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ORIGINAL PAPER

Sustainable multivariate analysis for land use management in El-Sharkiya, Egypt

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Abstract In Egypt, major sustainability variables could be identified as scarce of soil and water resources, environmental degradation, rapid population growth, institutional arrangement that includes land tenure and farm fragmentation, agricultural administration, lack of infrastructure, and credit utilization. The main objective of the current work is to evaluate the sustainable land use management (SLM) model through biophysics and socioeconomic elements for the purpose of combating sustainability constraints that preclude the agricultural development geospatially. In this research, from the geomorphologic point of view, the obtained results showed three main landscapes. They were identified in the study area as: fluviolacustrine plain, Aeolian deposits, and flood plain. The study area was dominated by some physical and chemical degradation processes with different scales breaking down the equilibrium of soil stability. The SLM model was implemented and assessed from multivariate perspective points of productivity, security, protection, economic viability, and social acceptability. Four SLM classes were outlined as follows: class I, land management practices that did meet sustainability requirements with a score ≥0.65, which represented 31.0 % of the considered agricultural study area; class II, land management practices that were marginally above the sustainability threshold and represented 12.6 %; class III, land management practices that were slightly below the threshold of sustainability and represented 8.60 %; class IV, land management practices that did not meet sustainability requirements with index values >0.1 that represented 47.86 %. As a general conclusion, it is found that land management practices tend to be unsustainable in the area under investigation for certain constraints that play motivated roles in lowering the targeted land sustainability.

Keywords Multicriteria decision analysis · Sustainable land management (SLM) · Socioeconomic evaluation · El-Sharkiya governorate

Introduction

Land sustainability is the ability of an agricultural system to meet evolving human needs without destroying and, if possible, by improving the natural resource base on which it depends (USAID 1988). In addition, land sustainability concerns the long-term productive performance of systems and is primarily a function of the environmental quality, economic viability, and socioeconomic well-being of the farming population (Dumanski 1993). Sustainable agriculture is defined as the way of practicing agriculture, which seeks to optimize skills and technology to achieve long-term stability of the agricultural enterprise, environmental protection, and consumer safety. It is achieved through management strategies that help the producer to select hybrids and varieties, soil-conserving cultural practices, soil fertility programs, and best management programs (Gold 1999, 2007). Exactly, this definition points out that sustainable agricultural development is a multivariate concept.

The importance of sustainable agriculture is no longer in any doubt; it is at the heart of a new social contract between society as a whole and its farmers. Nevertheless, implementing sustainability remains a difficult issue. The concept of sustainability has yet to be made operational in many agricultural situations (Gafsi et al. 2006). In order to achieve better sustainable land use management results, an assessment of the planning is necessary to reduce the gap between planning practice and research regarding landscape, which still needs bridging (Antonson 2009).

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As a tool for conflict sustainable management, multicriteria evaluation has demonstrated its usefulness in many sustainability policy and management problems (Hayashi 2000; Bell et al. 2001). The main point of force is the fact that the use of various evaluation criteria has a direct translation in terms of plurality of values used in the evaluation exercise. From this point of view, multiple-criteria decision analysis can be considered as a tool for implementing the tackling of sustainability issues properly.

As mentioned before, sustainable development is a multidimensional concept, including socioeconomic, ecological, technical, and ethical perspectives (Munda 2005). As a consequence, sustainability issues are characterized by a high degree of conflict. Therefore, the main objective of this study is to show that multiple-criteria analysis is an adequate approach for dealing with sustainability conflicts at different levels of analysis. To achieve this objective, the sustainable land use management (SLM) decision approach was implemented.

Sustainable land management, as defined by the TerrAfrica partnership (2006), is the adoption of land use systems that, through appropriate management practices, enable land users to maximize the economic and social benefits from the land while maintaining or enhancing the ecological support functions of the land resources (FAO 2009). Within the sphere of agriculture, the SLM model includes the maintenance over time of soil productivity. This requires the combination of soil fertility treatment with soil and water conservation measures. SLM will prioritize different elements of this combination depending on the terrain, ecosystem, climate, and land use that determine the potential forms of the ecosystem. The SLM approach encompasses biophysical, socioeconomic, and environmental concerns that must be viewed in an integrated manner (Woodfine 2009).

The decision supporting system based on the framework of SLM is an expert system technology, which used to evaluate the current condition of sustainability through the calculation of productivity, security, protection, viability, and acceptability indices (Smyth and Dumanski 1993). Indeed, SLM requires the integration of technologies, policies, and activities in the rural sector, particularly agriculture, in such a way that enhances economic performance while maintaining the quality and environmental functions of the natural base. To evaluate sustainable land management, five criteria are needed; these include: productivity, security, protection, viability, and acceptability (Dumanski 1997).

The spatial analyses model is a very important technique to gather, even manipulate, and process the spatial variables within the Geographic Information System (GIS). The spatial multiagent programming model has been developed for assessing policy options in the diffusion of innovations and resource use changes (Berger 2001). 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 GIS. Sustainable agricultural development is one of the prime objectives in all countries in the world, whether developed or developing. The broad objective of sustainable agriculture is to balance the inherent land resource with crop requirements, paying special attention to the optimization of resource use towards the 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. In principle, it contains two main 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.

