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Assessment of Soil Quality Using Remote Sensing and GIS Techniques in Some Areas of North-East Nile Delta, Egypt

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THE STUDY area is located north-east Nile Delta, north Ismaillia - south Port Said Governorates on the west side of Suez Canal, with total area approximately of 183136 ha. The water resources in the study area depend on Nile water flowing to the area through El-Salam Canal in the northward of the area meanwhile the southern part is supplied from Ismaillia canal. There are changes between land use/cover feature in investigated area for year 2000 and year 2015. The total area of bare soil are decreasing, about 33799 ha also the total area of urban areas are increasing about 2760 ha also the total area of vegetation are increasing; about 23270 ha and the area of water bodies are increasing; about 7770 ha. Soil quality evaluation is a tool to improve soil management and land use system. A large number of different physical, chemical and biological properties of soil, known as soil quality indicators, are used to soil quality assessment. The geo-statistical approaches for GIS were used to produce the spatial variability for soil quality map for the studied area. The final goal of this study is to present soil quality assessment based on properties such as EC, pH, OM, CEC, ESP and $CaCO_3$. The study derived estimates of soil fertility from the vegetation quality using the Normalized Difference Vegetation Indices (NDVI) obtained from the satellite remote sensing data. High soil quality class occupies small area of the area around (16 %), while the intermediate class occupies 28.5% and low soil quality occupies 55.5 %.

Keywords: Nile Delta, Remote sensing and GIS, NDVI, Geostatistical, Soil quality.

Soil is a complex environmental medium with high heterogeneity where solid, liquid and gaseous components interact within a multitude of physical, chemical and biological interrelated processes. Soil provides ecosystem services such as food, water, timber, and fiber; regulating services that affect climate, floods, disease, waste and water quality; cultural services that provide recreational, aesthetic and spiritual benefits; and supporting services such as nutrient cycling (MEA, 2005). Land evaluation has developed from soil science; methods for the evaluation of the potential for the productivity of soil have recently been called “land” evaluation methods (Mueller *et al*., 2010). In the 1970s, FAO proposed the concept of land quality and published a frame-work for land evaluation (FAO, 1976). Since then, research on land quality has progressed gradually. Land quality has been defined as “the condition and capacity of land, including its soil, climate, topography and biological properties, for purpose of production, conservation, and environmental management” (Pieri *et al*., 1995). The definition of soil quality (SQ) has long been a challenging issue, since soils present high variability in properties, characteristics and functions. The most integrative definitions are those established by Doran and Parkin (1994) and Harris *et al*. (1996), who defined SQ as the capacity of a soil to function within the limits of use, landscape and climate (ecosystem) to protect air and water quality, and to sustain productivity and plants, animals and human health. Nonetheless, despite the different definitions for SQ, there is no general consensus yet, likely due to the innate difficulty of definition of soil (Carter, 2002). Soil quality is an account of the soil’s ability to provide ecosystem and social services through its capacities to perform its functions under changing conditions (Toth *et al*., 2007). The simplest case of soil quality evaluation therefore is to assess the performing potential of soil by a single soil function. On higher levels of aggregation soil quality can express the sum of capacities.

Soil quality assessment is one of the core components of soil quality study, and several methods of soil quality assessment exist (Liang *et al*., 2006 and Kinoshita *et al*., 2012). Soil quality (SQ) assessments in different scenarios providing evidence about the interrelationship between SQ, land use and human health. There is a general consensus that there is a need to develop methods to assess and monitor SQ for assuring sustainable land use with no prejudicial effects on human health. The importance of adopting indicators of different nature (physical, chemical and biological) to achieve a holistic image of SQ (Zornoza *et al*., 2015). The Nemoro index method is one of the most commonly used methods for calculating of soil quality indices, both domestic and abroad (Zhang *et al*., 2009; Rahmanipour *et al*., 2014 and Bo *et al*., 2015). Soil quality indices (SQIs) are often management driven and attempt to describe key relationships between above- and below-ground parameters. In terrestrial systems, indices that were initially developed and modified for agro ecosystems have been applied to non-agricultural systems in increasing number (Blecker *et al*., 2012). The main threats to soil functioning abilities in Nile Delta are identified as compaction, salinization, alkalinization, water logging, erosion, sealing and contamination (Mohamed *et al*., 2013 and Abd El-Rahman , 2014). In addition, with rapid development of the 3S technology, better methods have been developed to assess land quality. Thapa and Murayama (2008) used an analytical hierarchical process (AHP) and geographic information system (GIS) to evaluate land used for peri-urban agriculture. Applying remote sensing (RS) and GIS to evaluate land quality and sustainable land use. Studying land utilization only by focusing on land quality has not contributed to solving such current problems as environmental degeneration and deterioration in land quality and land health (Dengiz & Baskan, 2009). Some researchers have developed new methods that integrate evaluation of land quality with other aspects such as sustainable land use, scenarios of land use, assessment of soil health, and estimating the environmental consequences of development (Doran and Zeiss, 2000; Masto *et al*., 2008 and Shearer *et al*., 2009). Agricultural land health assessment as an aggregate that takes into account the quality and productivity of land or soil as well as the soil environment, which is one of the targets and trends assessing soil productivity function.

