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ORIGINAL PAPER

Use of satellite data and GIS for soil mapping and monitoring soil productivity of the cultivated land in El-Fayoum depression, 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 for the studied area; and (2) monitoring soil productivity of the cultivated land in El-Fayoum depression. To fulfill these aims, 16 soil profiles were chosen to represent the different mapping units. Morphological description was carried out and soil samples were collected for physical and chemical analysis. Based on ETM images analysis 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. alluvial plain; 2. fluvio-lacustrine plain; 3. lacustrine plain. This study is based on comparing between the data extracted from previous study carried out in 1961 by RISW report and the data resulting from the current study to monitoring soil productivity in the studied area to make comparison as well as monitoring more realistic. Soil characteristics and productivity criteria are matched for getting soil productivity in the period 1961–2010. Monitoring of soil productivity includes the following main landscapes, i.e., lacustrine plain, fluvio-lacustrine plain, and alluvial plain. The soil characteristics of previous and current study were grouped and recalculated to meet the requirements of Riquier et al. (1970) modified by FAO (2007). The results reveal that: Generally, all the studied sites in El-Fayoum depression changed positively in the productivity grade except that the soil of lacustrine plain seems to be still degradable for the reason that it receives a lot amount of drainage water from all the soil of the depression. The improvement of the soil productivity grade in the studied area due to the good quality of land management such as: – sub-soil plugging and adding organic materials to overcome soil compaction; – establish drainage network system to reduce water logging; – leaching processing to remove the excess of salinity occurs in the studied area; – gypsum addition considering gypsum requirements to reduce soil alkalinity.

Keywords Spatial analyses · Physiographic and soil mapping · Soil productivity and El-Fayoum depression

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Introduction

Fayoum Governorate is occupying a depression west of the Nile at 90 km southwest of Cairo between latitudes 29°02′ and 29°35′ N and longitudes 30°23′ and 31°05′ E (Fig. 1). According to Egyptian Meteorological Authority (1996), Climatologically Normal for Egypt (2011), and Keys to Soil Taxonomy USDA (2010) the soil temperature regime of the studied area could be defined as thermic and soil moisture regime as torric.

Said (1993) reported that the geology of the area can be summarized as the following:

1. El-Fayoum depression itself is excavated in Middle Eocene rocks, which form the oldest exposed beds in the area and are composed essentially of gyps-ferrous shale, white marls, limestone, and sand (known as Ravine beds).

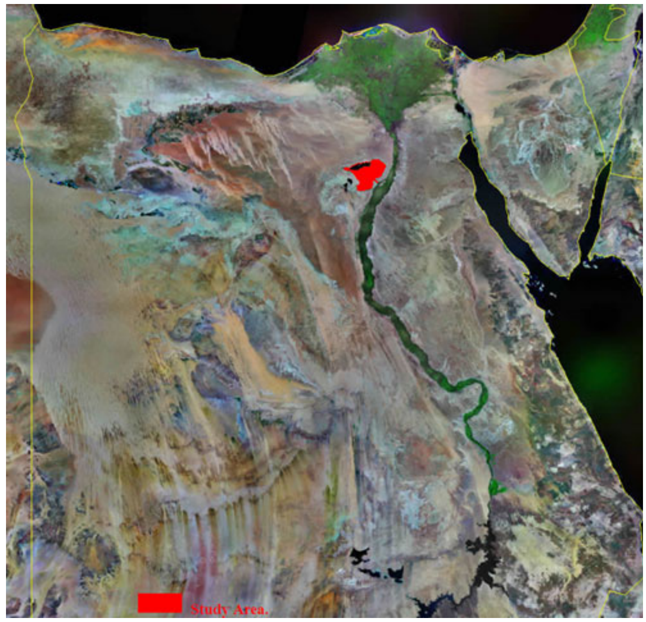


Fig. 1 Location of the studied area

2. The Oligocene beds, followed the Upper Eocene beds, are composed mainly of fluvio-marine variegated sands and sandstone, with alternating beds of shale-marls and calcareous grits containing silicified wood . Above this formation, there is basalt intrusions fissured as a horizon about 20–25 m thick.
3. The Pleistocene deposits which are mainly of fluvio-lacustrine origin, are forming the subsurface zone between the uppermost recent deposits of Holocene (Nile alluvial) and the Middle Eocene deposits at the bottom of El-Fayoum depression. These Pleistocene deposits are mainly composed of gravels and sands.

The present depression has been formed when the basin was subsided relative to the Nile River, allowing it to break through and to flood the area. This led to the formation of a thick fertile alluvium. The main identified landforms in El-Fayoum depression are recent and old lake terraces, depression, plain, and basins.

Soil productivity is not a luxury. Productivity capacity is dependent on basic chemical and physical properties such as texture, pH, and available water-holding capacity. This, coupled with differences in climate from one site to another, makes it difficult to evaluate differences in productivity capacity between soils or land parcels. A variety of productivity ratings have been developed to provide a common basis to compare one soil to another.