In Egypt, a sharp conflict exists between land supply and demands due to the lack of the necessary macro control of land use especially legal regulations and economic adjustments to market economy and also due to improper micro management. Overpopulation posed a very heavy burden to farmland, which was intensively used without sufficient protection, so sustainable land use is urgently required to solve this conflict and reduce the heavy burden (El-Nahry 2001). Besides, in a country like Egypt, major sustainability variables could be identified as scarce of land resources, degradation, rapid population growth, institutional arrangement that includes land tenure and farm fragmentation, agricultural administration, limitations of infrastructure, and economic credit utilization and high interest rates.

The main objective of the current work is to evaluate the SLM model approach through biophysics elements (productivity, security, protection) and socioeconomic aspects (economic viability and social acceptability) for the purpose of combating and tackling sustainability constraints that preclude agricultural development or to reduce them to acceptable levels of mass production endeavors.

Materials and methods

Study area

The El-Sharkia Governorate is one of the eastern delta's governorates. Officially, it is subdivided into 12 administrative districts. El-Hussaniya district is considered the largest as it covers 1,523.02 km^2 and represents 34.92 % of the total governorate surface area. In addition, Belbas district is the second greatest that occupied an area of 454.63 km^2 (10.42 %), whereas the other remaining districts exhibit small homogenous areas comparatively.

The targeted area incorporates an area of 4,575.86 km^2 approximately. It is bounded by longitudes 31°20′–32°15′E and latitudes 29°54′–31°12′N (Fig. 1). Geologically, this region belongs to the late Pleistocene, which is represented by some deposits of Neonile formations that lower its course at a rate of 1 m/1,000 years (Said 1993). From the pedoclimatological point of view and based on the climatologically normal for Egypt (Egyptian Meteorological Authority 2011) and USDA Soil Taxonomy (2010), the study area is located in and could be classified into the thermic soil temperature regime, while the moisture regime is torric.

Field practices and laboratory analyses

A semidetailed soil survey was conducted to establish the field condition and confirm map boundary delineation. Soil samples were collected after digging 15 profiles and making the detailed field description. A GPS handheld unit for field scouting was used to determine the precise location (in UTM units) based on the GPS global navigation system.

Soil samples obtained from the field were used for the determination of particle size distribution, bulk density, and soil compaction (based on the soil core method) according to Klut (1986). The electrical conductivity (EC, in decasiemens per meter), soil pH (1:2.5 abstract), organic matter (OM, in percent), percent $CaCO_3$, soluble cations and anions, exchangeable sodium, macro nutrients, and cation exchange capacity (CEC) were determined according to USDA (2004).

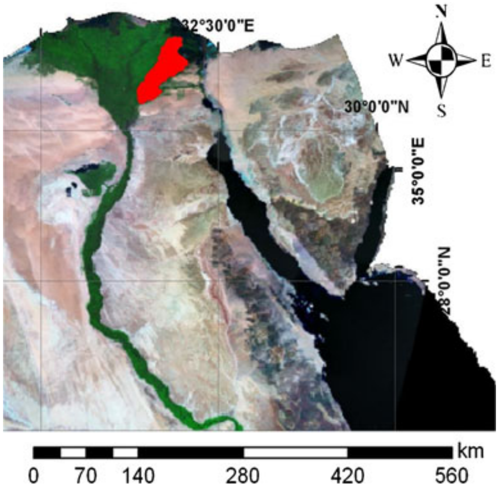

Fig. 1 Location map of the study area (*red*)

Digital image processing

The digital image processing of the Landsat-enhanced thematic mapper (ETM+) satellite image, which was acquired in 2010, was executed using ENVI 4.7 software to elaborate preprocessing and classification of the satellite image (ITT 2009) (Fig. 2). Digital image processing included gap filling of ETM+ scan-line corrector (SLC)-off images in which all missing pixels in the original SLC-off image have been replaced with estimated values based on histogram-matched scenes. Data were calibrated to radiance using the inputs of image type, acquisition date, and time. The image was stretched using linear 2 % and smoothly filtered, and its histogram was matched according to Lillesand and Kiefer (2007). The image was atmospherically corrected using the FLAASH module and rectified radiometrically and geometrically (ITT 2009).

Digital terrain mapping

Particularly, the mapping of landscape attributes that are utilized in landform characterization can be derived with reasonable accuracy using the available Shuttle Radar Topography Mission (SRTM) Digital Elevation Model (DEM) (Brough 1986; USGS Geological Survey 1998; Dobos et al. 2000). Currently, DEMs are available for most of the globe but vary significantly in horizontal and vertical resolution depending on the choice of data source and generation techniques, which are very critical to the quality of a DEM (Weibel and Heller 1991). At present, there are various sources of elevation data, including topographic map contours and elevation points, field surveys, aerial photographs, satellite images acquired from stereo viewing sensors and space-based radar and laser devices (Band 1986). The DEM of SRTM data of 30 m resolution (Fig. 2) was processed to automatically extract most of the landform units available in the study area. The 30-m spatial resolution was essential in order to coincide with that of the Landsat ETM+ imagery to identify the geomorphology and terrain features analysis.

