellite imagery was processed using a band combination of 4 (NIR), 5 (MIR), and 3 (Red), whereas the Landsat 8 imagery (OLI/TIRS 2016) was processed using a band combination of 5-6-4. The distinct LULC classes in the area were detected using a supervised technique. Using this method, four LULCs were identified: agricultural land, dunes, fish farm, lake, and urban. Different training sets were assigned for each LULC class before executing the supervised classification for each image, and then confirmed using hundreds of ground truth points taken from the field in 2016 from particular places that shared the same locations in the 2002 and 2016 images. A signature file was constructed for each date based on the training samples and the separability analysis within each class. The implementation of these hundred points were used to create the classified LULC thematic maps for each assigned date using the resulted signature file (2002 and 2016).

The detail on satellites used, the kind of images, and their bandwidths are indicated in Table 1. The source of the images is from https://www.usgs.gov (accessed on 30 June 2016). ENVI software was used to process and analyze the images.

Table 1. Criteria of the satellite images used for years 2002 and 2016.

Landsat 7 Enhanced Thematic Mapper Plus (ETM+) for the Year 2002			Landsat 8 Operational Land Imager (OLI) and Thermal Infrared Sensor (TIRS) for the Year 2016		
Bands	**Wavelength (mm)**	**Resolution (m)**	**Bands**	**Wavelength (mm)**	**Resolution (m)**
Band 1—Blue	0.45–0.52	30	Band 1—Ultra Blue (coastal/aerosol)	0.435–0.451	30
Band 2—Green	0.52–0.60	30	Band 2—Blue	0.452–0.512	30
Band 3—Red	0.63–0.69	30	Band 3—Green	0.533–0.590	30
Band 4—NIR	0.77–0.90	30	Band 4—Red	0.636–0.673	30
Band 5—SWIR 1	1.55–1.75	30	Band 5—NIR	0.851–0.879	30
Band 6—Thermal	10.40–12.50	60 * (30)	Band 6—SWIR 1	1.566–1.651	30
Band 7—SWIR 2	2.09–2.35	30	Band 7—SWIR 2	2.107–2.294	30
Band 8—Panchromatic	0.52–0.90	15	Band 8—Panchromatic	0.503–0.676	15

Table 1. *Cont.*

Landsat 7 Enhanced Thematic Mapper Plus (ETM+) for the Year 2002			Landsat 8 Operational Land Imager (OLI) and Thermal Infrared Sensor (TIRS) for the Year 2016		
Bands	**Wavelength (mm)**	**Resolution (m)**	**Bands**	**Wavelength (mm)**	**Resolution (m)**
* ETM+ Band 6 is acquired at 60 m resolution, but products are resampled to 30 m pixels.			Band 9—Cirrus	1.363–1.384	30
			Band 10—Thermal 1	10.60–11.19	100 * (30)
			Band 11—Thermal 2	11.50–12.51	100 * (30)
			* TIRS bands are acquired at 100 m resolution, but are resampled to 30 m in delivered data product.		

2.3. Fieldwork and Laboratory Analysis

The soil survey was conducted with a semi-detailed survey by combining remote sensing data and field visits to identify different soil patterns. DEM SRTM 30 m is preprocessed to generate terrain to represent the height of the ground surface to extract the landform units used in the field visit. Longitudes and latitudes, as well as elevation, are defined in the field by using GPS "System Corporation MAGELLAN"—GPS NAV DLX-10 TM for recognizing the soil profile location within the studied area. Sixty soil profiles were generated up to depth of soil water in the study area (Figure 2). Detailed morphological descriptions were carried out following the guidelines for soil description, which include various surface characteristics, i.e., coordinates, elevation, slope, topography, landform, vegetation, parental material, land use, drainage, and different soil layers [28]. Description of soil profile layers was carried out in the field, and includes: color, texture, structure, consistency, cementation and compaction, roots, and all other features recognized in each layer. Soil samples were collected from each described layer according to the morphological features to determine the physical and chemical characteristics, i.e., soil depth, texture, pH, EC, OM, SAR, ESP, CEC, $CaCO_3$, BD, N, P, K. A total of 213 soil samples were collected from the different horizons of each profile and the appropriate laboratory analyses were executed.

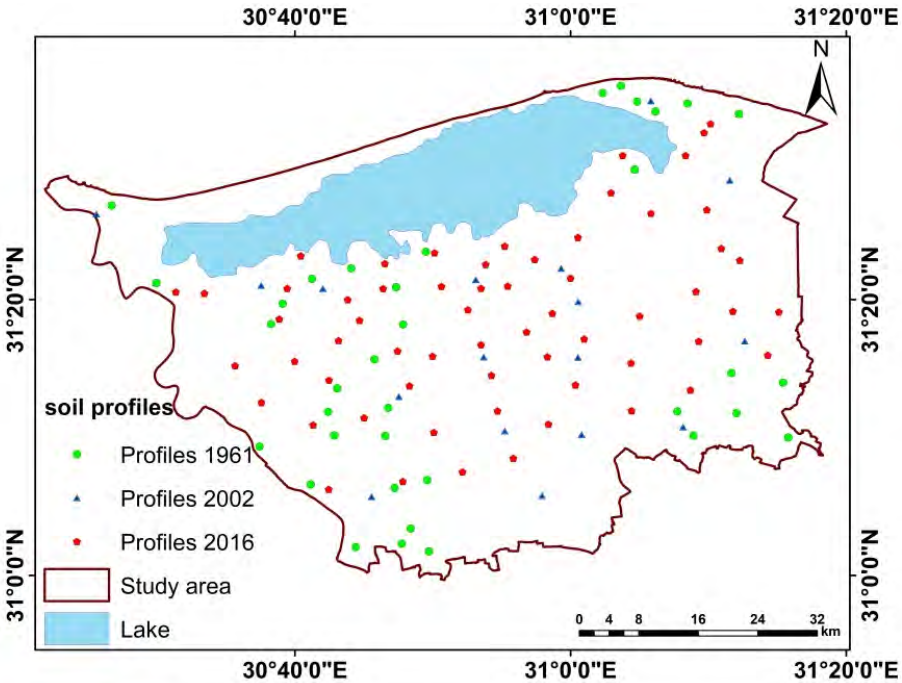

Figure 2. Location of the soil profiles in the study area.

2.4. Preparation of Soil Samples and Methods of Analysis

The soil samples collected in 2016 were air-dried, gently crushed, sieved through a 2 mm sieve and kept for analysis. Fractions of less than 2 mm were subjected to the following analyses.

Particle size distribution was analyzed after the following pretreatments: removal of carbonates using HCl, removal of organic matter using H_2O_2, and removal of soluble salts by leaching using distilled water. Sodium hexameta-phosphate (EDTA) was used as a dispersing agent, and then the pipette method was carried out to determine the % clay, % silt, and % sand [29]. Total calcium carbonate was determined by Collin's calcimeter [30]. Organic matter content was determined according to Nelson and Sommers [31]. Soil reaction (pH) was determined in the soil paste using the Beckman pH meter. The electrical conductivity (EC) of the saturated soil paste extract was carried out according to Black (1985) [32]. The saturation of soil water extract components was determined, including the carbonates and bicarbonates, by titration using phenolphthalein and bromocresol green as indicators [33]; the chlorides using Mohr's method [33]; the sulphates were calculated by the difference between the total cations and anions. Calcium and magnesium were determined by the versenate (EDTA) method using ammonium chloride as a buffer and EBT as an indicator for calcium [33]. Sodium and potassium were determined photometrically using a Perkin Elmer flame photometer [33].

2.5. Soil Classification

Soils were categorized from soil order through soil family according to the keys of Soil Taxonomy, and soil taxa were interpreted and presented according to the Soil Survey Manual [34].

2.6. Active Land Degradation Assessment

This study is based on the comparison between the data extracted from the Survey Report of the Ministry of Agriculture [35–37] and the analysis of the recent remote sensing validated by field trip missions taking place in 2016. The FAO/UNEP [38] and UNEP Staff [39] approach methodologies were applied for assessing soil degradation.