Productivity ratings in general are numbers that reflect relative value of a soil for agricultural. In many instances, these ratings have been based on physical and chemical properties of soils and the effect that these properties have on productivity for the most commonly grown crops.

Riquier et al. (1970) suggested the following rating for evaluating soil productivity, i.e., excellent I (65–100), good II (35–64), average III (20–34), poor IV (8–19), and extremely poor to nil V (0–7).

Land evaluation is a vital link in the chain leading to sustainable management of land resources. It is assigned the indispensable task of translating the data on land resources into terms and categories, which can be understood and used by all those concerned with land improvement and land use planning. The different types and procedures in land evaluation are gradually being developed. Interpreting soil qualities and site information for the agricultural use and management practices is integrated using geographical information system (FAO 1991, 2007). The land quality is a complex attribute of land which acts in a manner distinct from the actions of other land qualities in its influence on the suitability of land for a specified kind of use (FAO 1985) it is the ability of the land to fulfill specific requirements for the land utilization type (Van Diepen et al. 1991). The spatial analysis was used in this study, it can be defined as the analytical techniques associated with the study of locations of geographic phenomena together with their spatial dimensions and their associated attributes (ESRI 2001). Spatial analysis is useful for evaluating suitability, for estimating and predicting, and for interpreting and understanding the location and distribution of geographic features and phenomena. The use of spatial analyses techniques in evaluating the land capability allow producing multi-thematic maps and outlining the limiting factors, accordingly suitable suggestions could be attained to understanding how to deal with these soils for sustainable agricultural use. The solution for providing food security to all people of the world without affecting the agroecological balance lies in the adaptation of new research tools, particularly from aerospace remote sensing, and combining them with conventional as well as frontier technologies like geographic information systems (GIS). Soil productivity development is one of the prime objectives in all countries in the world, whether developed or developing. The broad objective of sustainable agriculture productivity is to balance the inherent land resource with crop requirements, paying special attention to optimization of resource use towards achievement of sustained productivity over a long period (Lal and Pierce 1991). Sustainable development is development that meets the needs of the present without compromising the ability of future generations to meet their needs. It contains within two key concepts: the concept of needs, in particular the essential needs of the world's poor, to which overriding priority should be given; and the idea of limitations imposed by the state of technology and social organization on the environment's ability to meet present and future needs. Sustainable development is maintaining a delicate balance between the human need to improve lifestyles and feeling of well-being on one hand, and preserving natural resources and ecosystems, on which we and future generations depend. GIS and RS offer a great potential to capture data through a variety of observation platforms and integrate them through their common spatial network. This advanced approach justifies the involvement of object-oriented database structures in the decision-making process as this digital framework is an efficient system for marinating data records for easy access toward decision making (Adrian et al. 2010).

The aim of this study is to use spatial analyses techniques in monitoring soil productivity at El-Fayoum depression throughout:

- producing the physiographic–soil map of the study area scale 1:50.000 reduced to the attached map
- monitoring of soil productivity in the studied area by using Riquier et al. (1970) model modified by FAO (2007).

Materials and methods

Digital elevation model (DEM) of the study area has been generated from the elevation points (recorded during the field survey by GPS) coupled with contour lines extracted from the recent topographic map scale 1:50.000, and the vector contour lines; ArcGIS 9.2 software was used for this function. Landsat ETM images (2010) (Fig. 2) and DEM