The delineation of soil map units and boundary detection was carried out by digging 15 soil profiles and confirmed through the collection number of soil and groundwater samples. It is worth mentioning that the morphology description of soil profiles was done based on the FAO guidelines (2006), while soil classification was assigned according to Keys of Soil Taxonomy USDA (2010) (Table 1). The different landforms were initially determined from the satellite images and DEM following the methodology developed by Dobos et al. (2002) (Fig. 3). The satellite ETM+ image was draped over the DEM to get a feel of the natural 3D terrain, to better

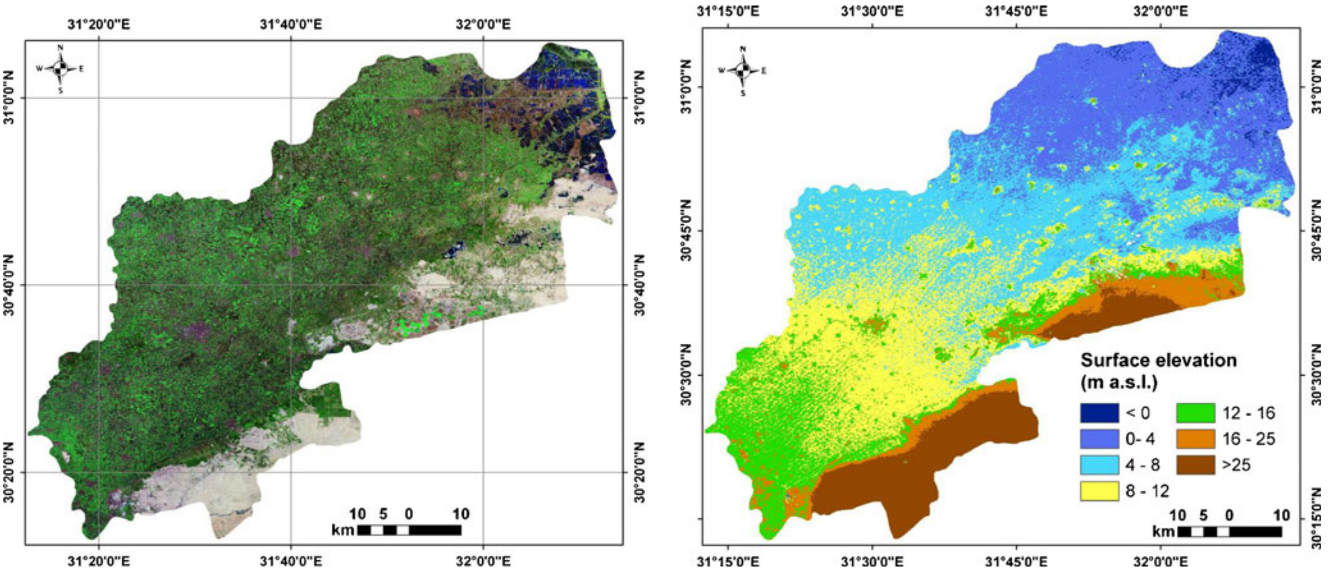

Fig. 2 Satellite ETM+ image (*left*) and Digital Elevation Model (DEM) data (*right*) of the area under investigation

understand the geomorphologic units, and to facilitate delineation and extraction of physiographic units (El-Baroudy 2011). The physiographic units were described according to Zink and Valenzuala (1990). ArcGIS 9.3.1 and arc spatial analyst extension (ESRI 2009) were run out for mapping different soil attributes and building the targeted SLM spatial model (SLMSM) Malczewski (1999). Nevertheless, socio-economic data of the examined area were obtained in reference to the environmental description report of the Sharkiya Governorate statistics bureaus (EEAA 2009).

Evaluation of the sustainable land use management

In this research, the international Framework for Evaluating Sustainable Land Management (FESLM) system was implemented. Mainly, indicators of FESLM were explored as inputs to feed up and run the designed SLMSM (Smyth and Dumanski 1993).

The SLMSM design was done based on the spatial geo-processing tools of ArcGIS 9.3.1 software. Thus, Table 2 illustrates the sustainable land use management index and the associated values and classes.

Results

To assess sustainable land use management, the current work was multistage as follows:

Geomorphology and soils

Satellite image interpretation indicated that the investigated area included three main landscapes: (a) fluviolacustrine plain with five distributed landforms, i.e., clay flats (high and low elevation), sabkhas, swamps, and water bodies; (b) Aeolian deposits including sandy remnants (high and low elevation); (c) flood plain containing overflow mantle, overflow basins and decantation basins, river terraces, and turtle backs. The last mentioned landforms were levelly classified in regard to its high and low geomorphology elevation.

The soil layer showed the distribution of different soil subgreat groups, where the Vertic Torrifluvents subgreat group was dominant. It covers an area of 2,720.24 km^2 that represents 62.56 % of the alluvial soils. Typic Quartizipsamments is found at the eastern fringes of the study area with 778.33 km^2 (17.90 %) of the total area. Aquollic Salorthids and Typic Torriorthents exhibit areas at the northeast part and cover 328.64 and 241.62 km^2 that correspond to 7.56 and 5.56 % of the total investigated area, respectively.

Patches of Typic Calciorthids, Typic Torrifluvents, and Typic Torripsamments were in scattered distribution and occupied 84.94, 49.73, and 106.72 km^2 that represent 1.95, 1.14, and 2.45 %, respectively. In addition, limited coverage of rock land and rock escarpments was found mainly in the southeastern corner of the examined place and exhibited 34.73 and 3 km^2 that referred to 0.8 and 0.07 %, respectively.