2.7. Quantitative Land Degradation Assessment

A quantitative assessment for the soil degradation method was applied after the Universal Soil Loss Equation (USLE) for four land degradation processes: salinity, alkalinity, compaction, and waterlogging. The criteria were used to determine the degree, class, and rate of different types belonging to land degradation, as shown in Tables 2 and 3.

Table 2. Criteria used to determine the degree of different types of degradation after FAO/UNEP [2].

Criteria/Degradation Type	Indicator	Unit	None1	Slight2	Moderate3	Severe4
Salinization	ECe	dS m^{-1}	<4	4–8	8–16	16–32
		Class	Non	Slight	Moderate	Severe
Alkalization	ESP	%	<10	10–15	15–30	30–50
		Class	Non	Slight	Moderate	Severe
Compaction	Bulk density	g m^{-1}	<1.2	1.2–1.4	1.4–1.6	>1.6
		Class	loose	Slight	Hard	Very hard
Waterlogging	Waterlogging	cm	>150	150–100	100–50	<50
		Class	Non	Slight	Moderate	Severe

Table 3. Criteria used to determine the classes and rates of different types of degradation after FAO/UNEP [2].

Chemical Degradation	Salinization/Increase in EC dS m^{-1} y^{-1}	Alkalinization/Increase in ESP % y^{-1}
Non to slight	<0.5	<0.5
Moderate	0.5–3	0.5–3
High	3–5	3–7
Very high	>5	>7
Physical Degradation	**Compaction (Increase in Bulk Density g $cm^{-3}y^{-1}$)**	**Waterlogging (Increase in Water Table per cm y^{-1})**
Non to slight	<0.1	<1
Moderate	0.1–0.2	1–3
High	0.2–0.3	3–5
Very high	>0.3	>5

2.8. Spatial Modeling for Land Degradation

GIS supports studies of land degradation by providing a good platform of data base storage, modeling, presentation of results and development of a user-friendly interface. Combined with GPS, the navigation of degradation areas can easily be evaluated. The spatial models were created using ArcGIS 10.5, a software from ESRI, using the Model Builder extension. Model Builder adds utility to ArcGIS; in particular, a model window provides advanced techniques for extending software capabilities, by allowing the user to design and share your models as tools and to create and implement simple workflows. Within the model document, users create models. The diagrams represent model processes, as shown afterwards in Figure 3. These processes are defined as chained model nodes depicting input data, geo-processing functions, and output or derived data. Each type of model node is represented as a distinctly shaped and colored icon. Using the Model Builder in ArcGIS, a model was developed for each of the respective land degradations in the years examined. Once the land degradation variables of each model were determined by the USLE for each type, all input shape files of the land degradation types were converted to discrete grid formats using the vector conversion functions. Grid files are composed of pixels, to which one can assign different values.

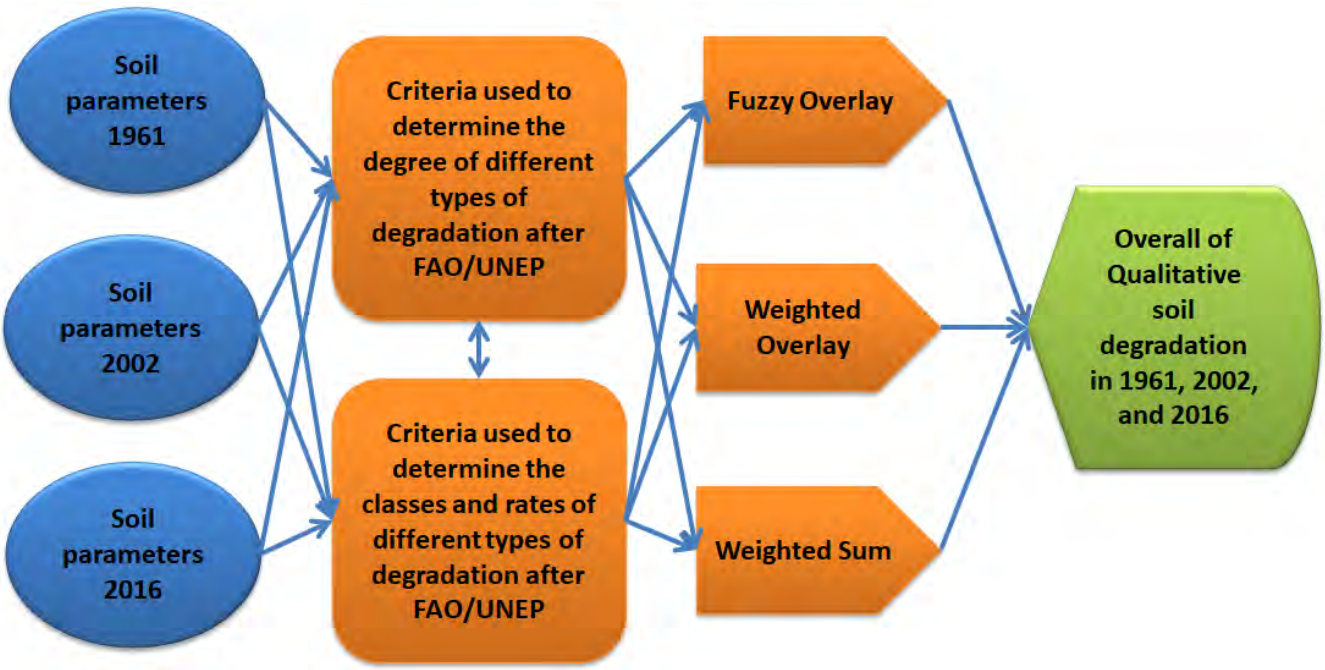

Figure 3. Model builder for overall qualitative soil degradation in 1961, 2002, and 2016.

3. Results and Discussions

3.1. LULC Classes Using Supervised Classification

The different LULC classes were extracted from the satellite images from2002 and 2016 and the results obtained are presented in Table 4 and Figures 4 and 5.

Table 4. The percentage of area coverage for LULC classes in 2002 and 2016.

LULC Classes	2002 (%)	2016 (%)
Agricultural Land/Natural Vegetation	72	68
Dunes/Sabkha/Sand Sheet	9	6
Fish Farm	6	10
Burullus Lake	8	6
Urban	5	10

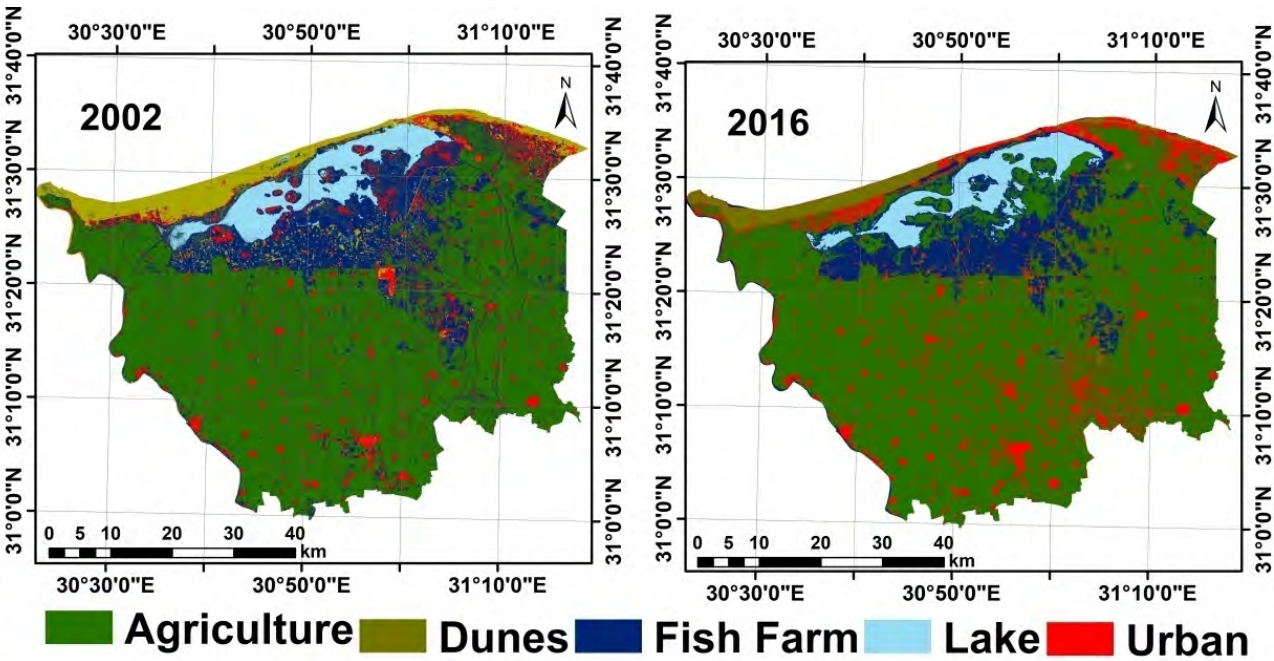

Figure 4. The land use/land cover classification maps in years of 2002 and 2016.