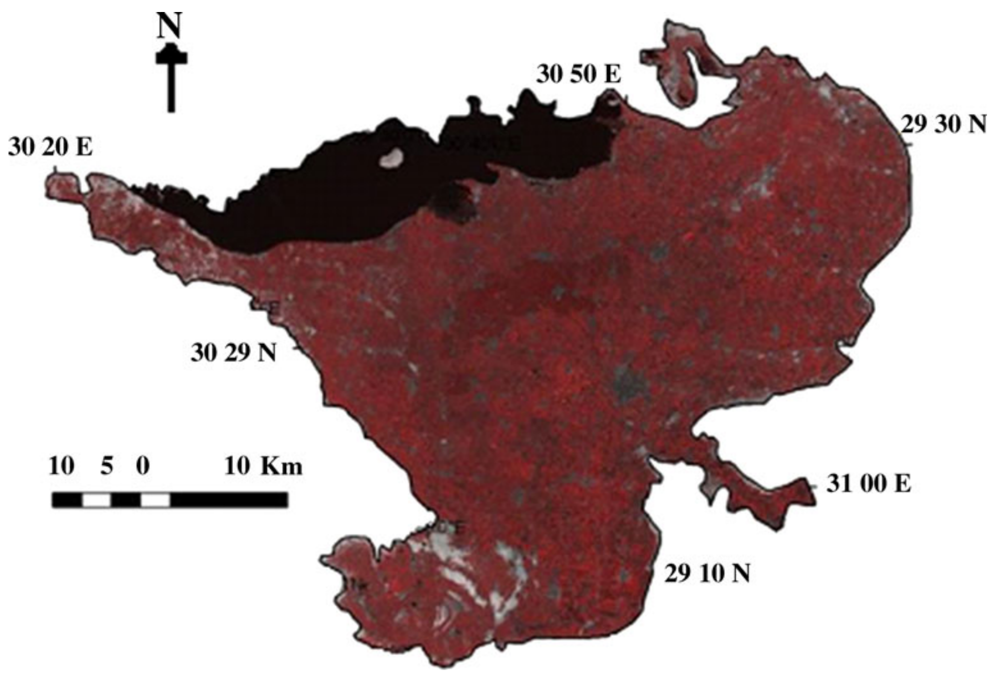


Fig. 2 Enhanced Landsat ETM+ image of the studied area

was used in ENVI 4.7 software (ITT 2009). Data were calibrated to radiance using the inputs of image type, acquisition date and time. Image was stretched using linear 2%, smoothly filtered, and their histograms were matched according to Dobos et al. (2002) and Lillesand and Kiefer (2007). Image was atmospherically corrected using FLAASH module to produce the physiographic map of the study area .Morphological description of 16 soil profiles representing the different physiographic units (Fig. 3) were carried out according to the field book for describing and sampling soils (USDA 2002) and guidelines, edited by FAO (2006). Representative 16 soil profiles were chosen to represent the different mapping units. The laboratory analyses were carried out using the soil survey laboratory methods manual (USDA 2004) and Robert (2008). The soils were classified to the sub great group level on the basis of the key to soil taxonomy (USDA 2010). The correlations between physiographic and taxonomic units were carried out in order to produce the physiographic–soil map of the studied area (Elberson and Catalon 1987). The spatial analyses function in ArcGIS 9.2 was used to create the thematic layers of Moisture content, Drainage condition, Effective soil depth, Texture/structure, Soluble salt concentration, Organic matter content, Mineral exchange capacity/nature of clay and Mineral reserve. The thematic layers were matched.

Based on comparing between the data extracted from RISW report, (1961) and the data resulting from this study the previous and actual soil productivity map were produced; the land productivity classes were defined to monitoring soil productivity in the studied area using the rating and procedure after Riquier et al. (1970) model modified by FAO (2007).

Results and discussion

Physiographic and soils of El-Fayoum depression

Field survey data, Landsat ETM images, and DEM were used to define the physiographic units in El-Fayoum depression as shown in (Fig. 4). The correlation between physiography and soils were carried out, the produced data reveal that the soils of the main physiographic units in the area could be arranged under the landscape level in the following:

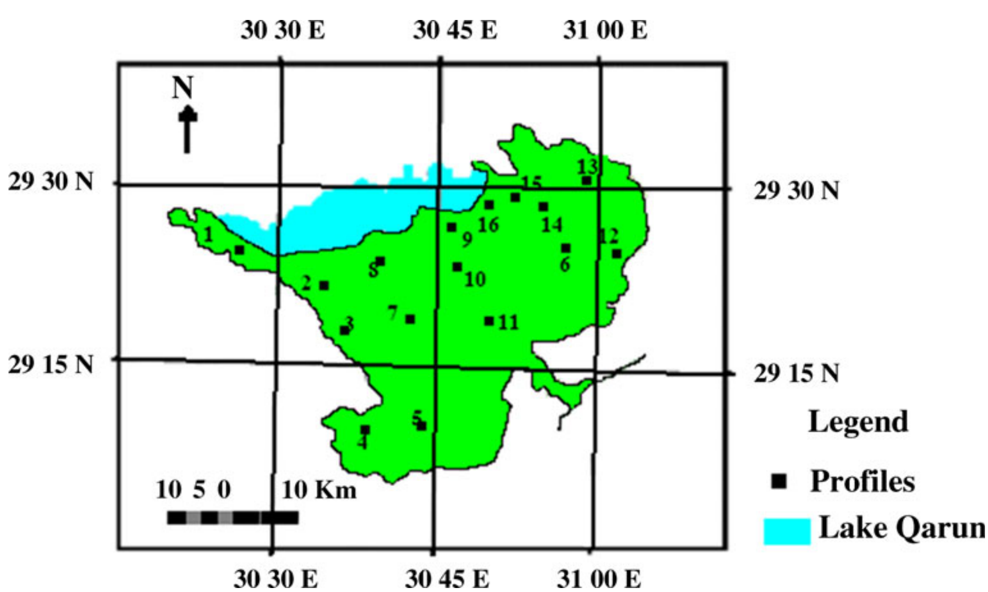
Soils of the lacustrine plain

This landscape includes the lacustrine terraces of different elevation. It covers an area of 198.00 km^2, including soils of relatively high terraces, soils of the moderately high terraces and soils of the relatively low terraces. These are represented by soil profiles 9, 15, and 16, respectively, and are classified to the sub-great group level as Typic Haplosalids. The soil depth, salinity, exchangeable sodium percent (ESP), and $CaCO_3$ percent of this landscape ranges from 60 to 100 cm, 12.80 to 39.30 dS/m, 10.20% to 19.30%, and 6.60% to 30.40%, respectively.