Soils of fluviolacustrine plain

Soils of this landscape are expressed by relatively high- and low-level clay flats and dry and wet sabkhas. The obtained data illustrated clay flat landforms with different soil depths that range from 70 to 90 cm, while for

Table 1 Physiographic characteristics of the investigated area

Landscape	Relief	Lithology/ origin	Land form	Mapping unit	Profile no.	Area %	Soil classification	Type of soil sets
Fluviolacustrine plain	Almost flat to gently undulating	Fluviolacustrine deposits	Relatively high clay flats	CF1	1	8.01	Vertic Torrifluvents	Cons.
			Relatively low clay flats	CF2	2	2.30	Vertic Torrifluvents	Cons.
			Dry sabkha	DS	5	0.95	Gypsic Haplosalids	Cons.
			Wet sabkha	WS	6	1.83	Typic Aquisalids	Cons.
			Fish bounds	FB	–	4.84	–	–
			Swamps	S	–	1.32	–	–
			Gypsiferrous flats	GF	–	3.42	–	–
			Water bodies	WB	–	0.39	–	–
Aeolian plain	Gently undulating	Aeolian deposits	High sandy remnants	OS1	3	7.96	Typic Torripsamments	Cons.
			Low sandy remnants	OS2	4	8.84	Typic Torripsamments	Cons.
Flood plain	Almost flat to gently undulating	Alluvial deposits	Over flow mantle relatively low	OM_1	7	2.65	Typic Torrifluvents	Cons.
			Relatively high	OM_2	8	4.69	Typic Paleargids	Assoc.
			Over flow basin relatively low	OB_1	9	6.75	Vertic Torrifluvents	Cons.
			Relatively high	OB_2	10	3.99	Typic Natrargids	Assoc
			Decantation basin relatively low	DB_1	11	7.52	Typic Torrifluvents	Cons.
			Relatively high	DB_2	12	18.57	Typic Torrifluvents	Cons.
			River terraces relatively high	T_1	14	6.91	Vertic Torrifluvents	Cons.
			Relatively low	T_2	15	8.74	Vertic Torrifluvents	Cons.
			Turtle backs	TB	13	0.32	Typic Torripsamments	Cons.

dry and wet sabkhas, it ranged between 30 and 20 cm. Soil texture class was mainly clayey. Soils were compacted especially in dry sabkhas and some additional spots of clay flats. Soil reaction (pH) numbers were slightly alkaline (8.00 and 8.20). The EC values were highly determined and range between 13.11 and 21.00 dS/m. Calcium carbonate was relatively high in content and ranged between 8.10 and 11.20 %. The high values of $CaCO_3$ detected might indicate the abundance of shell fragments present (inert $CaCO_3$). The organic matter content is relatively acceptable for agricultural production under the aridity conditions and recorded 1.7–1.9 %. The CEC was comparatively high, where it ranged between 50.00 and 60.00 meq/100 g soils that matched with the high observed amount of clay content (50.10–54.31 %). Exchangeable sodium percentage (ESP) was relatively high to very high, where it ranged between 19.20 and 28.10 %. From the fertility point of view, the macro nutrients (NPK) were determined relatively in sufficient amounts (81.24, 29.15, and 300.34 ppm, respectively). In the fluviolacustrine plain, soils were classified as Vertic Torrifluvents for the clay flat landforms, Gypsic Haplosalids for dry sabkhas, and Typic Aquisalids for wet sabkhas.

Soils of Aeolian deposits

This landscape included high- and low-level sandy remnant landforms. The analytical data of such landforms reported that soil depths ranged between 100 and 120 cm. Soil texture class was mainly sand. Soil reaction (pH) values ranged between 7.7 and 8.0. The EC measurements were between 7.40 and 11.30 dS/m. The $CaCO_3$ content was relatively low and ranged between 1.10 and 2.40 %. Obviously, the organic matter content was relatively low and has a range of 0.20–0.40 %. CEC was very low and reflect the less amounts of clay fraction and organic matter as well. CEC ranged between 4.00 and 8.10 meq/100 g soils. ESP was considerably high to very high, where it ranged between 17.40 and 24.00 %. The measured levels of macro nutrients (NPK) indicate that the soil was efficiently fertile. In principle, soils of this unit were classified as Typic Torripsamments.