The Normalized Difference Vegetation Index (NDVI), a relative measure of vegetation health and photosynthetic process, is increasingly used for evaluating vegetation productivity decline or improvement. The relationship between the NDVI and vegetation productivity is well-established theoretically and empirically (Pettorelli *et al*., 2005 and Safriel, 2007). Previous studies (Wang *et al*., 2008; Zhao & Running, 2010; Fensholt *et al*., 2012) have found that NDVI is strongly correlated with NPP and is often used to estimate NPP at global, national and regional scales, and served as an indicator of NPP to monitor temporal changes in vegetation. Above-ground net primary production (represented by NDVI) showed to increases with increasing annual precipitation (Huxman *et al*., 2004). Correlation studies between climate factors (rainfall and temperature) and NDVI have been used to distinguish between human-induced and climate-induced biomass productivity, where any NDVI trends not explained by rainfall and temperature dynamics are ascribed to human actions (Herrmann *et al*., 2005; Wessels *et al*., 2007; Vlek *et al*., 2010 and Le *et al*., 2012). Combined with global climate data, the remote sensing data are used extensively to infer land degradation at global, continental and regional scales (Herrmann *et al*., 2005; Bai *et al*., 2008b; Hellden & Tottrup, 2008 and Vlek *et al*., 2008), often with rather conflicting results.

The current study was carried out to (i) evaluate the soil quality depending on soil physical and chemical characteristics as well as biodiversity factors; (ii) assess the effects of land use changes on soil quality properties in east of Nile Delta using remotely sensing data; and (iii) produce soil quality status map of north-east of Nile delta.

Materials and Methods

Site description

The studied area occupies the southern part of EI-Salam Canal. It extends towards the north edge of Ismailia Governorate on the west side of Suez Canal, it is bounded by longitudes 31° 51' - 32° 19' E and latitudes 30° 35' - 31° 03' N, (Fig. 1). It is covers an area of 183136 ha, having an elevation from 0 to 30 m above sea level. The study area is characterized by arid condition where the climatic data were collected from Port Said and Ismailia Stations, as monthly average of period from 2000 to 2013. Figures 2 and 3 represent the meteorological data of Port Said and Ismailia stations. The average temperature was 21.67 °C in Port Said and 21.60 °C in Ismailia, with a wide difference between summer and winter months. Total annual rainfall in Port Said was 71.3 mm and decreased to 38.3 mm in Ismailia. The values of relative humidity varied from 68 to 73 % in Port Said and 51 to 65 % in Ismailia,. The wind velocity ranged between 15.9 to 19.4 km/h at Port Said Station recorded in December and April, respectively. While at Ismailia it was 10.6 and 15.6 km/h recorded in November and April, respectively.

Remote sensing and GIS

To study changes in land use and vegetation cover as indicators of soil quality ETM$^+$ scene dated to 21-4-2000, Path/Row 176/39 and Operational Land Imager (OLI) land sate 8 acquired on 19-04-2013, Path/Row: 176/39 were used in this study. The spectral resolution of OLI in the electromagnetic spectrum ranging in different spatial resolutions (Table 1), where bands 1-7, and 9 have a spatial resolution of 30 meters, bands 10 and 11(thermal bands) (TIRS) has 100 meters, meanwhile band 8 (panchromatic) has spatial resolution of 15 meters . The OLI (Band 3, 4, 5, 6 and7) image is geometric corrected and projected to the UTM Zone 35N coordinate system using WGS 84 datum. Software ENVI, 5.1 (the Environment for Visualizing Images) was used for image processing and analyses of the OLI satellite data.