Soils of the fluvio-lacustrine plain

The total area of this landscape is 550.70 km^2, including the landforms of recent terraces (188.30 km^2), old terraces (23.40 km^2), oldest terraces (124.60 km^2), and basins (218.50 km^2). These landforms are represented by the soil profiles 1, 2, 3, 6, 8, 12, 13, and 14 the first five profiles are Typic Haplocalcids and the latter three profiles are Typic

Fig. 3 Distribution of the studied investigated sites



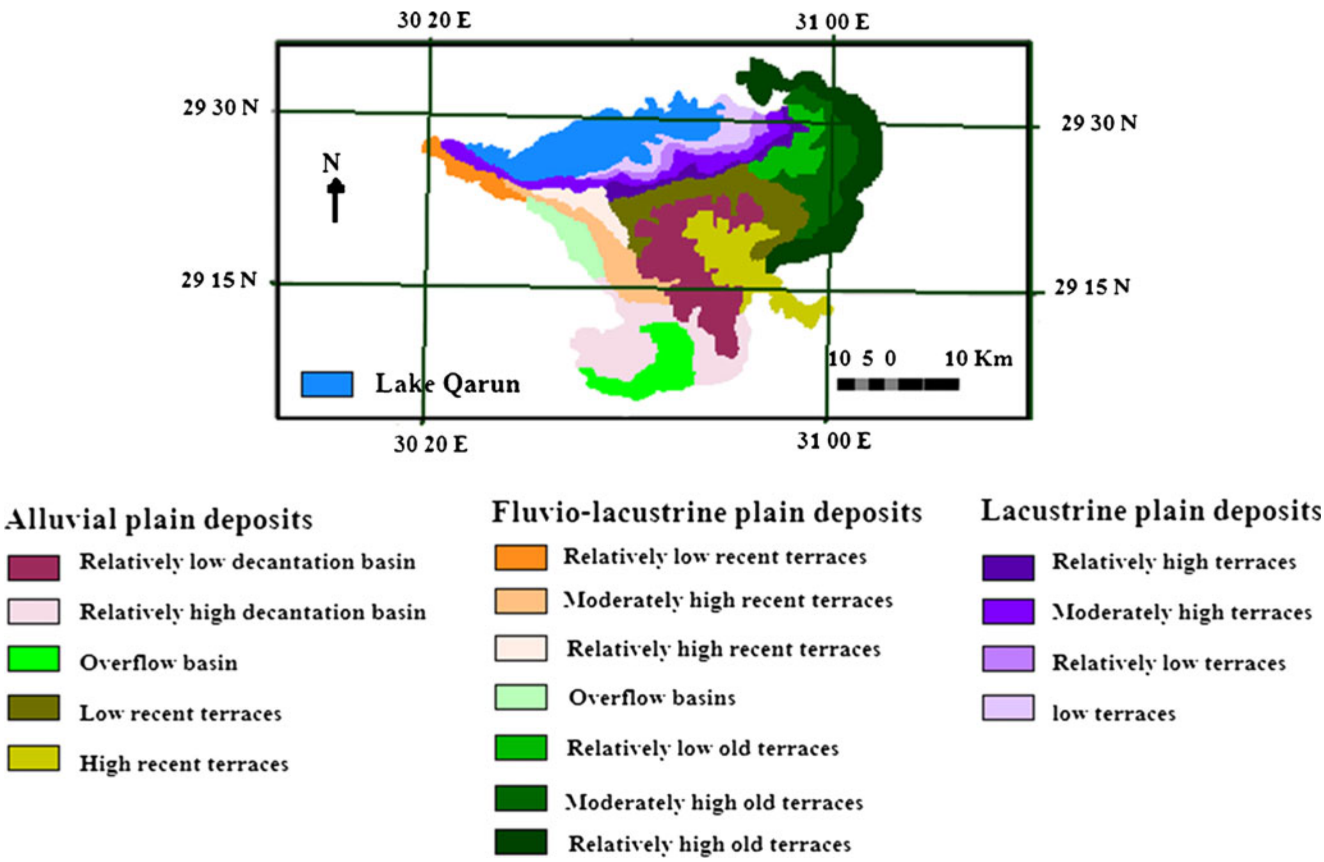


Fig. 4 Physiographic—soils map of the studied area

Torrifluvents. In this landscape, the following soil characteristics range in the following: soil depth (70 to 120 cm), soil salinity (2.10 to 6.90 dS/m), ESP (11.20% to 31.40%) and $CaCO_3$ content (6.30% to 28.20%).