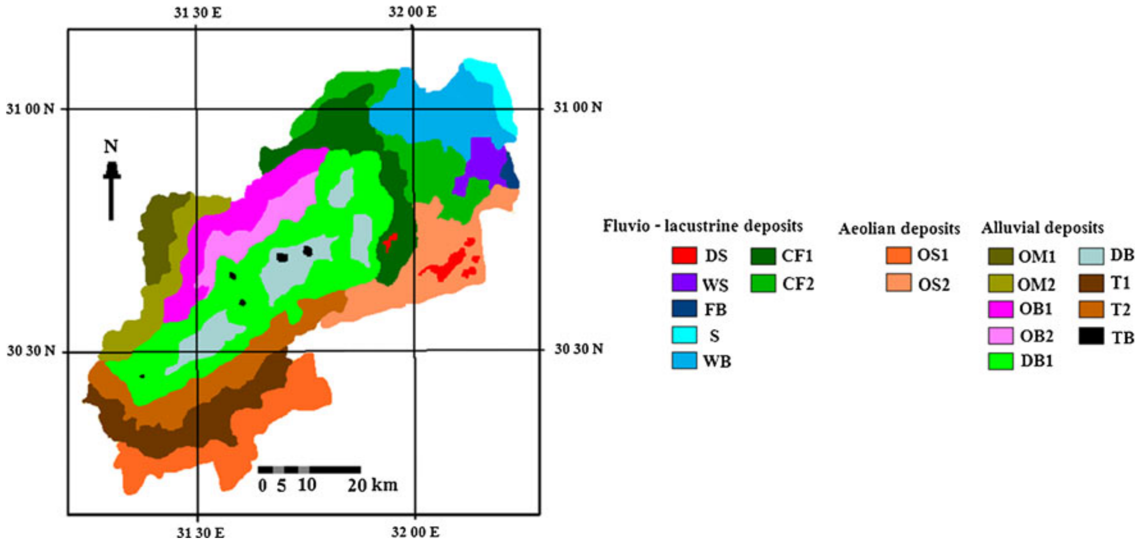

Fig. 3 Physiography and soils of the studied area

Soils of flood plain

The flood plain topographic unit included four landforms: overflow mantle, overflow basin, decantation basin, and river terraces. The obtained data indicated that soil depths ranged between 90 and 150 cm. Soil texture class was clayey. Soil reaction (pH) values ranged between 7.3 and 8.2. Soil salinity state was from none to moderately saline, and its EC measurements ranged between 1.60 and 9.40 dS/m. The $CaCO_3$ content was relatively low, 0.30–1.10 %. Organic matter content was between 1.10 and 1.60 %. CEC was comparatively high, where it ranged between 34.18 and 48.16 meq/100 g, which corresponded to the observed high clay content (36.40–50.10 %). ESP was relatively high and ranged between 10.10 and 20.20 %. Concerning soil fertility, levels of macro nutrients (NPK) were sufficient. Soils of this unit were classified as Vertic Torrifluvents for overflow basins and river terraces. Overflow mantle and decantation basins were classified as Typic Torrifluvents. Meanwhile, overflow basin units were classified as Typic Natrargids. Generally, Fig. 3 and Table 2 show the main geomorphologic units with the associated soil legend in the area under consideration.

Table 2 Sustainability index and associated values and classes

Values	Land use/management status	Class
0.6–1	Meet the sustainability requirements	I
0.3–0.6	Marginally but above the threshold of sustainability	II
0.1–0.3	Marginally but below the threshold of sustainability	III
0–0.1	Do not meet the sustainability requirements	IV

Sustainable land use management spatial model

To assess sustainable land use management of the agricultural system, five sustainability indicators are considered (productivity, protection, security, economic viability, and social acceptability) and were modeled as follows:

Deriving the indicator index of the investigated area

Indicator indices could be calculated through a series of values for the input criteria that concern productivity (*A*), security (*B*), protection (*C*), economic viability (*D*), and social acceptability (*E*). Calculating series of values for each criterion was based on specified python expression resulting in five datasets for each input criteria.

Discussion

Productivity

The productivity index considered the value (PRI) of ten indicators for determining the soil productivity, viz.: relative yield percent (*A*), organic carbon percent (*B*), pH (*C*), CEC in milliequivalents/100 g soil (*D*), available nitrogen in parts per million (*E*), available phosphorous in parts per million (*F*), available potassium in parts per million (*G*), soil depth in centimeters (*H*), EC per decasievert per meter (*I*), and ESP (*J*).

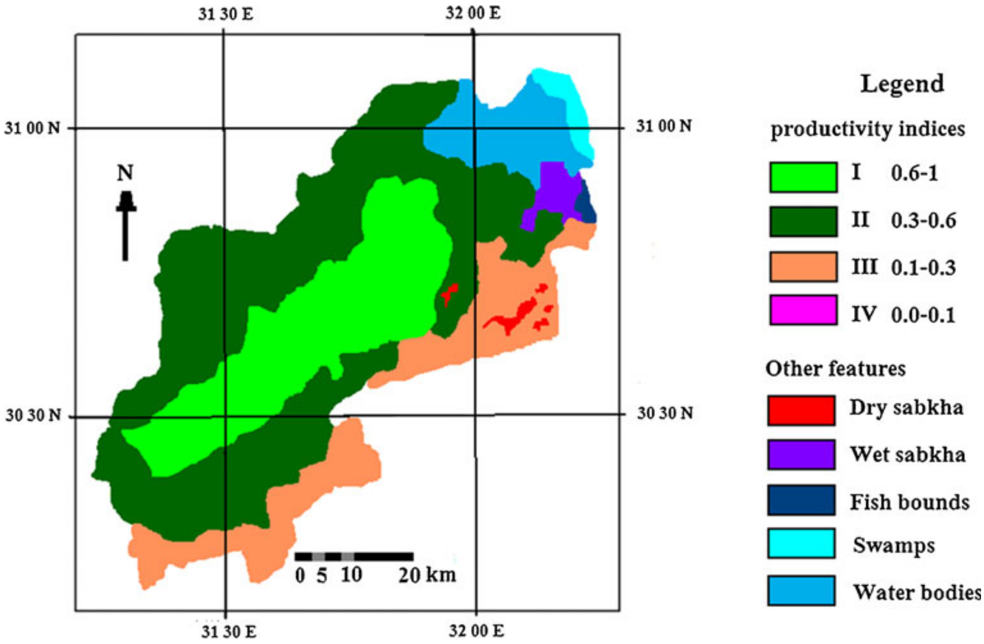

Fig. 4 Productivity indices of the studied area

$$PRI = A/100 \times B/100 \times C/100 \times D/100 \times E/100 \times F/100 \times G/100 \times H/100 \times I/100 \times J/100.$$

Results obtained from the first stage of executing the SLMSM model (getting productivity index by calculating the series of values). The output results indicated that land productivity in some parts of the flood plain that was represented by mapping units (DB1, DB2) did meet the sustainability requirements (class I), where the productivity index record in these areas is 0.65. Meanwhile, the rest of the flood plain and fluviolacustrine plain units were marginally above the sustainability requirements, where the indices of productivity ranged between 0.43 and 0.59, which represented (class II). On the other hand, Aeolian deposits were lying below the sustainability requirements (class III), whereas its productivity index ranged between 0.28 and 0.29. The low values of productivity index obtained were

