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Soil quality assessment of El-Fayoum depression, Egypt, using remote sensing and GIS

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Abstract

El-Fayoum depression has a major source of irrigation Nile water in Bahr Youssef canal. It also has a special nature among all the other depressions. Between 1990 and 2020, there were changes in land use/cover. The entire area of bare soil is reducing by approximately 20427 ha, whereas the total area of urban areas is expanding by approximately 16335 ha, the total area of vegetation is increasing by approximately 3347 ha, and the total area of water bodies is increasing by approximately 860 ha.

Soil quality assessment is a tool for bettering soil management and land use. Soil quality indicators are a collection of physical, chemical, and biological aspects of soil that are used to measure its quality. The spatial variability for soil quality map for the study area was created using geostatistical techniques for GIS. The study's end purpose is to give a soil quality assessment based on parameters including EC, pH, OM, CEC, ESP, texture and $CaCO_3$. Using the Normalized Difference Vegetation Indices (NDVI) collected from satellite remote sensing data, the researchers calculated estimations of soil fertility from vegetation quality.

High soil quality occupies a small portion of the studied area, around 1.9 percent, while moderately soil quality occupies the largest portion of the studied area, around 52.7 % of the total area studied, and low soil quality occupies around 45.4 percent of the studied area.

Keywords: El-Fayoum depressions, Remote sensing and GIS, Soil quality

Introduction

Soil is a heterogeneous environmental medium with many solid, liquid, and gaseous components that interact in a variety of physical, chemical, and biological processes. Soil quality assessment interprets the most suitable use of its properties for crop production (FAO, 1993 and Debeljak et al. 2019). Soil quality refers to its capacity to function and sustain productivity (Doran and Parkin ,1994 and Harris et al. 1996). Soil quality refers to its ability to provide services as a result of its ability (Toth et al., 2007). The most basic scenario of soil quality evaluation is to analyze its capacity to give high crop production (Liang et al., 2006, Kinoshita et al., 2012 and Kome et al. 2020). It is important to assess and monitor soil quality to ensure sustainable use with minimal adverse consequences (Zornoza et al., 2015 and Kumar et al. 2019). One of the most widely used methods for determining soil quality index (SQI) is the Nemoro index (Zhang et al., 2009; Rahmanipour et al., 2014 and Bo et al., 2015). Management-driven soil quality index defines essential linkages between above- and below-ground elements (Blecker et al., 2012 and Mandal and Giri, 2021). Compaction, salinization, alkalization, water logging, erosion, sealing, and contamination are principal challenges to soil fertility in the Nile Delta (Mohamed et al., 2013, Abd El-Rahman, 2014 and Justin et al., 2021). Thapa and Murayama (2008) employed an analytical hierarchical process (AHP) and a geographic information system (GIS) to analyses land used for peri-urban agriculture. Land use research that focuses solely on land quality has not aided in the resolution of contemporary issues such as environmental degradation and land deterioration (Dengiz and Baskan, 2009). Some researchers have created new approaches that combine land quality assessment with additional factors such as sustainable land use, land use scenarios, soil health assessment, and environmental repercussions (Doran and Zeiss, 2000; Masto et al., 2008 and Shearer et al., 2009 and Justin et al., 2021). The Normalized Difference Vegetation Index (NDVI) is a relative measure of vegetation health and photosynthetic activity used to assess the decline or increase of vegetation productivity. There is a link between the NDVI and vegetation production (Pettorelli et al., 2005 and Safriel, 2007).

Climate factors and NDVI correlation was used to discriminate between human-induced and climate-induced biomass productivity (Herrmann et al., 2005; Wessels et al., 2007; Vlek et al., 2010 and Le et al., 2012 and Lyu et al., 2020). Remote sensing data can be combined with global climate data to determine land degradation (Herrmann et al., 2005; Bai et al., 2008b; Hellden & Tottrup, 2008; Vlek et al., 2008, and Zakeri and Mariethoz, 2021.