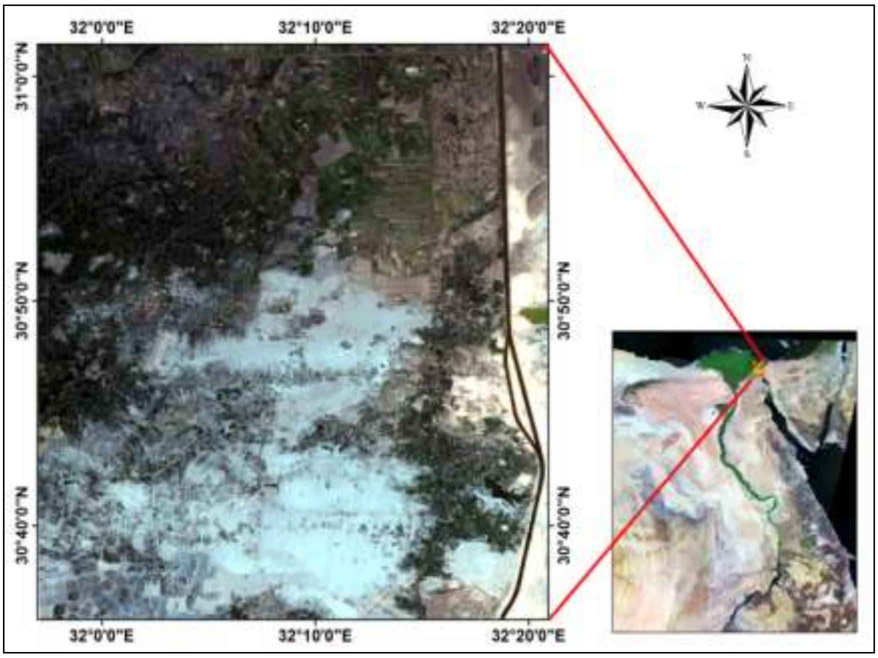

Fig. 1. Location map of the studied area

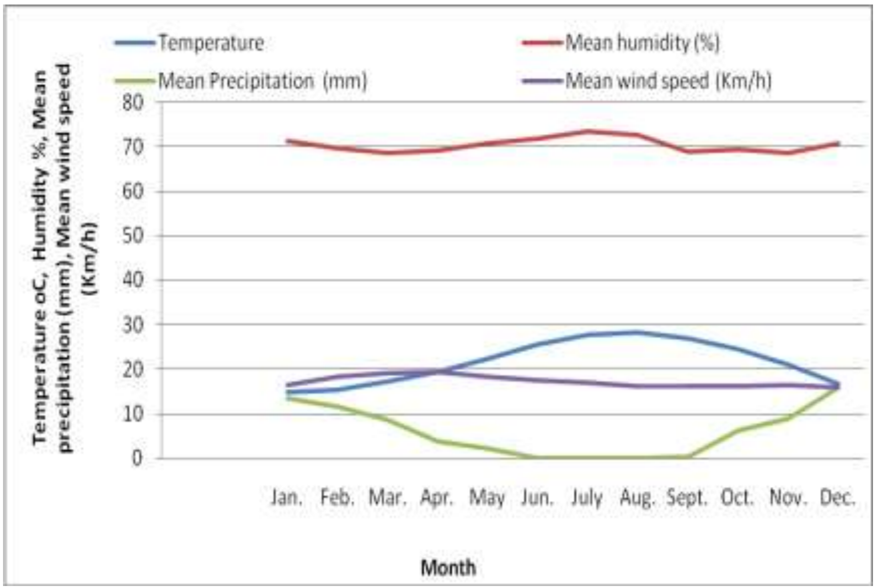

Fig. 2. Climatologic data of Port-said station

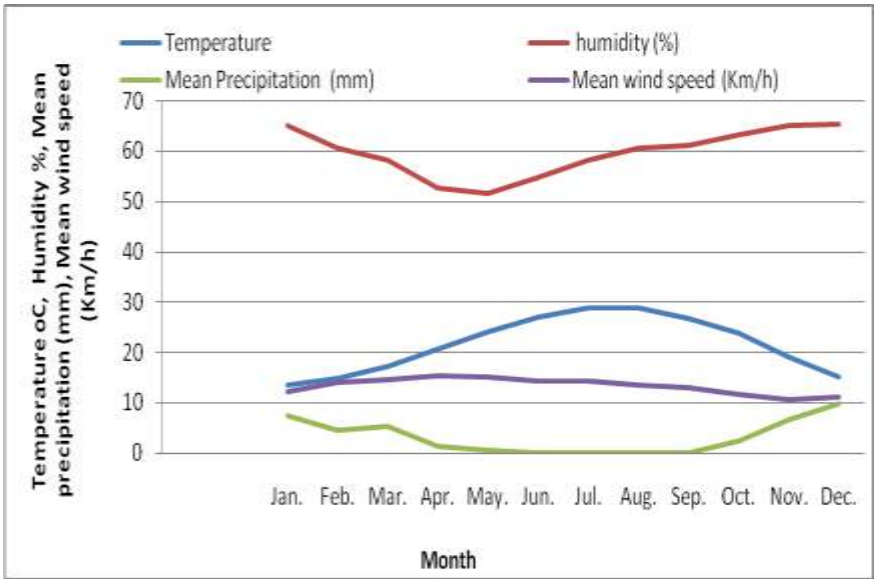

Fig. 3. Climatologic data of Ismailia station

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

Image enhancement is done by digital image histogram manipulation Gaussian stretch enhancement to expand the narrow range of brightness values present in the image.