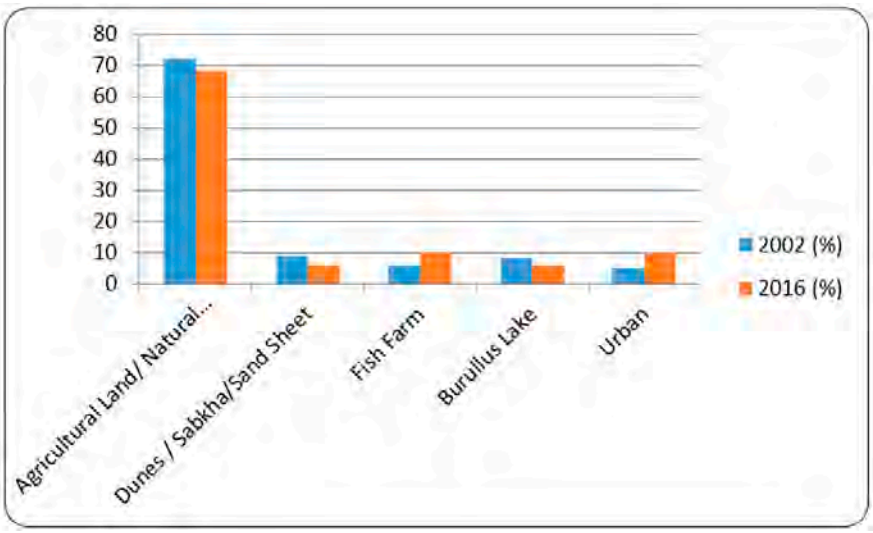

Figure 5. The percentage for each LULC class from 2002 and 2016.

During the classification processes, it was difficult to differentiate some categories of land use, such as plants in agricultural land and natural plants, so they were combined into one classification called agriculture. Similarly, it was also difficult to differentiate between sand dunes, sabkha and sand in one category, namely the Dunes. Despite the efforts of the Egyptian state to prevent construction on agricultural lands, an increase in urbanization on agricultural lands was observed in the period between 2002 and 2016 at the expense of agricultural lands. Where the capacity of agricultural land declined by 4%, all came as a result of the increase in urbanization expansion in the region.

The LULC-classified maps underwent an accuracy assessment examination using overall accuracy and the Kappa coefficient. The overall classification accuracies for the dates studied are 0.96 and 0.97 for agriculture; for dunes they are 0.90, 0.91; for fish farm, 0.95 and 0.96, and for urban, 0.92 and 0.93 for the years 2002 and 2016, respectively, which indicates a high accuracy for all classified maps. Additionally, the overall Kappa statistics are 0.95, 0.90, 0.94, and 0.92 for 2002, and 2016, respectively.

3.2. Physiographic and Soil Units in the Area

Building the physiographic map was based on an interpretation of the slope derived from the Digital elevation model (DEM SRTM 30 m) overlapped with satellite images and integrated with field work survey and analytical data. It reveals that the study area contains three main classes: flood plain, lacustrine deposits, and coastal plain. The field studies and laboratory analyses of the collected soil samples resulted in the characteristics shown in the Table 5. A significant decrease of 3% of total area from the area coverage of the Dunes, Sabkha and Sand Sheet classes, is referred to by Dunes in Figure 4. This change was due to the continuous reclamation processes over the non-cultivated areas and urban encroachment as well. The area covered by the lake water decreased by 2% between 2002 and 2016, in complete contrast to the area cover of the water of fish farms, which increased by 4% of the total area.

Table 5. Soil properties in the study area.

Characteristics	Soils of Flood Plain	Soils of Lacustrine Deposited	Soils of Coastal Plain
Texture	Clay for all profiles	Sandy clay loam and loamy sand	Sandy soils
Depth & Drainage	Moderately deep to deep soils	Moderately deep to deep soils & poor and moderately to well-drained	Very deep
Structure	Moderate-to-strong structure evolution and blocky to massive and columnar. The consistence is slightly hard when dry, slightly sticky and slightly plastic.	Moderate-to-strong structure evolution and blocky to massive and columnar. The consistence is slightly hard when dry, slightly sticky and slightly plastic.	Single grain. The consistence is hard when dry, non-sticky and non-plastic.
Horizon boundary	Diffuse smooth boundary	Diffuse smooth boundary	Clear and diffuse smooth boundary
Bulk density	1.30 and 1.47 g cm^{-3}, increases with depth		
$CaCO_3$ content	1.04 to 5.38%	0.46 to 3.97%	0.21 to 1.24%
pH	8.00 to 8.60	7.80 to 8.50	7.1 to 8.8
ECe	0.99–7.90 dS m^{-1}	1.58–79.0 dS m^{-1}	1.38–3.36 dS m^{-1}
Dominated cation	Dominated by Na^+ cation followed by Ca^{2+} or Mg^{2+} cations alternately, while K^+ cation is the least soluble component.	Dominated by Na^+ cation followed by Ca^{2+} and Mg^{2+} cations, while K^+ cation is the least soluble component.	Dominated by Na^+, Mg^{2+}, Ca^{2+}, while K^+ cation is the least soluble component.
Dominated Anion	Dominated by Cl^- ion or $SO_4{}^{2-}$ ion alternately followed by $HCO_3{}^-$. Thus, sodium chloride or sodium sulfate seems to be dominating in these soils.	Cl^- ion followed by $SO_4{}^{2-}$ ion and $HCO_3{}^-$	Cl^- ion followed by $SO_4{}^{2-}$ and by $HCO_3{}^-$

Table 5. *Cont.*

Characteristics	Soils of Flood Plain	Soils of Lacustrine Deposited	Soils of Coastal Plain
Organic matter content	0.34 to 2.78%	0.33 to 3.03%	0.52 to 2.19%
Cation Exchange Capacity	33.12 to 46.92 meq/100 g of soil	33.12 to 46.92 meq/100 g of soil	6.9 to 18.36 meq/100 g of soil
ESP	3.41 to 14.86%	6.01 to 43.85%	5.09% and 12.69%

3.3. Soil Classification of the Study Area

The pedological study of the study area produced the following soil map units. The spatial distribution of these units is shown in Figure 6 and Table 6. The highest magnitude soil unit is *VerticTorrifluvents*, occupying an area of 1812.96 km^2 (58.71%) of the southern part of the investigated area. It is bonded at the north end by batches of *TypicHaplosalids* and mostly by *AquallicSalorthids*, which surround the Lake Brullus area. The latter soil classification unit occupies an area of cultivated land equivalent to 810.24 km^2 (26.2%). *TypicHaplosalids* has a covered area of 7.91% (244.40 km^2) compared with the previous units, which have a lower frequency around the lake. While the frequencies are very slight, they were found in the rest of the soil units. The dune area was 85.67 km^2, representing 2.8% in narrow strips along the northern border of the study area. Figure 3 and Table 5 show that the order of the soil units depending on the occupation area is as follows: *VerticTorrifluvents*, *AquallicSalorthids*, *TypicHaplosalids*, *TypicQuartzipsamments*, *Sanddunes*, *TypicTorrifluvents*, *TypicTorripsamments* and *TypicSalorthids*.