The current study was carried out on El-Fayoum depression to (i) evaluate the soil quality, (ii) assess the effects of land use changes on soil quality properties and (iii) produce soil quality status map of El-Fayoum governorate.

Materials and Methods

Site description

El-Fayoum depression, where El-Fayoum Governorate exists, is a huge depression about 90 kilometers south of Cairo, between latitudes 29 º 10` and 29 º 30` N and longitudes 30 º 20` and 31 º 10` E (Figure 1). It covers an area of 228145.2 ha. The climate is a desert one: arid with long hot rainless summer, mild with very low or no winter some rare and irregular storms may take place over scattered localities during winter. The average temperature range is 13.3 °C to 29.2 °C. Humidity varies from 41 % in May to 72 % in December and February, Figure 2 shows the climatologically diagram of El-Fayoum.

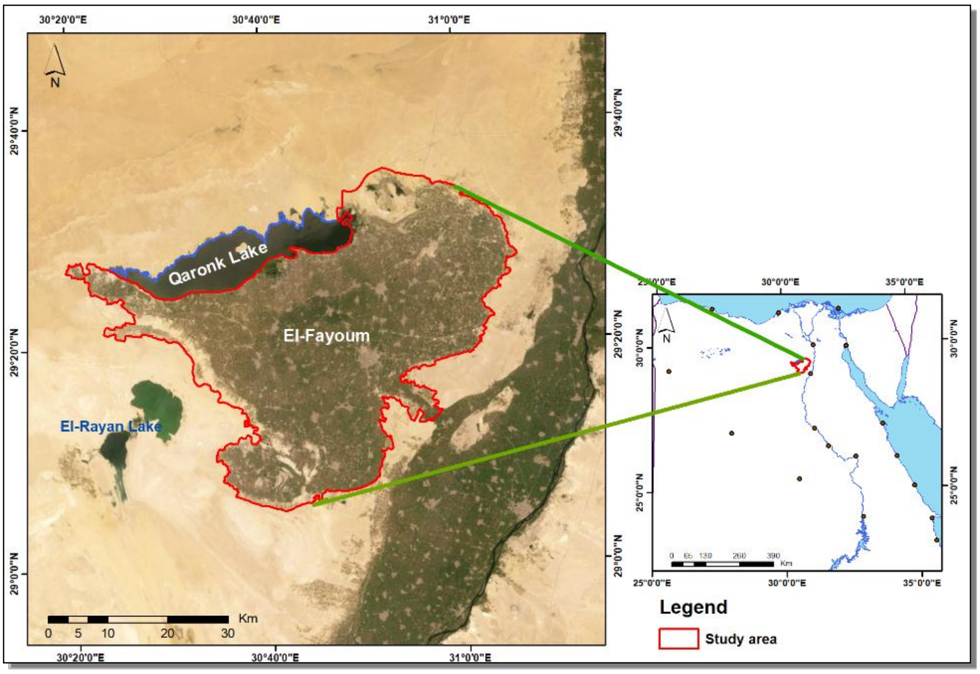

Fig 1: Location map of the studied area

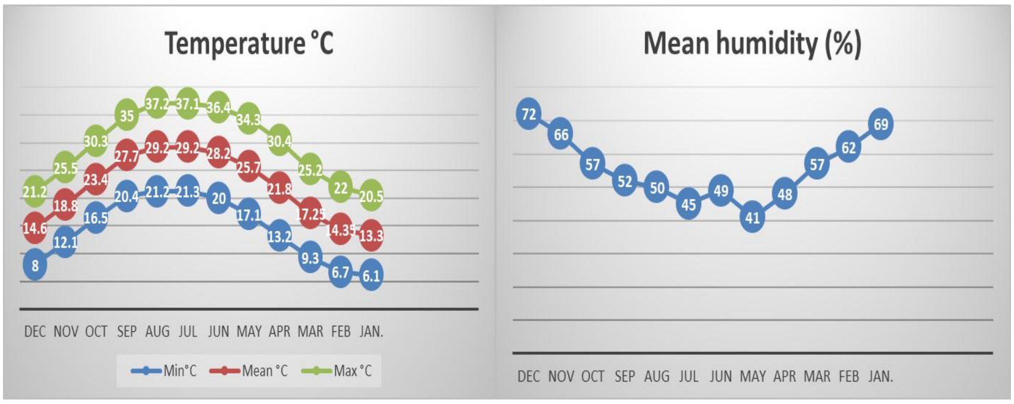

Fig 2: Climate data of El-Fayoum station

Remote sensing and GIS

To study changes in land use and vegetation cover the followings were used: ETM$^+$ (scene on 3-8-2000, Path/Row 177/40) and Operational Land Imager (OLI) land sate 8 acquired on 10-8-2020, Path/Row 177/40). The spectral resolution of OLI in the electromagnetic spectrum (Table 1) was used with bands 1-7, and 9 at a spatial resolution of 30 meters, bands 10 and 11(thermal bands) (TIRS) at 100 meters. Bands have spatial resolution of 15 meters. The OLI image (Band 3, 4, 5, 6 and7) is geometric corrected and projected to the UTM Zone 35N co-ordinate system using WGS 84 datum. Software ENVI, 5.3 (Environment for Visualizing Images) was used for image processing and analysis of the OLI satellite data.

Table 1. Landsat 8 characteristics.

Spectral band	Wavelength (μm)	Spatial resolution (m)
Band (1): Coastal/Aerosol	0.433-0.453	30
Band (2): Blue	0.405-0.515	30
Band (3): Green	0.525-0.600	30
Band (4): Red	0.630-0.680	30
Band (5): Near infrared	0.845-0.885	30
Band (6): Short wavelength infrared	1.560-1.660	30
Band (7): Short wavelength infrared	2.100-2.300	30
Band (8): Panchromatic	0.500-0.680	15
Band (9): Cirrus	1.360-1.390	30
Band (10): Long wavelength infrared	10.30-11.30	100