Soils of the alluvial plain

The alluvial plain dominates the south and southwest parts of the depression with an area of 853.20 km^2. This landscape includes the landforms of recent terraces with different elevations (479.30 km^2) and the basins (385.20 km^2). The soils of these landforms are represented by the soil profiles 4, 5, 7, 10, and 11, and are classified under Vertic Torrifluvents, Typic Torrifluvents, and Typic Haplargids. The soils of this landscape are characterized by moderately-deep-to-deep soil profiles (90–140 cm), low salinity (2.60–4.40 dS/m), low to high exchangeable sodium percent (11.30–32.10%), and low to high $CaCO_3$ content (4.70–34.80%).

Monitoring of soil characteristics in the studied area

A comparative study was carried out to monitor changes in soil characteristics based on some selected soil properties such soil depth, organic matter percent, total soluble salt (TSS) percent, and ESP as shown in Figs. 5, 6, 7, and 8. Monitoring of soil characteristics includes the following main landscapes, i.e., lacustrine plain, fluvio-lacustrine plain, and alluvial plain. Figure 5 shows the change of soil depth form shallow to deep in 1961 to moderately-deep-to-very-deep soil profile in 2010 due to the reclamation process in the studied area, especially that a good draining network surface and subsurface drainage was done. On one

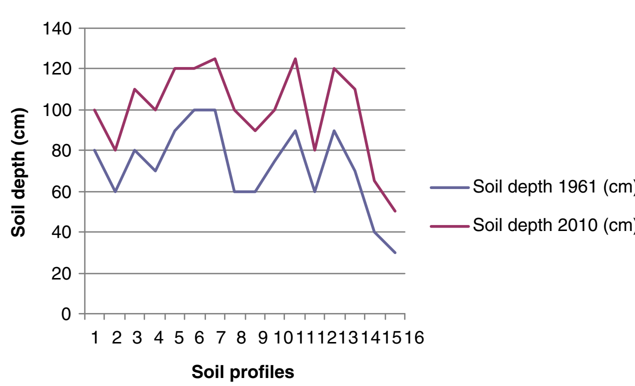


Fig. 5 Monitoring of soil depth in the studied area during the period of 1961 and 2010

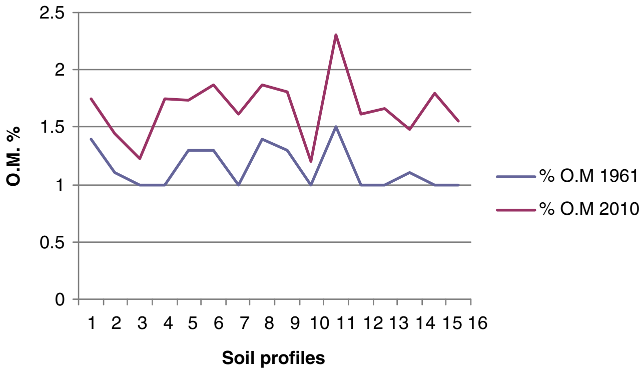


Fig. 6 Monitoring of organic matter percent in the studied area during the period of 1961 and 2010

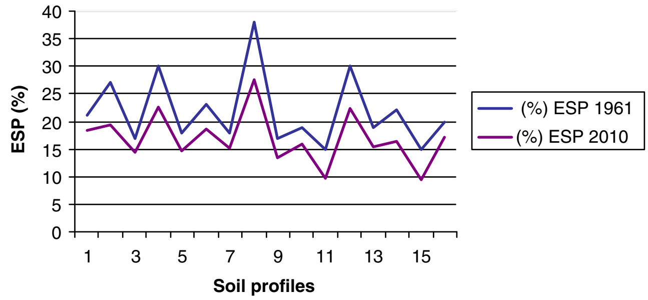


Fig. 8 Monitoring of ESP in the studied area during the period of 1961 and 2010

hand, Fig. 6 shows the change in organic matter content from 1–1.5% in 1961 to 1.2–2.5% in 2010 due to the addition of organic manure to soil and continues planting after 1964 may lead to increase the organic matter in the soil. Generally, TSS decreased in soil which changed from 0.3–1.7% in 1961 to 0.2–1.1% in 2010 because of the leaching processes and draining network (Fig. 7). Also, Fig. 8 shows that ESP decreased in the studied area from 15–37% (moderately sodic to very strongly sodic) in 1961 to 10–27% (sodic to srongly sodic) in 2010. The improvement in ESP due to the application of Gypsum to the soil and leaching that established a good draining network. The application of gypsum to the soil leads to the removal of sodium and its replacement by calcium on the exchange sites which reduces deflocculation and allows natural aggregation of particles that eventually restores good soil structure.