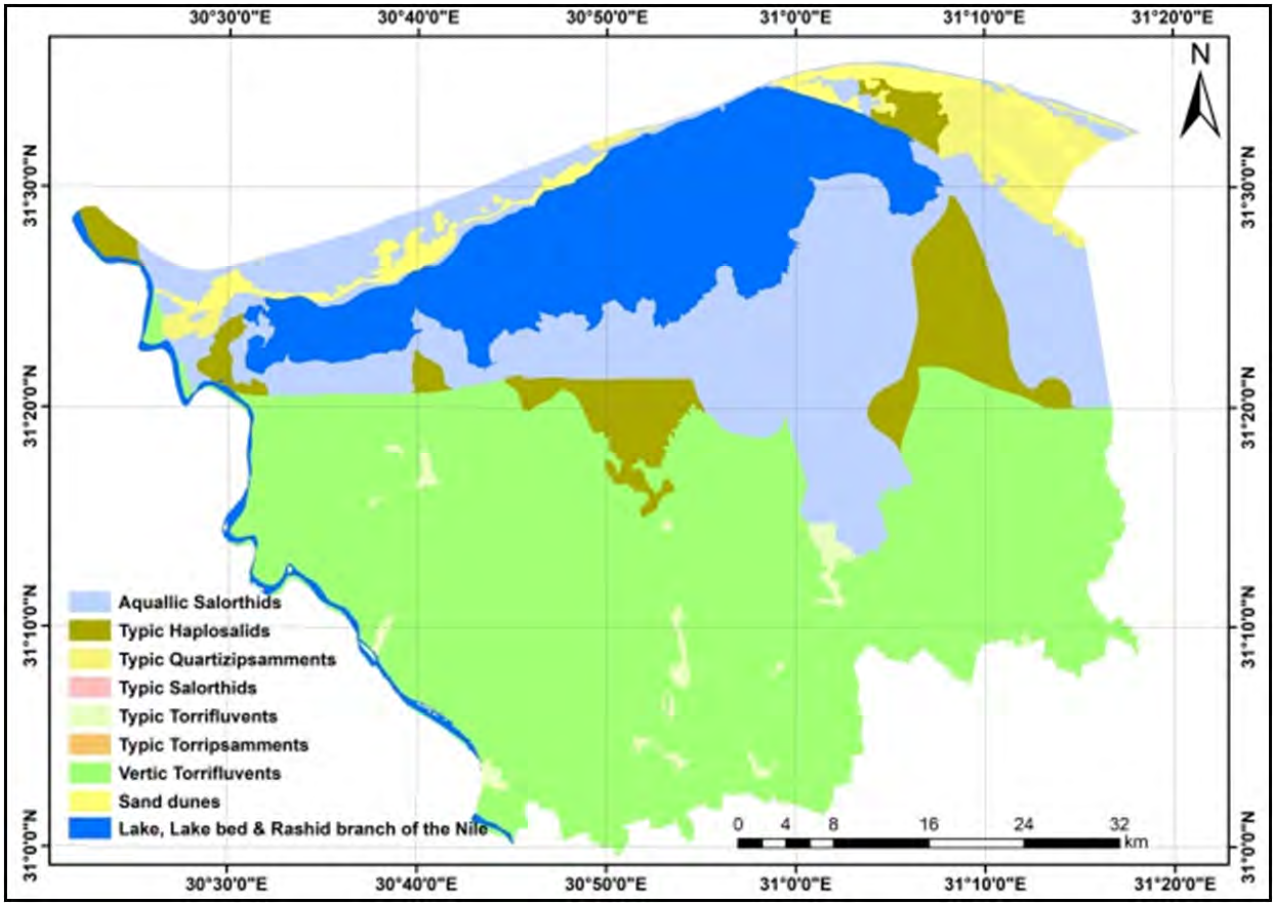

Figure 6. Soil taxonomy units of the study area, 2016.

Table 6. Areas and frequencies of soil sub-groups in Kafr El Sheikh Governorate.

Type (Sub Group)	Area (km^2)	%
AquallicSalorthids	810.24	26.24
TypicHaplosalids	244.40	7.91
TypicQuartzipsamments	94.07	3.05
TypicSalorthids	0.06	0.00
TypicTorrifluvents	40.44	1.31
TypicTorripsamments	0.13	0.00
VerticTorrifluvents	1812.96	58.71
Sand dunes	85.67	2.77
Total	3087.97	100.00

It was noted that *AquallicSalorthids*, *TypicSalorthids* and *TypicHaplosalids* were found to be the highly affected by salinity, alkalinity, compaction, and waterlogging. *VerticTorrifluvents* and *TypicTorrifluvents* were found to be highly affected by salinity, alkalinity, and compaction. *TypicQuartzipsamments* and *TypicTorripsamments* of dune area were found to be affected by salinity hazards.

3.4. Comparative Studies of Physiochemical Soil Characteristics

An assessment of soil physical and chemical properties was carried out in the studied area in1961 [35–37]. The results revealed that the soil properties had strongly changed due to land reclamation, conservation, and land management. This research focused on data available in 1961, 2002, and 2016. Since the sampling points are not at the same locations, the estimated degradation is based on changes in the spatial distribution of properties generated using the geostatistical method in ArcGIS. The quantitative comparison of the land degradation at the different dates (1961, 2002, and 2016) was carried out using spatio-temporal variance techniques.

A very important factor in crop productivity management is soil depth (Figure 7). In this study, the soil depth differed in each of the study periods, where the average depth (90–100 cm) occupied 45% of the total area in 1961, while in 2002 it reached 26% of the total area, and in 2016 it was 29% of the total area. Despite this fluctuation in the values, an increase in the shallow soil depth ($\leq$70 cm) ratio was observed from 13%, and 18% to 24% of the total area for the years studied, respectively. It is very clear that the mismanagement of the area has caused soil deterioration in form of waterlogging. It is certain that the depth of the soil in hot areas is an influential factor in the salinity of the land. These results are in direct agreement with the results obtained in the previous studies [7,40,41].

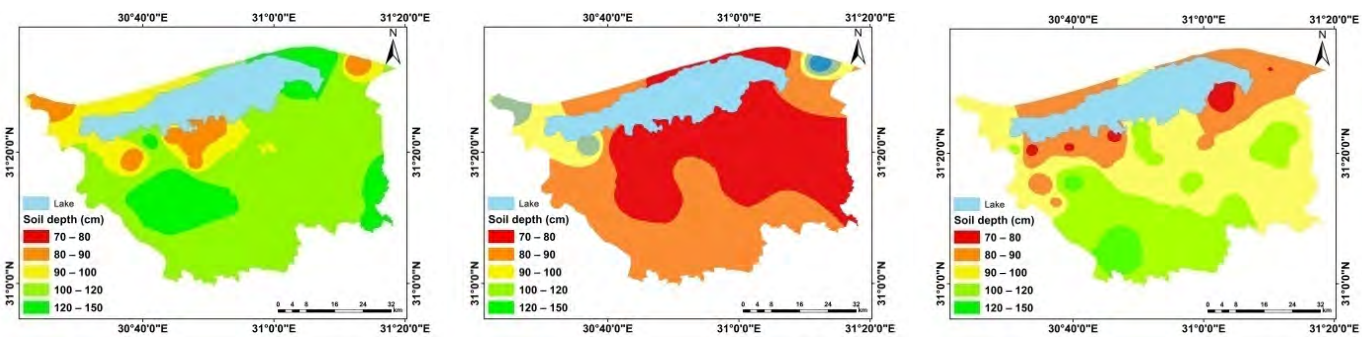

Figure 7. Soil depth maps in 1961, 2002, and 2016.