Band (11): Long wavelength infrared	11.50-12.50	100

Digital image enhancement

Digital image histogram manipulation used for image enhancement. Gaussian stretch enhancement was used to expand the narrow range of brightness in the image.

Classification assessment

Supervised classification was done using Support Vector Machine 'SVM' approach after field verification. The SVM is a classification system derived from statistical computations which provides reliable classification results (Chen et al., 2004 and Angel, 2020). SVMs have been used in many remote sensing-based applications. Such as land use and land cover, forest, and agriculture. SVMs were effective in handling the complex distributions of heterogeneous land cover of the study area.

Soil quality assessment

Soil quality assessments are conducted by evaluating indicators of physical, chemical and biological properties of soils. They can also be morphological or visual features of plants. Indicators are measured to monitor management changes in the soil (USDA, 2001). Table 2 show indicators of soil quality. Soil quality index includes three steps as follows (Karlen et al., 2003). 1) selection of indicators, 2) score assignment for the selected indicators and 3) integration of indicators in one index. In the current study, standard scoring functions (Andrews et al., 2002 and Qi et al., 2009) were used and scores (ranging between 0 and 1) were assigned. Based on the indicator sensitivity of soil quality, three types of functions were applied associated with high, low, or moderate values (Liebig et al., 2001). They are: 1) “More” function applies to CEC and OM for their roles in soil fertility, water availability and structural stability (Marzaioli et al., 2010). 2) “Less” function applies to K factor, because if high would be restrictive for soil functionality; and to equivalent calcium carbonate), because if high, in arid and semiarid climates, will have a negative effect on soil pH and mobility of nutrients. 3) “Optimal” function applies to pH and EC. In this case, threshold values or optimal ranges are: pH 7 (Liebig et al., 2001) and EC of 0.2 to 2 dSm^{-1}. Scores are assigned using the "more" or the "less" depending on whether the indicator is below or above the optimal range (Andrews et al., 2002).