Classification assessment

Supervised classification was achieved using Support vector machines SVM approach after field verification. SVMs have been used in many remote sensing-based applications. For example, land use and land cover, forest and agriculture tasks. SVMs classifier turned out to be an effective method of handling not only the complex distributions of the heterogeneous land cover classes that characterized the study area but also in various spatial resolution scales. SVM is a classification system derived from statistical learning theory that provides good classification results from complex and noisy data (Chen *et al*., 2004).

Soil quality assessment

Soil quality assessments are conducted by evaluating indicators can be physical, chemical and biological properties, processes, or characteristics of soils. They can also be morphological or visual features of plants. Indicators are measured to monitor management induced changes in the soil (USDA, 2001). Table 2 show indicators of soil quality.

Soil quality index includes the following three steps: (1) selection of indicators, (2) score assignment for the selected indicators and (3) integration of indicators in one index (Karlen *et al.*, 2003). In this 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, where the most reliable soil functionality was associated with high, low or intermediate values (Liebig *et al*., 2001): (1)

"More is better" function was applied to CEC and OM for their roles in soil fertility, water partitioning and availability and structural stability (Marzaioli *et al*., 2010). (2) "Less is better" function was applied to K factor, because their high concentration was considered restrictive for a good soil functionality and to equivalent calcium carbonate (TNV), because its high values, in arid and semiarid climates, had a negative effect on soil pH and on mobility of nutrient elements (3) "Optimal range" function was applied to pH and electrical conductivity. In this case, threshold values or optimal ranges were identified: 7 for pH (Liebig *et al*., 2001) and 0.2–2 dSm^{-1} for electrical conductivity and scores were assigned using the more is better or the less is better function depending on whether the indicator value was below or above the optimal range (Andrews *et al*., 2002).

TABLE 2. Data set of indicators for soil quality

Indicator	**Relationship to Soil Health**
Soil organic matter (SOM)	Soil fertility, structure, stability, nutrient retention, soil erosion, and available water capacity
Physical	
Soil structure	Retention and transport of water and nutrients, habitat for microbes, and soil erosion
Depth of soil and rooting	Estimate of crop productivity potential, compaction, and plow pan
Infiltration and bulk density	Water movement, porosity, and workability
Chemical	
Electrical conductivity	Plant growth, microbial activity, and salt tolerance
Extractable nitrogen (N), phosphorus (P), and potassium (K)	Plant available nutrients and potential for N and P loss

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, and to family level for the profile description. Soils in the study area are belonging to two soil orders, Aridisols and Entisols.

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 Fig. 4. The identified taxonomic units of the studied area are summarized in Table 3.

TABLE 3. Soil classification of the studied area

Soil Taxonomy	Area / ha.	Area %
Typic Natrargdis	5354.25	3.1
Typic Haplargids	2561.40	1.46
Gypsiferrous swamps	1300.50	0.74
Typic Haplogypsids	3031.10	1.73
Typic Haplosalids	37993.31	21.7
Typic Torrifluvents	19527.26	11.15
Typic Torripsamments	51759.01	29.56
Typic Torriorthents	29599.50	16.91
Vertic Haplargids	5044.60	2.88
Vertic Torrifluvents	10630.01	6.07
Urban	2883.10	1.65
Island	426.42	0.24
Water	4971.11	2.84
Total	175080.5	100