Soil salinity (Figure 8) is a limiting production hazard factor to the crops, especially those sensitive to this parameter. The degree of soil salinity hazard in the area was found

to range from light to severe in all study periods. The proportion of non-saline and saline land results was reduced to 53%, 41%, and 33% in 1961, 2002, and 2016, respectively. This decrease in good lands in terms of low salinity confirms the negative impact of humans on the area and consequently the poor agricultural management.

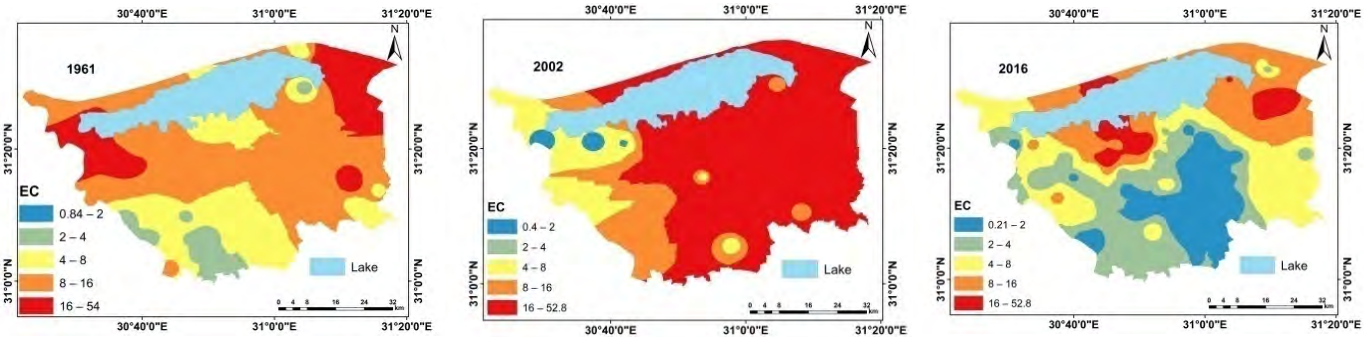

Figure 8. Soil EC maps in 1961, 2002, and 2016.

Weak soil structure leads to weak soil ability to infiltrate irrigation water through the different horizons of the sector. It is characterized as having a high pH (>8.5). In most cases, a solid clay layer is formed that may be deaf at depths ranging from 0.5 to 1 m. This thus affects the height of the depth of the groundwater within the soil sector and increases the proportion of shallow lands. The predominant presence of sodium carbonate makes these lands alkaline soils, with their unfavorable physico-chemical properties. It is clear from Figure 9 that the soil pH increased from 8 with limited alkalinity to 8.8, which is very alkaline, during the years 1961, and 2002 to 2016. The alkalinization degradation could be illustrated by the sodium adsorption Ratio (SAR) where there is a clear change in the SAR value, especially around the lake and in the eastern part of the Governorate, as seen in Figure 10.

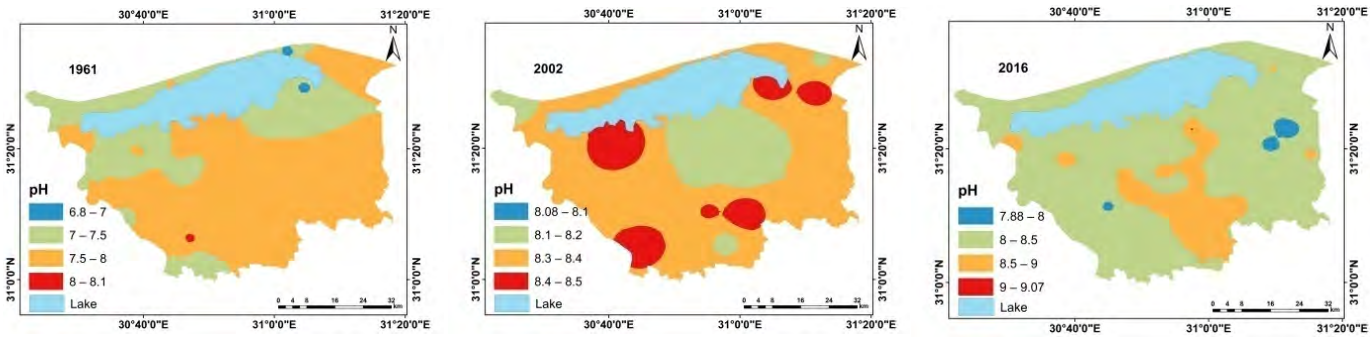

Figure 9. pH prediction maps in 1961, 2002, and 2016.

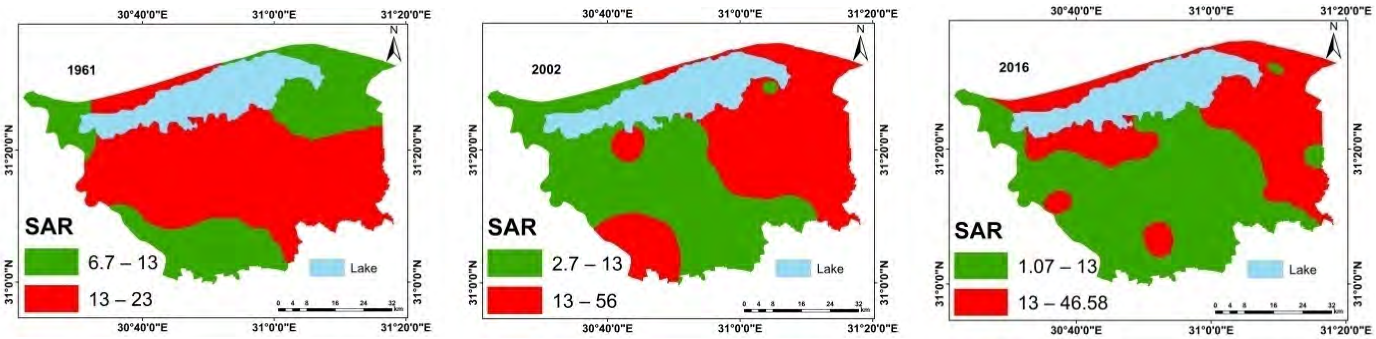

Figure 10. Prediction SAR maps in 1961, 2002, and 2016.

As seen in the Figure 11 lime content maps, all the soils studied are non-calcareous soils. Alkaline saline lands are considered among the most significant problems facing land management in the Nile Delta in Egypt. The results indicated the emergence of a remarkable improvement with the increase in the proportion of lime ins the soil on some of the soil's natural and vital properties. The values of the bulk density and of the percentage of each of the permanent wilting coefficients, as well as the number of micropores, decreased, while the percentage of field capacity, available water, total pores and water-retaining pores increased.

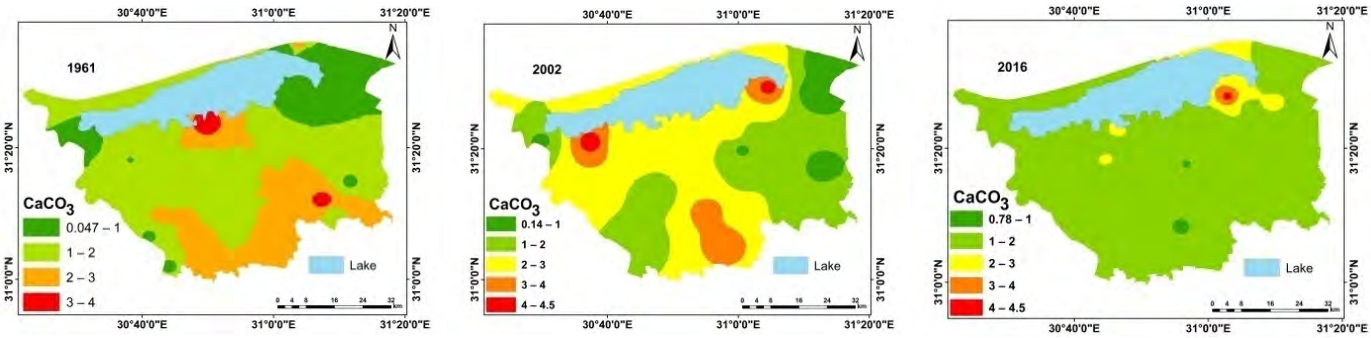

Figure 11. Lime content maps in 1961, 2002, and 2016.