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Results and Discussion

Soil mapping and classification

The soil classification of the Soil Taxonomy System (USDA, 2010) was applied up to the level of sub-great group for mapping unit. Aridisols and Entisols are the two soil orders found in the study area. Matching geomorphologic units with land characteristics and soil taxonomy, the final soil map was produced. Soil map was on a scale of: 1: 100000, as shown in Figure 3. The identified taxonomic units of the studied area are summarized in Table 3.

Table 3. Soil classification of the studied area

Geomorphologic units	Landforms	Profile No.	Soil Taxonomy
Old river terraces	High	7, 19, 25	Typic Torrifluvents
	Moderately high	3	Aquic Torrifluvents
		6, 12	Typic Torrivluvents
	Moderate	5, 11, 24	Typic Torrifluvents
	Low	4	Vertic Torrifluvents
		10	Aquic Torrifluvents
		23	Typic Torripsamments
	Alkali flats	9, 27	Typic Haplosalids
		26	Aquic Torripsamments
Basins	Overflow basin	1, 2	Typic Haplocalcids
		21	Typic Torrifluvents
		22	Vertic Torrifluvents
	Decantation basin	13, 20	Typic Torrifluvents
		28	Vertic Torrifluvents
Recent river terraces	High	16, 31, 32	Vertic Torrifluvents
		8	Typic Haplogypsids
	Moderatel	15, 30	Typic Torrivluvents
		17	Aquic Torriflvents
	Low	14	Vertic Torrifluvents
		18, 29	Typic Torrifluvents
		33	Typic Torripsamments

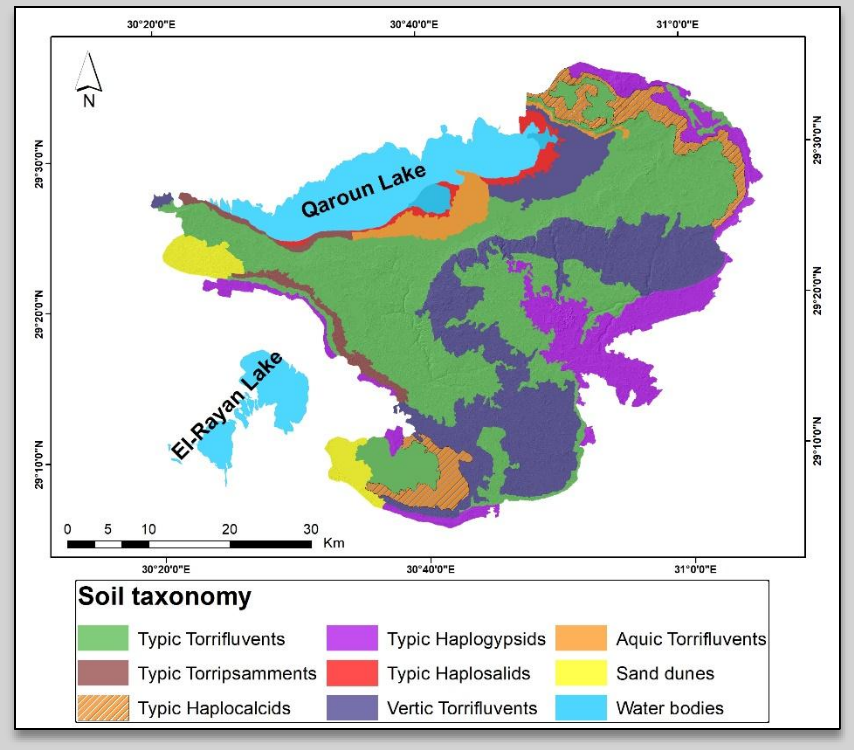

Fig. 3: soil map of the study area

Change in Land Use/Cover.

There was a marked change in Land Use/Cover area as shown in in the status of agriculture, bare soils, urban, and water bodies (Figures 4 and 5).