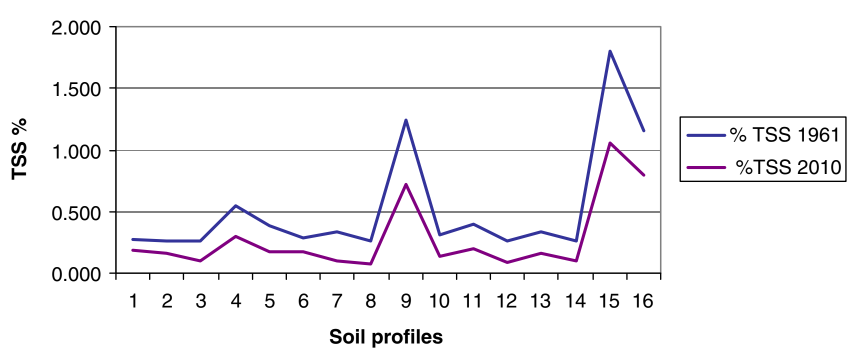
Monitoring of soil productivity in the studied area

A comparative study was carried out to monitor changes in soil productivity based on some selected soil properties defined by the productivity index as shown in Fig. 9. Soil characteristics and productivity criteria are matched for getting soil productivity. Monitoring of soil productivity includes the following main landscapes, i.e., lacustrine plain, fluvio-lacustrine plain, and alluvial plain. Table 1 represents the changes in area by square kilometers for each soil productivity grad (G) and index (PI) in the study area. The sites selection depends mainly upon previous study carried out by RISW (1961) to make comparison as well as monitoring more realistic. The soil characteristics of previous and current studies were grouped and recalculated to meet the requirements of Riquier et al. (1970) modified by FAO (2007) as follows:

Soil productivity changes in the lacustrine plain landform

This landscape includes the lacustrine terraces of different elevation; these are represented by soil profiles 9, 15, and 16 are classified as V (extremely poor to nil grades) in 1961 and as IV (poor grades) and V (extremely poor to nil grades) in 2010. Site number 9 changed positively from grade V (extremely poor to nil grades) to grade IV (poor grades), while site numbers 15 and 16 improved within the same productivity grade V (extremely poor to nil grades) as

Fig. 7 Monitoring of TSS percent in the studied area during the period of 1961 and 2010



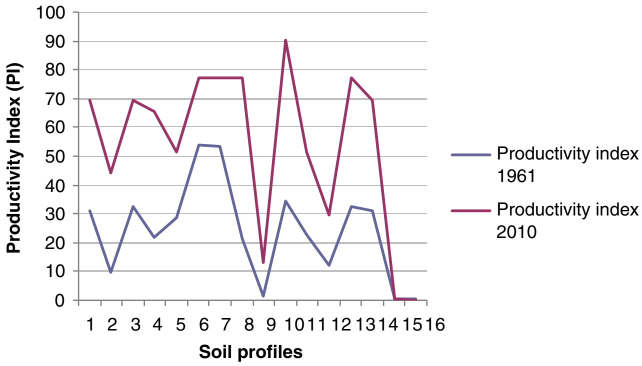


Fig. 9 Monitoring of Productivity index in the studied area during the period of 1961 and 2010

shown in Table 2, and Figs. 9, 10 and 11. The most limiting factors affected this landscape are moisture content, effective depth, drainage condition, texture/structure, organic matter content, and salinity.

Soil productivity changes in the fluvio-lacustrine plain landform

This landscape includes the recent terraces, old terraces, oldest terraces, and basins. These landforms are represented by the soil profiles 1, 2, 3, 6, 8, 12, 13, and 14 are classified as II (good grades), III and IV (poor grades) in 1961 and as I (excellent grades), II (good grades), and III grades (average grades) in 2010. Site No. 2 changed positively from grade IV (poor grades) to grade II (good grades), while site number 12 changed positively from grade IV (poor grades) to grade III (average grades); on the other hand, site number 6 changed positively from grades II to I (excellent grades).

Besides, sites number 1, 3, 8, 13, and 14 changed positively from grade III (average grades) to grade I (excellent grades) as shown in Table 2, Figs. 9, 10 and 11. The improvement of soil productivity grade in this landscape was due to the good quality of land management practice.

Soil productivity changes in the alluvial plain landform

This landscape includes the landforms of recent terraces with different elevations, old terraces, oldest terraces, and the basins. These landforms are represented by the soil profiles 4, 5, 7, 10, and 11 are classified as grade III (average grades) in 1961 and as grades I (excellent grades) and II (good grades) in 2010. Site number 7 changed positively from grade III (average grades) to grade I (excellent grades), while site numbers 5 and 11 changed positively from grade III (average grades) to grade II (good grades); on the other hand, site number 4 and 10 changed positively from grade III (average grades) to grade I (excellent grades) as shown in Table 2, and Figs. 9, 10 and 11. Besides, site numbers 1, 3, 8, 13, and 14 changed positively from grades III to I (excellent Grades). The improvement of soil productivity grade in this landscape due to the good quality of land management practice.