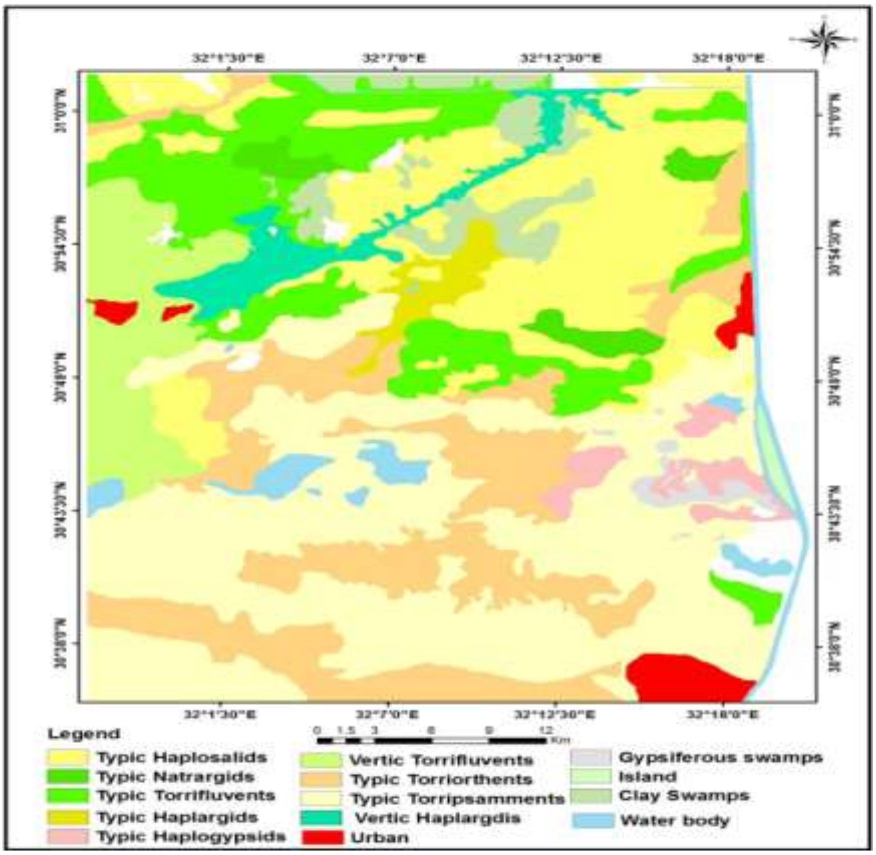

Fig. 4. Soil map of the studied area

Land Use/Cover in the investigated area from 2000 to 2015

The Land Use/Cover Area was generated from the available imagery by systematic interpretation, followed by ground truth and digitization using Landsat 2000 and 2015 imagery as shown in Fig. 5 and 6. There was a remarkable change in Land Use/Cover percent between the two dates 2000 and 2015. This detection helps in monitoring and evaluating differences in land use/cover due to environmental conditions and human actions in future between the acquisition dates of images involved, and with the use of multi-date images. Both dates deal with the status of bare soils, urban areas, vegetation and water bodies.

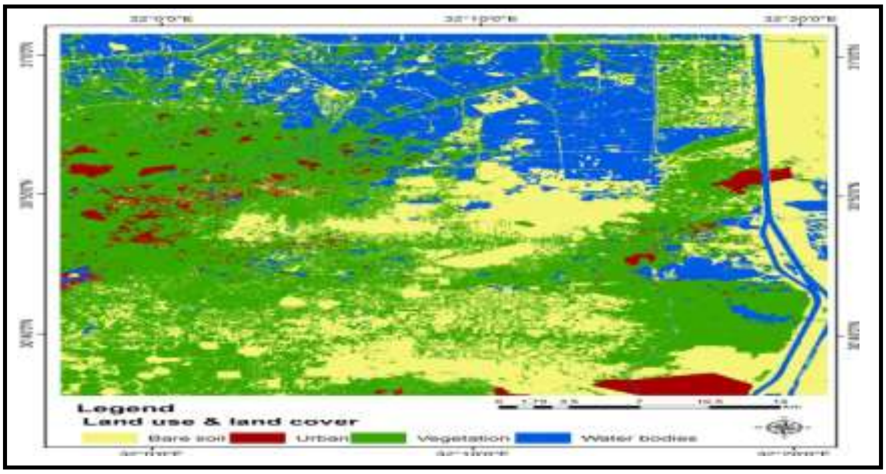

Fig. 5. Land Use/Cover map for the study area in 2000

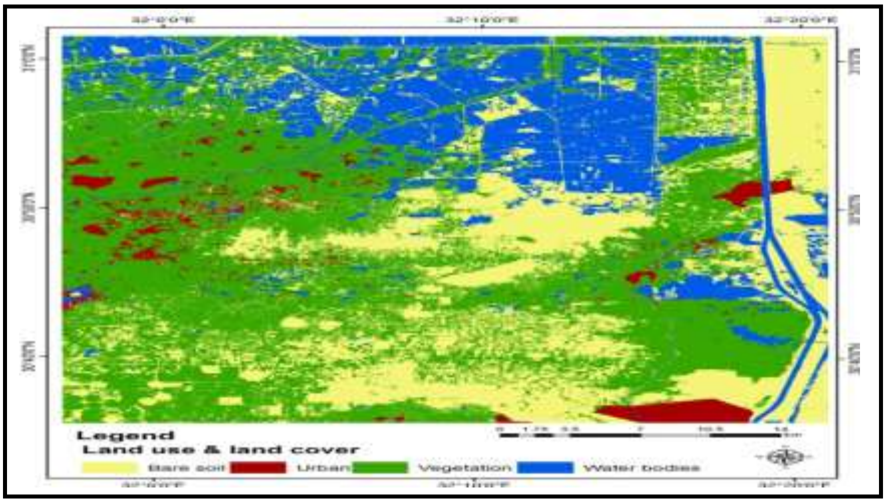

Fig. 6. Land Use/Cover map for the study area in 2015

Change detection in Land Use/Cover in the investigated area from 2000 to 2015.