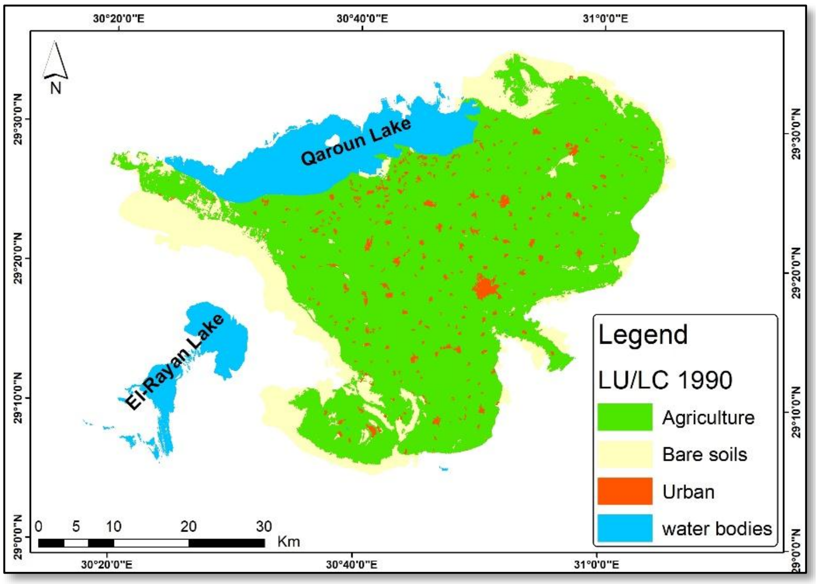

Fig. 4: Land Use/Cover map for the study area in 1990

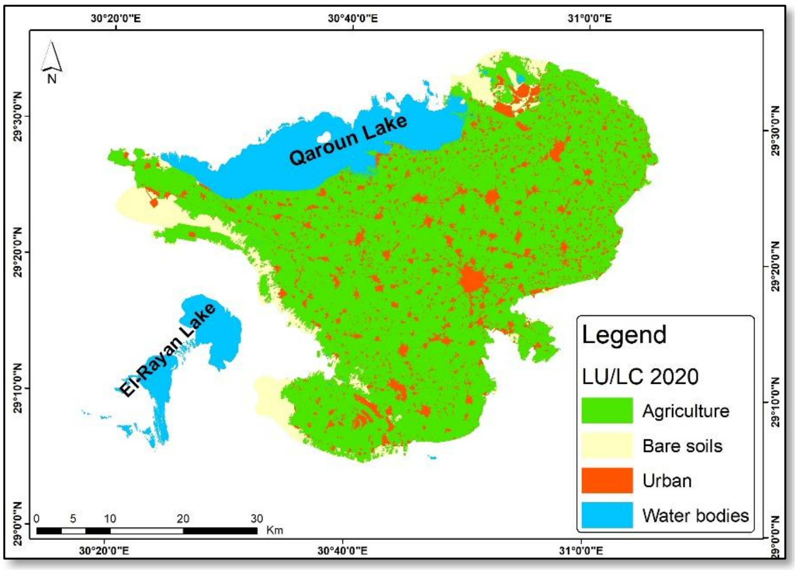

Fig. 5: Land Use/Cover map for the study area in 2020

There was a noticeable decrease in the bare soil area, with an average of 204.27 ha, and this decrease was the result of the reclamation of bare lands. Despite the increase in the area of reclaimed land, the area of agricultural land is almost constant or very slightly increased, and this is a result of the increase in urban encroachment ovrt the arable land. The water bodies were almost constant during the years 1990 and 2020.