Table 3 Security and protection characteristics of the mapping units

Mapping units	Security			Protection		
	A	*B*	*C*	*E*	*F*	*G*
CF1	<90	2.40	Low amount for a long time	Small gullies	Yes	Double cropping pattern
CF2	<90	2.60	Low amount for a long time	Small gullies	Yes	Double cropping pattern
OS1	<90	1.70	Low amount for a short time	Med. gullies	Yes	No cropping pattern
OS2	<90	1.90	Low amount for a short time	Med. gullies	Yes	No cropping pattern
OM1/OM2	365	0.90	High amount for a long time	No evidence	No	Double cropping pattern
T1/T2	365	0.90	High amount for a long time	No evidence	No	Double cropping pattern
OB1	365	0.70	High amount for a long time	No evidence	No	Double cropping pattern
OB2	365	0.70	High amount for a long time	No evidence	No	Double cropping pattern
DB1	365	0.70	High amount for a long time	No evidence	No	Double cropping pattern
DB2/TB	365	0.70	High amount for a long time	No evidence	No	Double cropping pattern

The security index consider the value (V) of three indicators, i.e., moisture availability per month/season (*A*), EC of irrigation water (*B*), and biomass percent (*C*) as determining security. The erosion hazard, i.e., evidence of erosion indicators (*E*), flooding hazard viz. evidence of submerged areas (*F*), and cropping pattern (*G*) indicators were used to determine the protection of the natural resources

$Security\,index(SI) = A/100 \times B/100 \times C/100$, $Protection\,index(PI) = E/100 \times F/100 \times G/100$

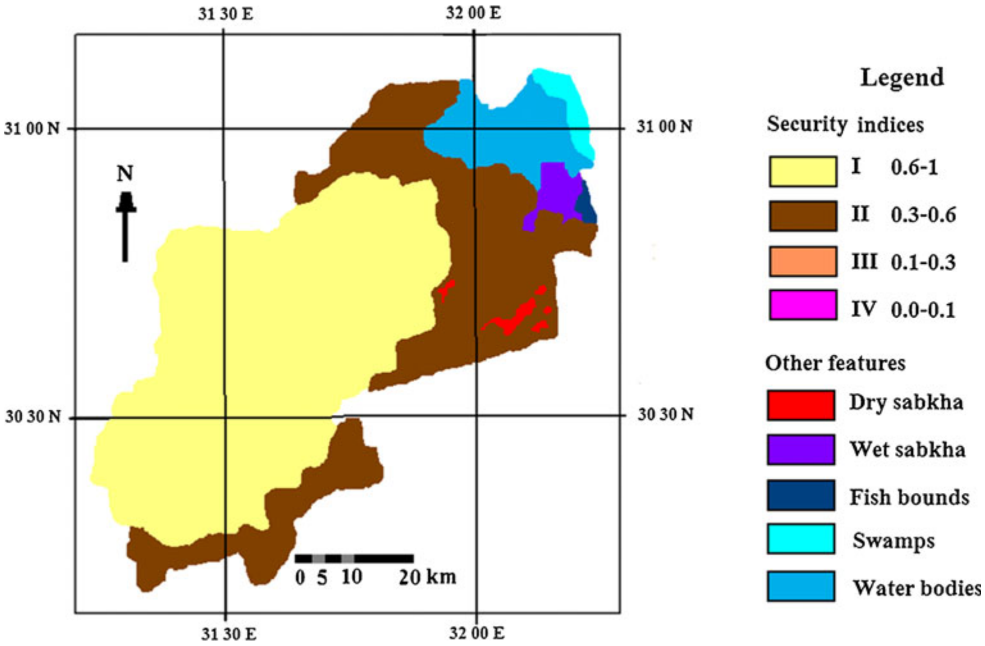

Fig. 5 Security index of the studied area in the Sharkiya Governorate

due to the decrease of relative yield, CEC, and available nitrogen, despite the increase of soil salinity. The productivity index calculations are illustrated in Fig. 4.

Security and protection indices

In tabular indication, Table 3 illustrates the security and protection characteristics in different mapping units within the study area. The obtained results derived from the first stage of executing the SLMSM spatial model system were explaining the security and protection indices from the calculation of the series of values. Geospatially, Figs. 5 and 6 express the security and protection indices in different mapping units, where security and protection practices in flood plain soils fitted with the sustainability requirements and show a range between 0.90 and 1.00 that represent class I. On the other side, security and protection indices of marine plains and the fluviolacustrine plain are marginally above the threshold of sustainability requirements, where their indices ranged between 0.44 and 0.50, and 0.34 and 0.58, respectively, which correspond to class II. The last mentioned categorization may cause stress in soil moisture and biomass, erosion hazard, and the unsuitability of the field cropping pattern.