There are changes between land use/cover feature in investigated area for the year 2000 and the year 2015. The summation area of bare soil for the year 2000 are 90446.6 ha and become for 2015 56647.5 ha with decreasing about 33799.1 ha also the sum area of urban area are 3541.9 ha for 2000 and become 6302.2 ha for 2015 with increasing about 2760.3 ha also the sum area of soils vegetation are 60927.1 ha for 2000 and become 84196.6 ha for 2015 with increasing in area about 23269.5 ha and the sum area of water bodies are 28219.7 ha for 2000 and become 35989.6 ha for 2015 with increasing in area about 7769.9 ha. Table 4 and Fig. 7 show the change detection between land use/cover features during the period of 2000 – 2015 in the study area.

TABLE 4. Change in the area of land use/cover of the study area between (2000 and 2015)

Feature	Area in 2000 (ha)	Area in 2015 (ha)	Exchange (ha)
Bare soil	90446.6	56647.5	- 33799.1
Urban	3541.9	6302.2	+ 2760.3
Vegetation	60927.1	84196.6	+ 23269.5
Water bodies	28219.7	35989.6	+ 7769.9

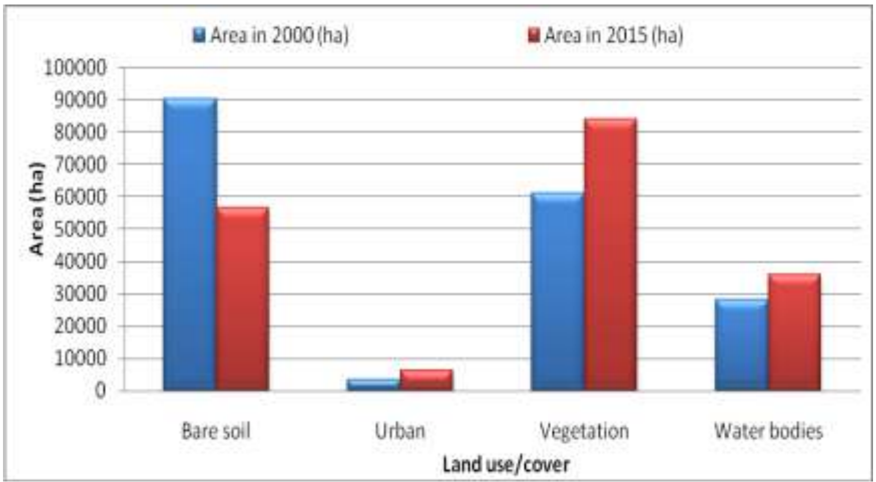

Fig. 7. Change detection between land use/cover features during the period of 2000 – 2015 in the study area

Soil quality

Soil quality evaluation is a tool to improve soil management and land use system. A large number of different physical, chemical and biological properties of soil, known as soil quality indicators, are used to soil quality assessment. These properties, that are sensitive to stress or disturbance, are calculated according to Rahmanipour *et al*. (2014). This approach resulted in a suitable evaluation of the effects of land management practices on soil quality. This latter result was particularly relevant in the studied area because the use of a limited number of indicators would reduce the cost of the analysis and to increase the sampling density in order to obtain a more detailed evaluation of soil quality through a geo-statistical approach.

The study derived estimates of soil fertility from the vegetation quality using the Normalized Difference Vegetation indices (NDVI) obtained from the satellite remote sensing data Landsat image data (bands 3 and 4) acquired in 2015 such data were used to compute the NDVI of the study areas. The detailed soil classification map produced was used to estimate soil fertility. The soil classification provided sufficient detailed analysis. The soil classes were regrouped based on the potential for the soil to release nutrients for crop use; for example a well- drained soils, with high percentage of loam is considered more fertile than a poorly drained sandy loam. The soil classes were indexed based on the potential of the soil to free nutrients for plant use. The calculated NDVI for the study area is shown in Figure 8.

Geo-statistical analysis

Geo-statistical analysis (Arc GIS 9.3 software) allowed mapping of the spatial distribution of soil quality classes identified using spatial interpolation methods as shown in Table 4. Interpolation is the process of predicting values to unknown sites, considering the information on the geographical location of the points, actually sampled. Model builder in Arc GIS used to integrate the available factors for determining soil quality for the investigated area as shown in Figure 9 and 10. The results show that class of High Soil Quality occupies small area of the studied area around 16 % while the Intermediate class occupies 28.5 %. The results show that the class of low Soil Quality occupies a larger area of the studied area, around 55.5 %.