Table 4: Change detection of the study area between 1900 and 2020

Feature	*Area in 1990 (ha)*	*Area in 2020 (ha)*	*Exchange (ha)*
Agriculture	153400	156747	3347
Urban	5800	22135	16335
Bare soil	36500	16073	- 20427
Water bodies	35715	36575	860

Soil quality

Soil properties are sensitive to stress or disturbance (Rahmanipour *et al*. 2014). The study derived estimates of soil fertility from the vegetation quality using the Normalized Difference Vegetation Index (NDVI) obtained from the satellite remote sensing data Landsat image data (bands 3 and 4) acquired in 2020. The detailed soil classification map produced was used for soil fertility. The soil classes were grouped on the potential to release nutrients for crops. For example, a well-drained soil, with high loam is more fertile than a poorly drained one. The soil classes were indexed based on the potential of the soil to provide nutrients for plant. The calculated NDVI values are shown in Figure 6.

Geo-statistical analysis

Geo-statistical analysis (Arc GIS 10.2 software) allowed mapping of the spatial distribution of soil quality classes using spatial interpolation as shown in Table 5. Model builder in Arc GIS was used to integrate the available factors for determining soil quality in the investigated area (Figures 7 and 8) area.

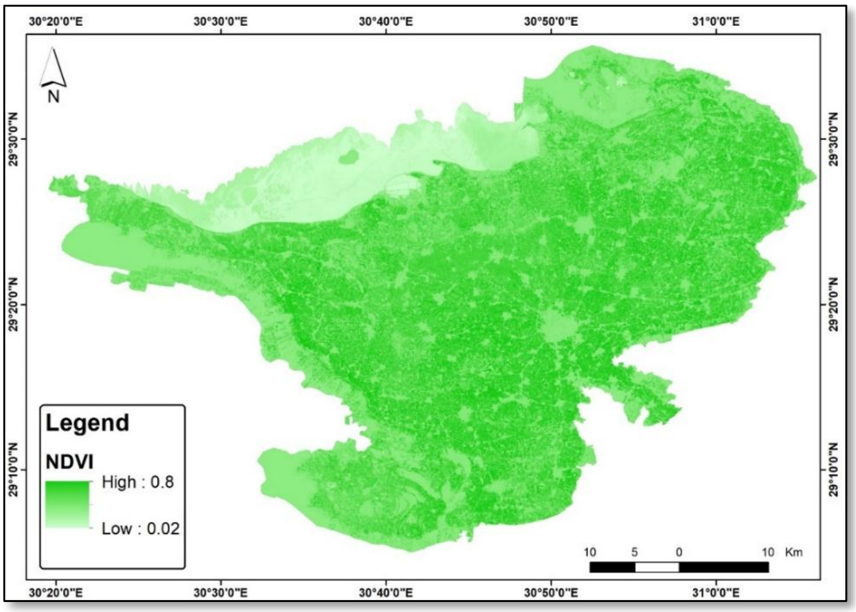

Fig. 6: Normalized Difference Vegetation Index NDVI of the study area