Conclusion

The use of spatial analyses allows producing multi-thematic layers of land characteristics, which offer a great source of data for the land use planners. The spatial distribution represents the correlation between the soil characteristics and landforms, with more detailed data, that can be used in extrapolation of soil characteristics in the different landforms. The obtained thematic layers in the database will be of great help and basic sources for the planners and decision makers in sustainable planning and monitoring the changes in soil productivity. The improvement of the productivity grade in the studied area due to the good quality of land management such as:

- sub-soil plugging and adding organic materials like compost to overcome soil compaction;
- establish drainage network system to reduce water logging;
- leaching processing to remove the excess of salinity occurs in the studied area;

Table 1 Area by square kilometers for each soil productivity grade and index in the study area

1961			2010		
PI	G	Area per km^2	PI	G	Area per km^2
0–7	Nil to extremely poor (V)	105.27	0–7	Nil to extremely poor (V)	23.28
8–19	Poor (IV)	764.23	8–19	Poor (IV)	67.86
20–34	Average (III)	2,959.66	20–34	Average (III)	256.29
35–64	Good (II)	244.63	35–64	Good (II)	2,711.50
65–100	Excellent (I)	Not found	65–100	Excellent (I)	1,014.85

PI productivity index, *G* productivity grades

Table 2 Assessment of soil productivity in the study area

Site No.	1961								PI*	G*	2010								PI*	G*
	H	D	P	T	S	O	A	M			H	D	P	T	S	O	A	M		
1	100	80	80	90	70	90	95	90	31.02	III	100	100	100	90	100	90	95	90	69.25	I
2	100	40	50	90	70	90	95	90	9.69	IV	100	80	80	90	100	90	95	90	44.32	II
3	100	80	80	90	70	85	95	90	32.55	III	100	100	100	90	100	90	95	90	69.25	I
4	100	80	80	100	50	85	95	85	21.96	III	100	100	100	100	90	90	95	85	65.40	I
5	100	80	100	60	70	90	100	95	28.72	III	100	100	100	60	100	90	100	95	51.3	II
6	100	100	100	90	70	90	100	95	53.86	II	100	100	100	90	100	90	100	95	76.95	I
7	100	100	100	100	70	85	100	90	53.55	II	100	100	100	100	100	90	95	90	76.95	I
8	100	80	50	100	70	90	95	90	21.54	III	100	100	100	100	100	90	95	90	76.95	I
9	100	80	50	100	5	90	95	95	1.62	V	100	80	80	100	25	90	95	95	12.99	IV
10	100	80	80	100	70	85	95	95	34.36	III	100	100	100	100	100	100	95	95	90.25	I
11	100	80	80	60	70	90	100	95	22.98	III	100	100	100	60	100	90	100	95	51.3	II
12	100	80	50	60	70	85	95	90	12.20	IV	100	80	80	60	100	90	95	90	29.54	III
13	100	80	80	100	70	85	95	90	32.55	III	100	100	100	100	100	90	95	90	76.95	I
14	100	80	80	90	70	90	95	90	31.02	III	100	100	100	90	100	90	95	90	69.25	I
15	100	40	50	60	5	85	100	95	0.48	V	100	40	50	60	5	90	100	95	0.51	V
16	100	40	50	60	5	85	95	95	0.46	V	100	40	50	60	5	90	95	95	0.49	V

Moisture (H), Drainage (D), Effective depth (P), Texture / structure (T), Soluble salt concentration(S), Organic matter content (O), Mineral exchange capacity / nature of clay (A) , Mineral reserve (M) , Productivity index (PI*) and Productivity Grades (G*)