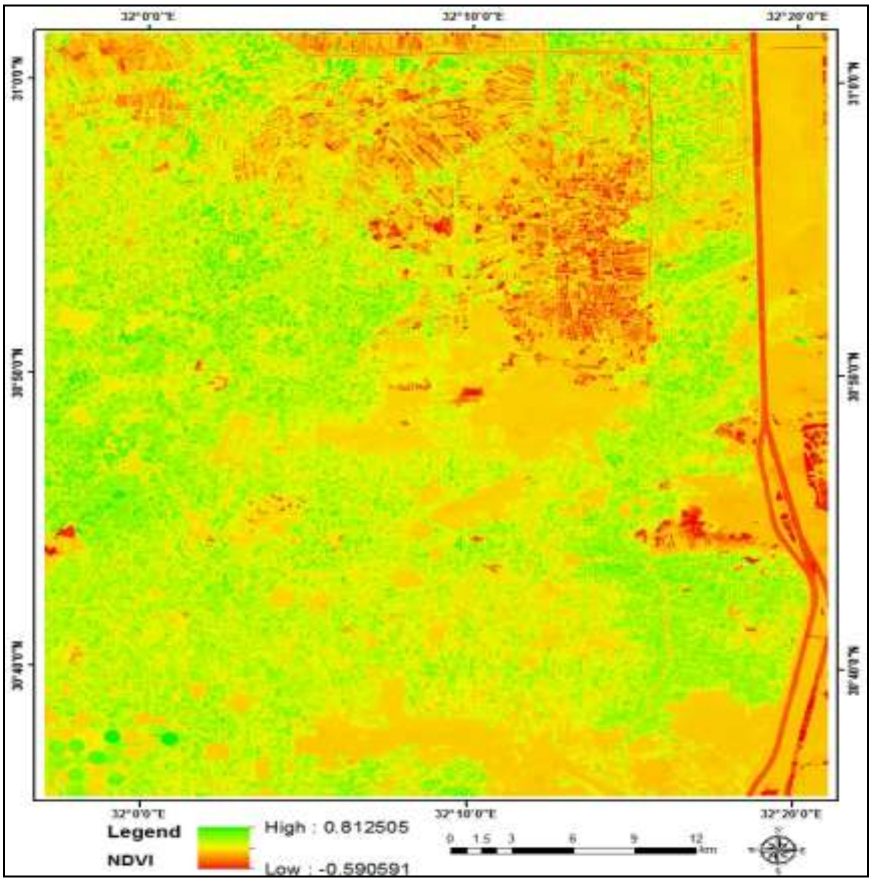

Fig. 8. NDVI used for soil quality assessment

TABLE 5. Soil quality classes

Soil Quality class	**Area in ha**
High	29438
Intermediate	52199
Low	101499

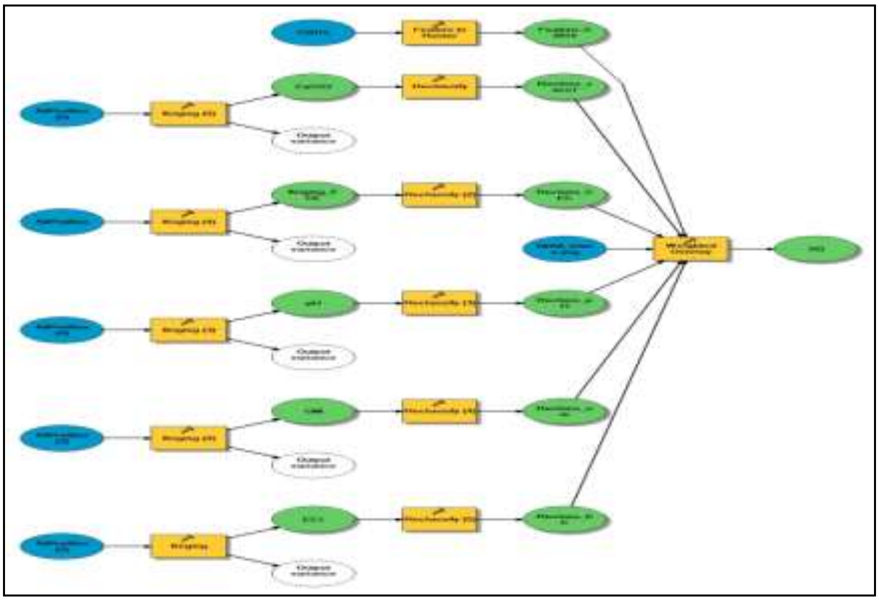

Fig. 9. Model builder used for soil quality assessment

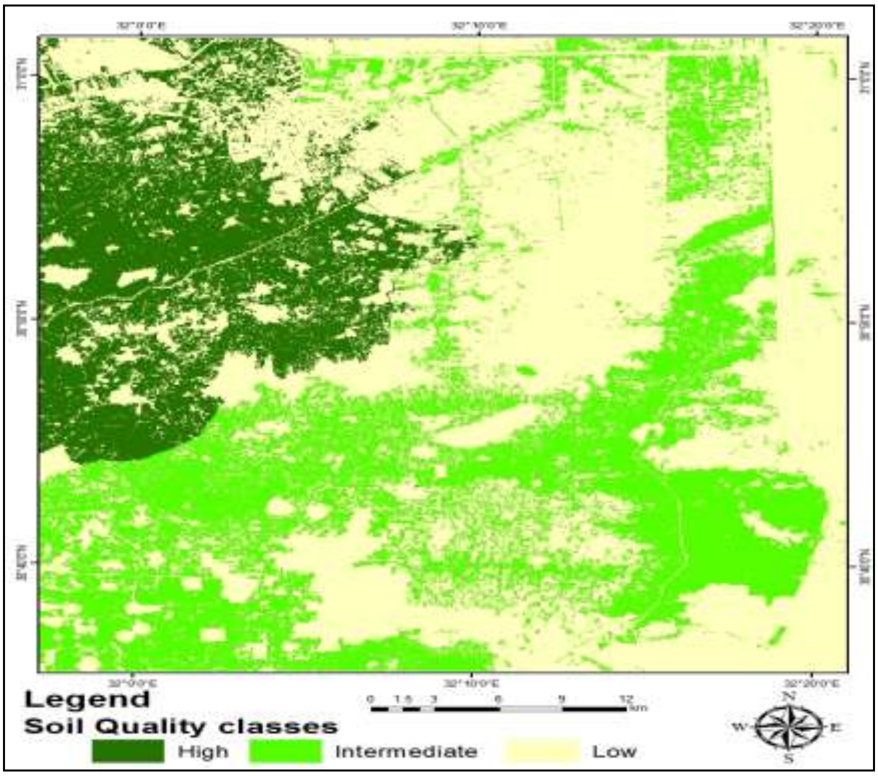

Fig. 10. Soil quality map for the study area

Conclusion

The results revealed are consistent with the change detection techniques applied for the study area. These techniques were studied independently with available images of the Landsat ETM of two dates. This has been done to understand analyses and evaluate the different change detections that occupied. The human factor is a considerable factor in both accelerating and initiating the problem of soil sealing (urban sprawl). The human activity causes many changes in the landscape which will have an impact on the rate of lowering soil quality degree. There is a need to develop methods to assess and monitor soil quality for assuring sustainable land use. A review of different soil quality assessment studies indicated that there is an increased concern of using indicators of different nature to assess soil quality. Soil quality indicators are physical, chemical, and biological properties, processes, and characteristics measured to monitor changes in the soil. Soil quality indicators are important to focus conservation efforts on maintain and improve conditions of the soils, evaluate their management practices and techniques, relate their qualities to those of other resources, collect the necessary information to determine trends, in soil health, and guide land manager decisions.