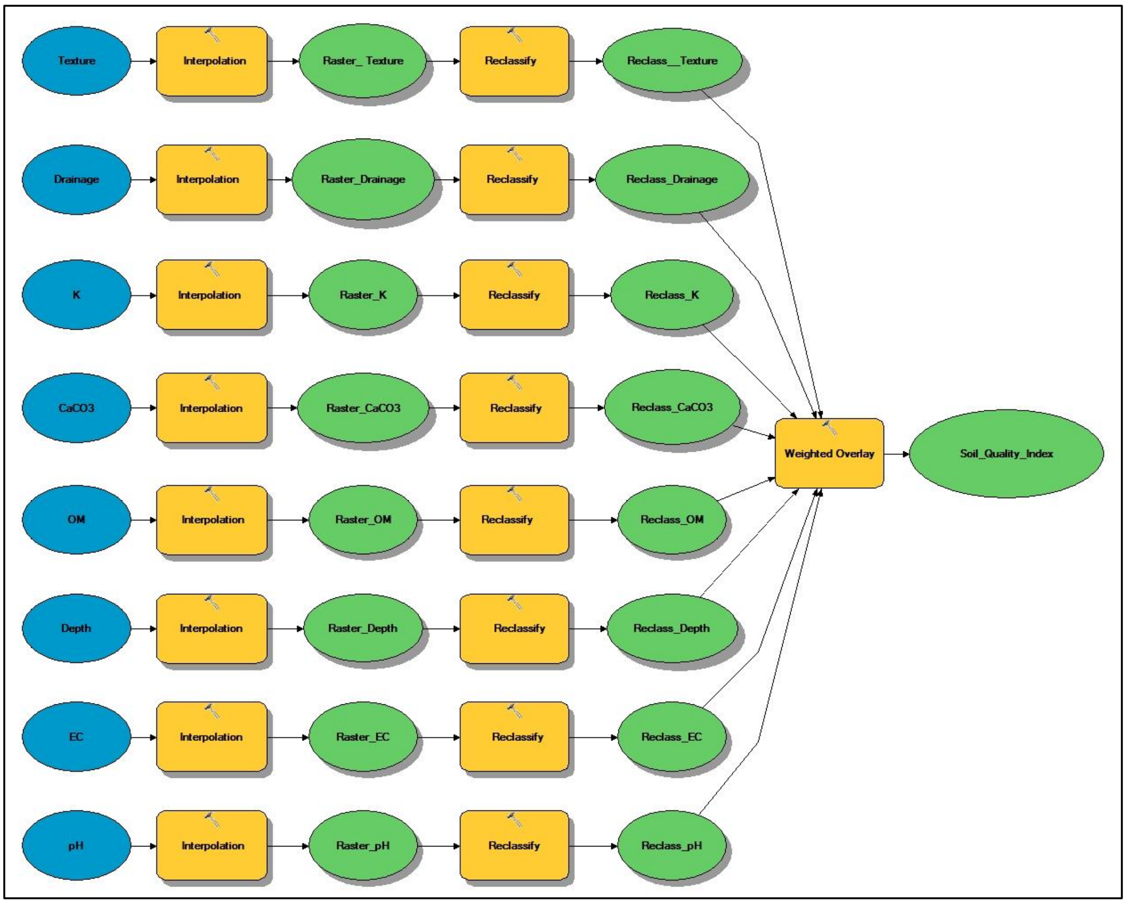

Fig. 7: model builder used for soil quality assessment

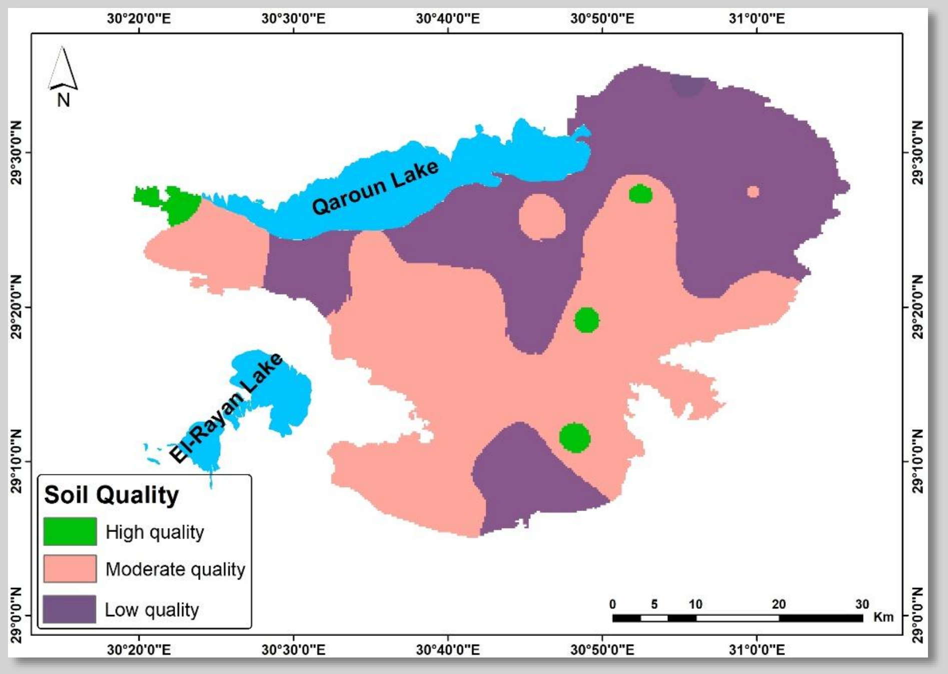

Fig. 8: Soil quality map of El-Fayoum governorate

Table 5: soil quality classes, the area(ha)and percentage (%) of the study area

Soil quality class	*area (ha)*	*percentage (%)*
High quality	3790.8	1.9
Moderate quality	102728.6	52.7
Low quality	88435.6	45.4

Conclusion

Procedures were tested using Landsat ETM image from two different dates. This was done to better comprehend the studies and analyses the many change detections that were present. The human factor plays a significant role in accelerating and initiating soil problems of urban encroachment over arable lands. Human activity alters the landscape in numerous ways, which has an impact on the rate at which soil quality deteriorates. To ensure sustainable land use, procedures to monitor soil quality must be done. Physical, chemical, and biological features, processes, and traits are examples of soil quality indicators used for assessing soil quality changes. Soil quality indicators are crucial for focusing conservation efforts on maintaining and enhancing soil conditions, as well as evaluating management approaches and procedures that are related to soil quality.

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تقييم جودة التربة في منخفض الفيوم ، مصر باستخدام الاستشعار عن بعد ونظم المعلومات الجغرافية