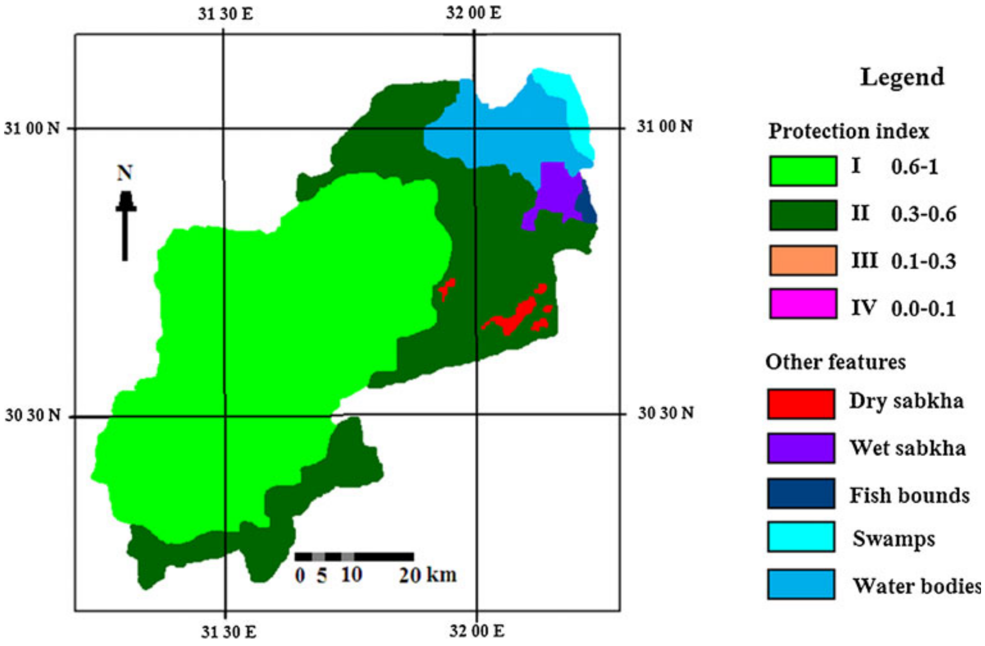

Fig. 6 Protection index of the studied area

Table 4 Economic characteristics of the distinguished mapping units

Mapping units	*A*	*B*	*C*	*D*	*E*	*F*	*G*
CF1	1.20	20.00	20.00	1.00	1.20	23.00	36.00
CF2	1.20	20.00	20.00	1.00	1.20	23.00	36.00
OS1	1.25	20.00	25.00	1.00	1.20	23.00	20.00
OS2	1.30	20.00	25.00	1.00	1.20	23.00	20.00
OM1/OM2	1.43	40.00	12.50	3.00	4.50	33.50	40.00
T1/T2	1.43	35.00	12.50	3.00	4.50	33.50	46.00
OB1	1.48	50.00	12.50	3.00	5.00	33.50	67.00
OB2	1.50	50.00	12.50	3.00	5.00	33.50	67.00
DB1	1.80	50.00	12.50	3.00	7.00	33.50	80.00
B2/TB	1.88	50.00	12.50	3.00	7.00	33.50	80.00

The economic viability index considers the value of seven indicators as determining economic viability, viz.: benefit cost ratio (*A*), percentage of off-farm income (*B*), difference between farm gate price and the nearest main market in percent (*C*), availability of farm labor man/feddan (*D*), size of farm holding in feddan (*E*), availability of farm credit percent (*F*), and percentage of farm produce sold in the market (*G*). $\mathit{Economic\ viability\ index}(EI)\ A/100 \times B/100 \times C/100 \times D/100 \times E/100 \times F/100 \times G/100$

Economic viability

Economic viability characteristics of the examined area are clearly represented in Table 4. The SLMSM model first stage executing results revealed the following: the economic viability of different landform units in Aeolian deposits and the fluviolacustrine plain were marginally below the motivated sustainability requirements (class III). The economic viability index in these areas ranged between 0.23 and 0.27. The economic viability in some parts within the flood plain (T1/T2) were slightly above the sustainability threshold (class II), where the economic index realized a value of 0.58. The rest of the flood plain map units (O.M1, O.M2, O.B1, O.B2, D.B1, and D.B2) expressed economic viability that did match with the sustainability requirements (class I) and showed a viability index that ranged between 0.61 and 1.00. From the economic point of view, the less obtained viability index may be attributed to the low ratio of coast benefits, restricted availability of farm labor, limited farm size, low percentage of farm production and marketing, and lower off-farm income. Figure 7 shows the georeference economic viability indices of the delineated mapping units.

Social acceptability

The obtained results of executing the SLMSM spatial model indicated that the distinguished landform of Aeolian deposit mapping units were faintly below