Fig. 10 Productivity index of the studied area in 1961

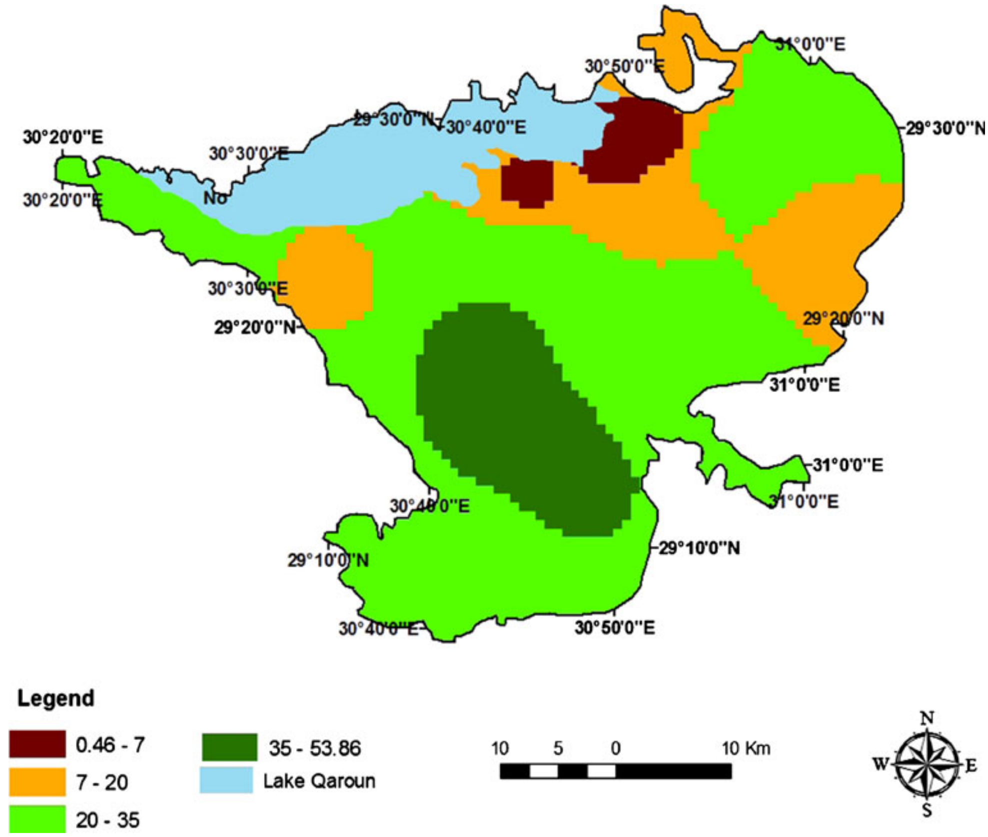
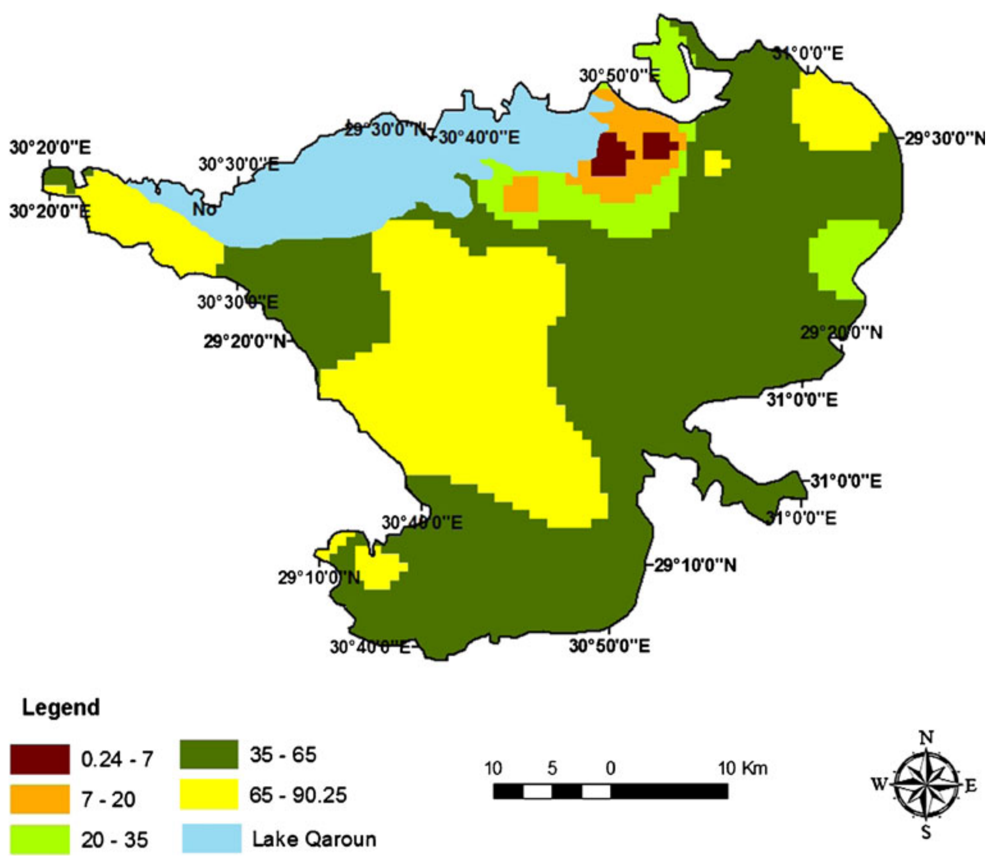


Fig. 11 Productivity index of the studied area 2010



– gypsum addition considering gypsum requirements to reduce soil alkalinity.

Recommendations

The economic situation of the farmers in Egypt is poor, aggravated by the relatively small farm sizes and different factors that limit agricultural production. The suggested management plans mentioned here is intended to improve on production and eventually economic situation of Egypt's farmers. The management plans proposed can be viewed into two perspectives: government-enforced plans and measures to be performed by the farmers themselves. The combinations between the management plans are related to the management in every test area in the application maps

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