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يختلف منخفض الفيوم عن كل المنخفضات الأخرى في مصر لأن المصدر الرئيسي لمياه الشرب والري يأتي من قناة النيل (بحر يوسف). كما أن لها طبيعة خاصة بين جميع المنخفضات الأخرى.

بين عامي 1990 و 2020 ، يوجد تغييرات كثيرة في استخدام الأراضي والغطاء الارضي في منطقة الدراسة. تتناقص مساحة التربة العارية بالكامل بنحو 20427 هكتارًا، بينما تتوسع المساحة الإجمالية للمناطق العمرانية بنحو 16335 هكتارًا ، ويزداد إجمالي مساحة الغطاء النباتي بحوالي 3347 هكتارًا ، وكذلك تزداد إجمالي مساحة المسطحات المائية بحوالي 860 هكتار.

تقييم جودة التربة هو أداة لتحسين إدارة التربة واستخدام الأراضي. مؤشرات جودة التربة هي مجموعة من الجوانب الفيزيائية والكيميائية والبيولوجية للتربة التي تُستخدم لقياس جودتها. تم إنشاء التباين المكاني لخريطة جودة التربة لمنطقة الدراسة باستخدام تقنيات الإحصاء الجغرافي لنظام المعلومات الجغرافية. الغرض النهائي من الدراسة هو تقديم تقييم جودة التربة بناءً على معايير تشمل EC ، ودرجة الحموضة ، و OM ، و CEC ، و ESP و القوام و CaCO3. باستخدام مؤشرات الغطاء النباتي (NDVI) التي تم جمعها من بيانات الاستشعار عن بعد عبر الأقمار الصناعية ، كما تم حساب تقديرات خصوبة التربة من جودة الغطاء النباتي.

تحتل جودة التربة العالية جزءًا صغيرًا من المنطقة المدروسة ، حوالي 1.9 بالمائة ، بينما تحتل الجودة التربة العالية المتوسطة وجودة التربة المتوسطة الجزء الأكبر من المنطقة المدروسة ، حوالي 97.6 ٪ من إجمالي المساحة المدروسة ، وتشغل جودة التربة المنخفضة الجزء الأصغر من المنطقة المدروسة حوالي 0.5 في المائة من إجمالي المساحة المدروسة.