There is no doubt that the most important factor by which soil quality is measured in terms of aeration, porosity, movement of water, and solute is the degree of soil compaction, which is expressed by the bulk density (Figure 12). Bulk densities above thresholds indicate impaired function and therefore affect soil quality by restricting the growth of roots; their weakness is due to the weak movement of water and air in the soil, and thus to shallow rooting of the plant and weak plant growth. This obvious negative effect of increasing the bulk density of the soil reduces the yield of crops due to the available vegetation cover, which is also important for protecting the soil from erosion. As seen in Figure 9, the soils in 2002 and 2016 are moderately compacted; most of the areas are 1.47, which, except in some parts in 2002, is high, but the texture is different—it is in the coastal dunes' area. The increase in bulk density was noted to be associated with soil compaction. Bulk density values of 1.30 to 1.47 g cm^{-3} would indicate soil compaction, but 1.3 g cm^{-3} values were also close to normal for coarse-textured soils. From Figure 9, it can be seen that the soil bulk density values have decreased gradually over the years.

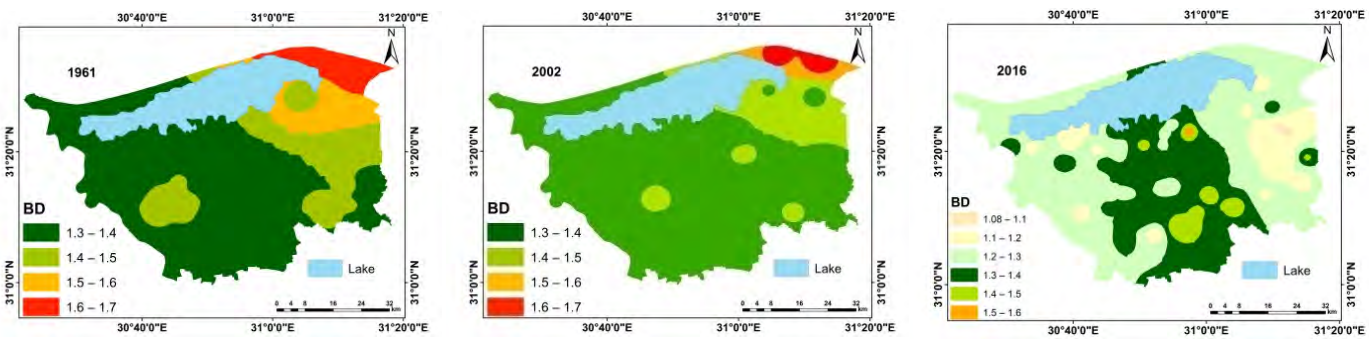

Figure 12. Soil bulk density maps in 1961, 2002, and 2016.

The importance of organic matter (OM) lies in its direct positive effects on the physical, chemical, and biological properties of the soil. It is known that the region had fish farming activity during the past three decades, which may be a determinant effect for the increase in the percentage of OM during the periods examined, as is evident from Figure 13 [42].

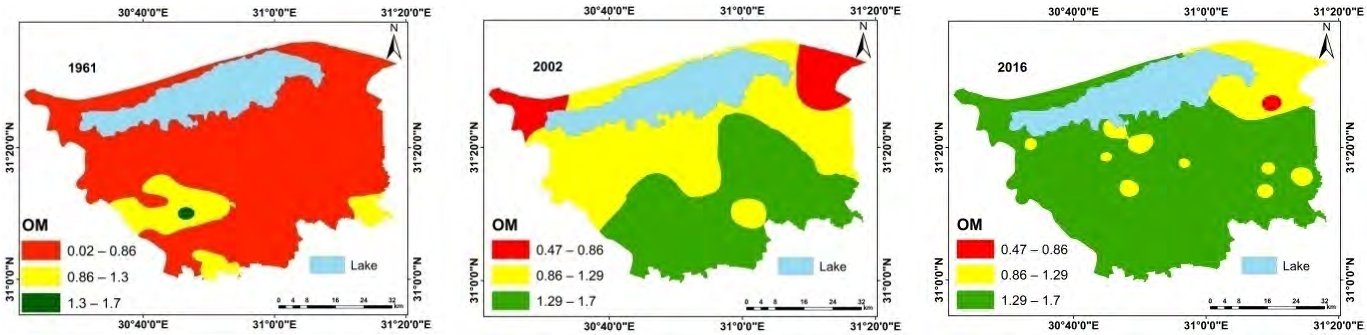

Figure 13. Organic matter content map in 1961, 2002, and 2016.

3.5. Climate Attributes

Changes in an area's average temperature and precipitation in Egypt were assessed based upon over 12 recent GCMs using a new version of MAGICC/SCENGEN coupled gas-cycle/climate modulus (MAGICC, Climate Resources Exchange International Pte. Ltd., Malacca Centre, Singapore), which drives a spatial climate change scenario generator (SCENGEN, Scorpion Computer Services). MAGICC is a simple climate model that computes the mean global surface air temperature and sea-level rise for particular emissions scenarios for greenhouse gases and sulfur dioxide [43]. The scenario for the development of irrigation conditions of the study area was derived from historical data: climatic data from 35 years (1979–2014). According to the Intergovernmental Panel of Climate Change report [44], the study area will likely be affected by increasing air temperature and decreasing precipitation systematically. The predicted scenario of climatic conditions of the study area, which is needed to study this, was worked out using results from the IPCC (Geneva, Switzerland), 2007 [44]. The annual precipitation is expected to decrease from 11 (current) to 8 mm y^{-1} in 2080. To compare the current climate with the projected climate in 2080, we chose temperature data for June, July and August, as these are the hottest months (Figure 14). Extremely hot days can be enough to reduce yield or even kill an entire crop. We also used December, January, and February as the coolest months. These conditions impose work on geneticists and plant breeders to produce new crop varieties that are better adapted to the expected climatic changes. In addition, climatic change is projected to have a significant impact on the amount of irrigation water entering the study province, which in turn will affect soil degradation and agricultural productivity.

The climate of Egypt is affected by several factors, the most important of which are the location, surface features, the general system of pressure, atmospheric depressions, and water bodies, all of which helped divide Egypt into several distinct climatic regions. The Mediterranean Sea is characterized by hot and dry summer months and moderate winters, with little rain falling on the coast. Egypt's climate can be distinguished into two climatic seasons: the hot, dry summer, which extends between May and October, and the mild, rainy winter, which extends between the months of November and April. The agricultural areas in the study area are located along the Nile Delta on the Mediterranean coast. These lands are characterized as fertile sedimentary soils formed thousands of years ago as a result of pumping of the Nile silt coming with the waters of the Nile River. These lands depend for irrigation on the waters of the Nile River, and these lands are alkaline in nature as a result of the high percentage of salt in them with the hot weather conditions.