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تقيـيم جـودة التربــة بأسـتخدام تقنيـات الاستشـعار عـن بعـد ونظـم المعلومـات الجغرافيـة فـى بعض منـاطق شـمال شـرق دلتـا النيـل - مصر

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تقع منطقة الدراسة شمال شرق دلتا النيل شمال الاسماعيلية – جنوب بورسعيد علـى الجانـب الغربـى لقنـاة السـويس والمسـاحة الكليـة لمنطقـة الدراسـة تقريبـا 183136 هكتار. وتعتمد منطقة الدراسة على مياه النيل فى الرى من خلال ترعة السلام فى الجانب الشمالى من المنطقة بينما الجانب الجنوبى تغذيه مياه ترعة الاسماعيلية. وتوجد تغيرات زمنية فى استخدامات التربة من عام 2000 وحتى عام 2015 حيث انخفضت مساحة الاراضى البور بمقدار 33799 هكتار وزادت المساحات العمرانية بمقدار 2760 هكتار بينما زادت المساحات الخضراء بمقدار 23270 هكتار اما الاجسام المائية فارتفعت مساحتها بمقدار 7770 هكتار. يعتبر تقييم جودة التربة بمثابة اداة لتحسين ادارة ونظام استخدام التربة وعدد كبير من خصائص التربة الطبيعية والكيميائية والبيولوجية تعرف كمؤشرات لتقييم جودة التربة. وقد استخدم التحليل الاحصائى المكانى لنظم المعلومات الجغرافية لانتاج التباين المكانى لخريطة جودة التربة لمنطقة الدراسة كما استخدم لتوضيح مدى ملاءمة التربة للزراعات المختلفة. ويعتبر الهدف النهائى من هذه الدراسة تقدير جودة التربة معتمدا على خصائص التربة مثل درجة الملوحة - رقم حموضة التربة - المادة العضوية - السعة التبادلية الكاتيونية - نسبة الصوديوم المتبادل - كربونات الكالسيوم. وهذة الدراسة مستمدة من استخدامات الأرض والغطاء الارضى وNDVI .والتحليل الاحصائى المكانى معتمدا على بيانات الاقمار الصناعية. الأراضى ذات الجودة العالية تمثل منطقة صغيرة من منطقة الدراسة حوالى16%، بينما الأراضى متوسطة الجودة تمثل 28.5%، و الأراضى منخفضة الجودة تمثل 55.5 ٪ .