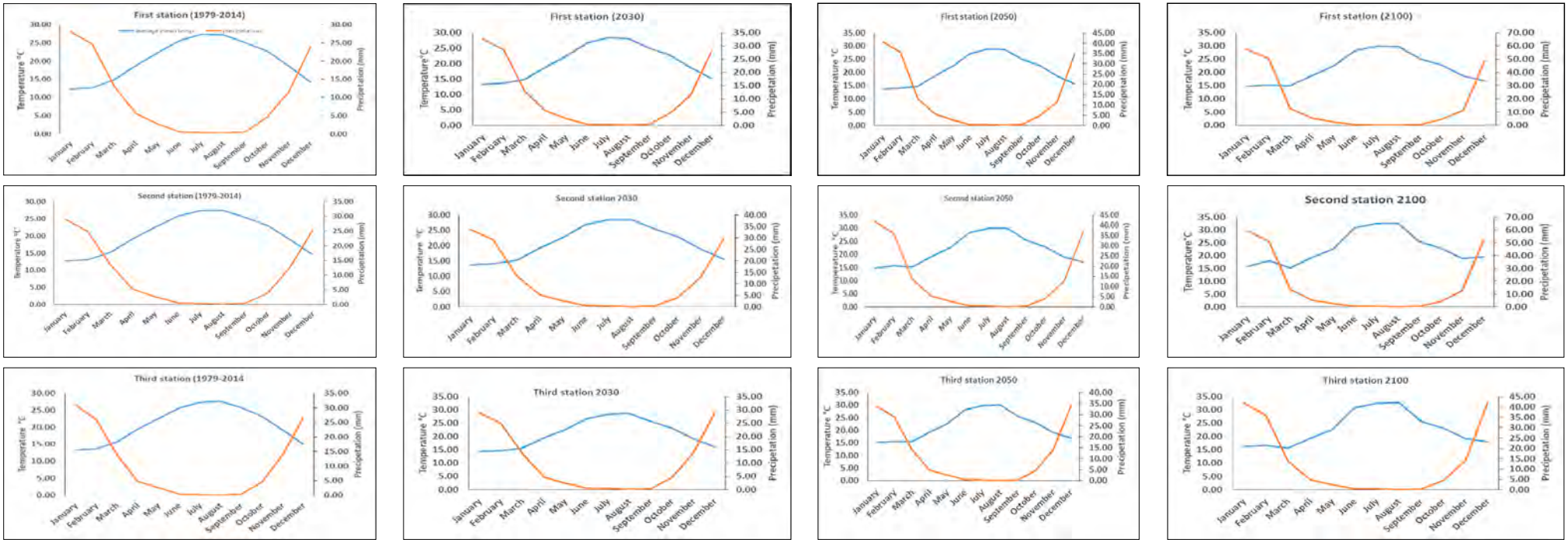

Figure 14. *Cont.*

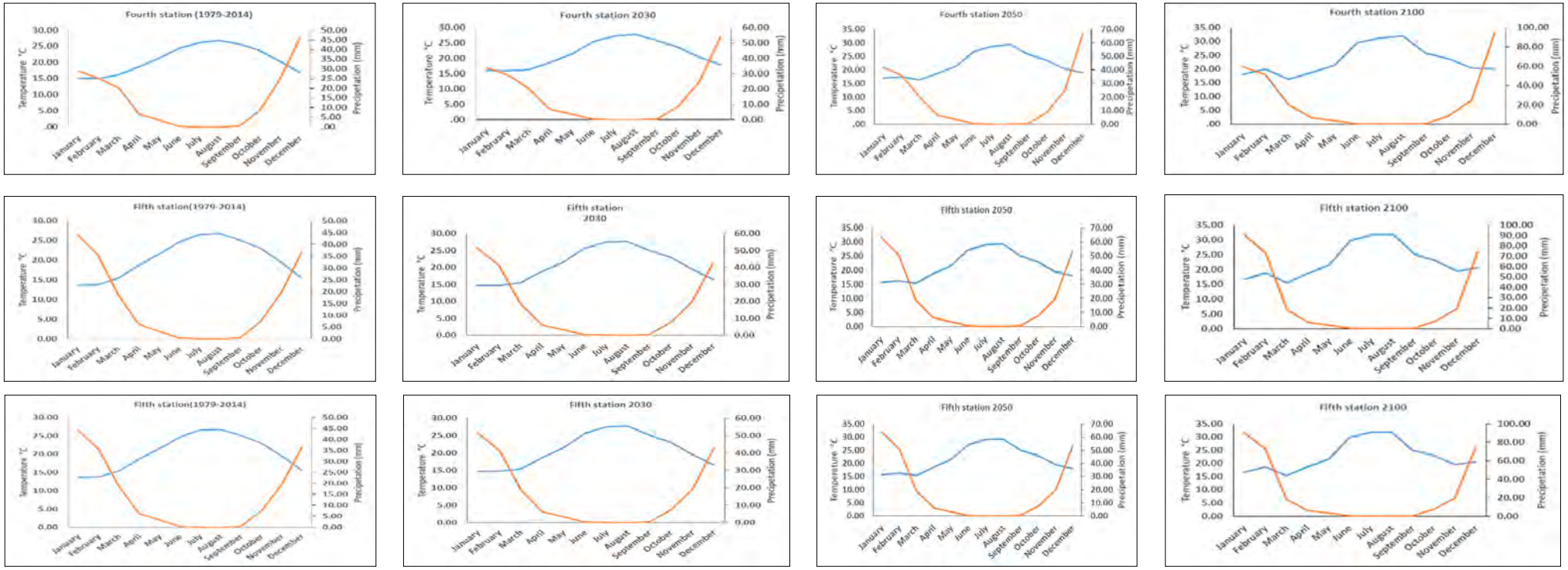

Figure 14. Climate change data.

Agriculture is concentrated in the Nile Delta, but it is exposed to multiple erosion processes as a result of surface irrigation and irrigation with water mixed with high salinity agricultural drainage water, which causes the process of flooding the lands with water and the occurrence of the phenomenon of drumming, especially with the intensive use of chemical fertilizers and pesticides. It also causes the lack of soil compensation for what has been lost of organic matter through organic fertilizers, especially with the interruption of the silt of the Nile after the construction of the High Dam. Another result is the absence of agricultural cycles and the appropriate crop composition, as well as their exposure to dredging operations with the aim of using the surface layer in the manufacture of red bricks, and their exposure to construction and crawl operations, which require modern and economical irrigation methods with cultivation of crops that are less water-intensive, that maintain the agricultural biodiversity that characterizes the region, and that reduce urban sprawl and construction at the expense of agricultural expansion in areas of the delta.

3.6. Overall of Quantitative Soil Degradation Assessment

Spatial models for overall qualitative land degradation in 1961, 2002, and 2016 were created using the Model Builder tool in ArcGIS 10.1 (spatial analyst extension), and a spatial model is represented as a flowchart in Figure 12. Land degradation variables (salinization, alkalization, compaction, lime content, and waterlogging) were exported in a raster, and each data set scored on a scale of 1 to 5 (very low, low, moderate, high, and very high), as shown in Figure 15. The data sets were then weighted according to their influence on the overall model (more weight = more influence). The model was applied to the land degradation variables to prioritize only those that were more determining.

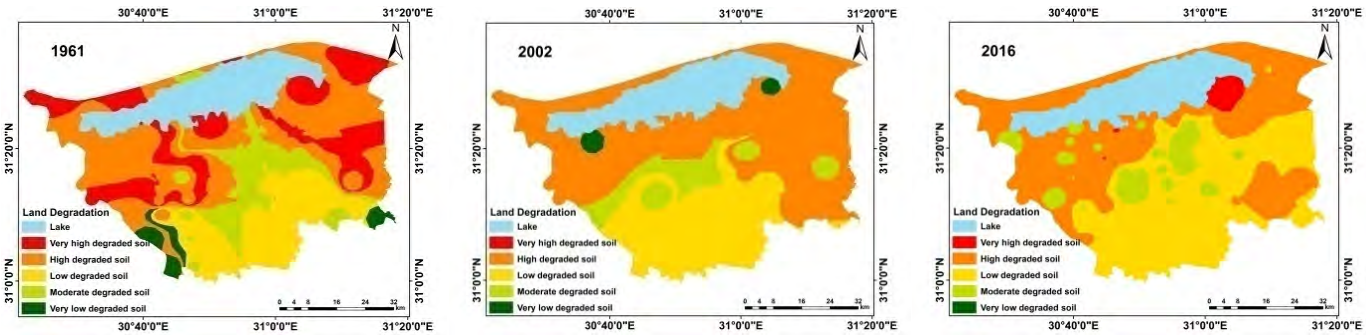

Figure 15. Overall qualitative soil degradation in 1961, 2002, and 2016.

During 2002–2016, soil sealing took place on 36,297.87 ha from the study area (9.7% of the total area) through urban sprawl and fishpond construction. It is expected that urban sprawl will increase 7% by 2020, which means that an additional 3,751 ha of productive soils will be lost from high capable soils from the study area.

As seen in Figures 16 and 17, and Table 7, the overall degradation change for the highly degraded soil increased with time from 1961 to 2016, while for the very highly degraded soil it decreased with time. However, the lowly degraded soil increased with time, and all the change was at the expense of the highly degraded soils due to the reclamation process and the soil management.

The results indicate the anthropogenic effects on the soil of the area over 35 years. This was obviously highlighted through soil sealing through the significant increase of urbanization over the highly fertile agricultural area. This urban sprawl in combination with the climate caused the negative impact on the soil. These results are in conjunction with the previous studies carried out in the region [45–52]. Accordingly, the changes of land properties and the overall land degradation processes in the area should be given more attention to apply decision support systems for better planning of land use.

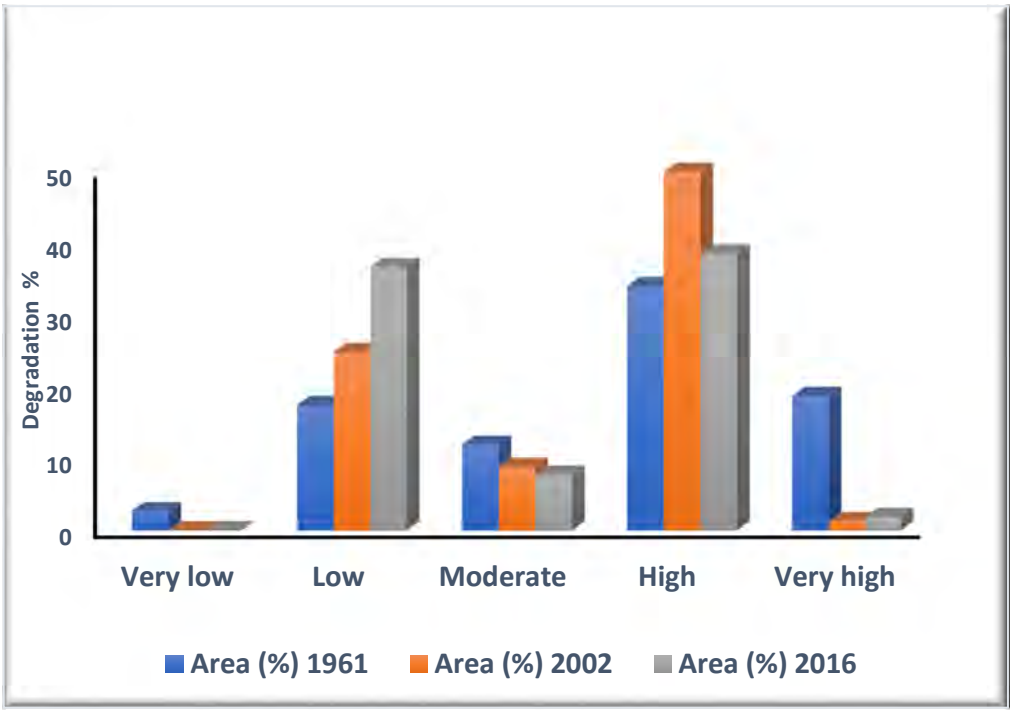

Figure 16. Overall qualitative soil degradation types in 1961, 2002, and 2016.

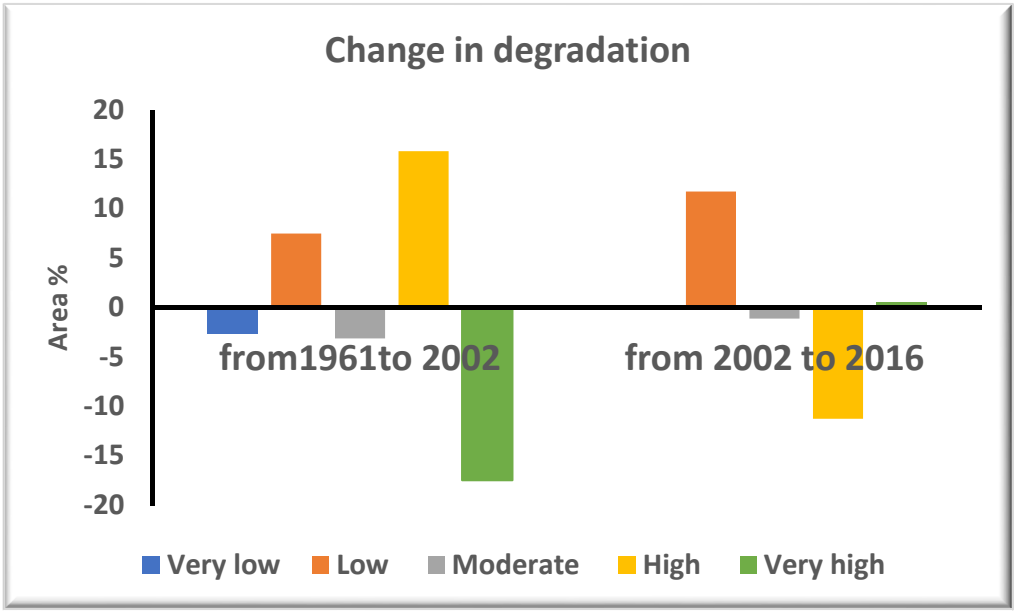

Figure 17. Overall qualitative soil degradation change in 1961, 2002, and 2016.

Table 7. Overall qualitative soil degradation change in 1961, 2002, and 2016.

Element	Area (%) 1961	Area (%) 2002	Area (%) 2016
Very lowly degraded soil	2.70	0.00	0.00
Lowly degraded soil	17.50	24.99	36.74
Moderately degraded soil	12.02	8.90	7.80
Highly degraded soil	34.06	49.88	38.62
Very highly degraded soil	18.74	1.26	1.86

4. Conclusions

The planned and frequent use of satellite-based technology to monitor soil degradation hazard tends to have economic feasibility. Timely depiction of forms of land degradation changes (salinity, water-logging) on the ground as a result of agriculture operations can help authorities and farmers to implement timely measures to mitigate the situation, and in turn can ensure that land productivity is maintained at the planned level. Furthermore, it could be a base for precision agriculture, whereby resources such as irrigation water and fertilizer are optimized.

The study needs to be implemented in all areas of the Nile Delta in order to make a future plan for agricultural use through building a land resource database for agricultural use. It is a very important, serious call for building data banks for the very limited agricultural land in the Nile valley and Delta. Urban expansion over agricultural land is a very important phenomenon and determines the yearly loss of fertile agricultural land in the Nile Valley and Delta; we therefore propose that decision-makers accurately monitor soils and that the Nile valley and Delta constitute a protectorate.

The results showed the importance of studies for inventorying land resources, directing their uses, and preparing their various maps by making use of remote sensing technologies and geographic information systems and integrating them with traditional methods. Also, studying and monitoring the deterioration and assessing its condition is an important step in rehabilitating degraded lands and improving the means and methods of sustainable development of land resources.

Thus, this study contributes toward improving land management and productivity and rationalizing its investment in order to reach sustainable development, including fertilization, the addition of soil conditioners, the selection of means and methods of water use. This also includes non-conventional water resources (saline, brackish, waste) and the rationalization of the use of all types of water in agriculture, as well as identification of irrigation needs from drainage and associated agricultural operations.

The most important recommendations of the study are:

- To develop integrated management systems for land resources and combating desertification.
- To develop land resources, choose their optimal use, and increase their productivity, by preparing land maps (soil-land use-land degradation, etc.).
- To develop and evaluate traditional agricultural operations in dry areas and encourage the exchange of knowledge and successful technologies.
- To develop non-conventional water uses to increase farm income while preserving land from degradation.

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