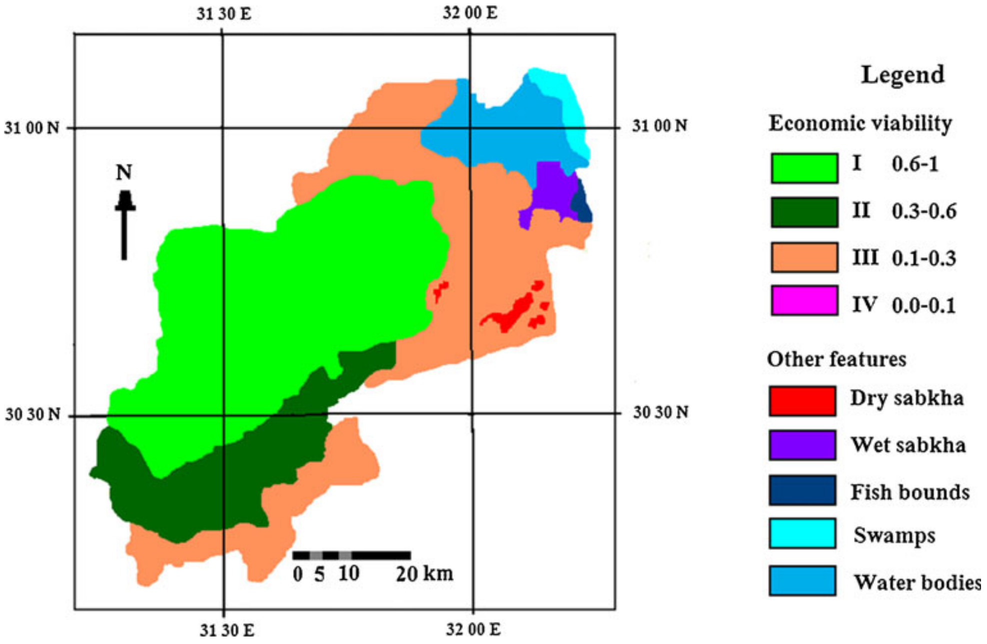

Fig. 7 Economic availability index of the area under investigation

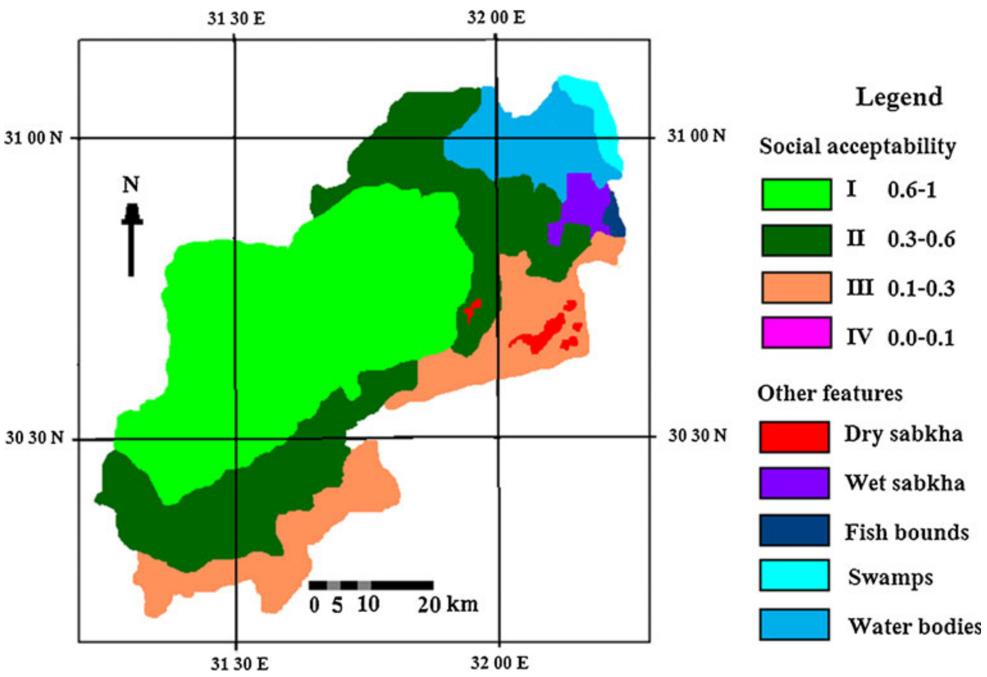

Fig. 8 Social acceptability index of the considered area

sustainability requirements (class III), where the social acceptability index was 0.21, which was considered rather low. Besides, in fluviolacustrine plain (CF1 and CF2) and some identified landforms of flood plain (T1/T2), the obtained social acceptability was relatively above the sustainability threshold of class II, where their calculated index ranged between 0.34 and 0.43. Nevertheless, the social acceptability index in the rest of the flood plain was higher, where it realized a value of 1.00, that corresponds with the sustainability requirements (class I). Indeed, the low obtained value index of social acceptability was mainly caused by the shortage in health and educational facilities in the local villages as well as lack of land user experiment and training allocated in regard to soil and water conservation. Figure 8 illustrates the social acceptability indices of the last considered map units. Table 5 represents the characteristics of social acceptability in the studied area, which were defiantly extracted from EEAA (2009).

Getting the sustainability index

The sustainability index was obtained by multiplying the indices of the five established indicators according to the following

Table 5 Social characteristics of the mapping units

Mapping units	*A*	*B*	*C*	*D*	*E*	*F*	*G*
CF1	Not official	Moderate	Shortage	20	c	Limited	Limited
CF2	Not official	Moderate	Shortage	20	c	Limited	Limited
OS1	Not official	Low	Non	20	c	Not available	Non
OS2	Not official	Low	Non	20	c	Not available	Non
OM1/OM2	Full	Full	Available	55	a	Available	Full access
T1/T2	Long term	Moderate	Shortage	36	c	Limited	Limited
OB1	Full	Full	Available	55	a	Available	Full access
OB2	Full	Full	Available	55	a	Available	Full access
DB1	Full	Full	Available	55	a	Available	Full access
DB2/TB	Full	Full	Available	55	a	Available	Full access

The social acceptability index considers the value (V) of seven indicators as social acceptability, viz.: land tenure (*A*), support for extension services (*B*), health and education facilities in the village (*C*), percentage of subsidy for conservation packages (*D*), training of farmers on soil and water conservation (*E*), availability of agro-inputs within 5–10 km (*F*), and village roads' access to the main road (*G*). $Social\ acceptability\ index(SOI) = A/100 \times B/100 \times C/100 \times D/100 \times E/100 \times F/100 \times G/100$

a There has been sufficient training, *b* somewhat sufficient training, *c* there has been no training

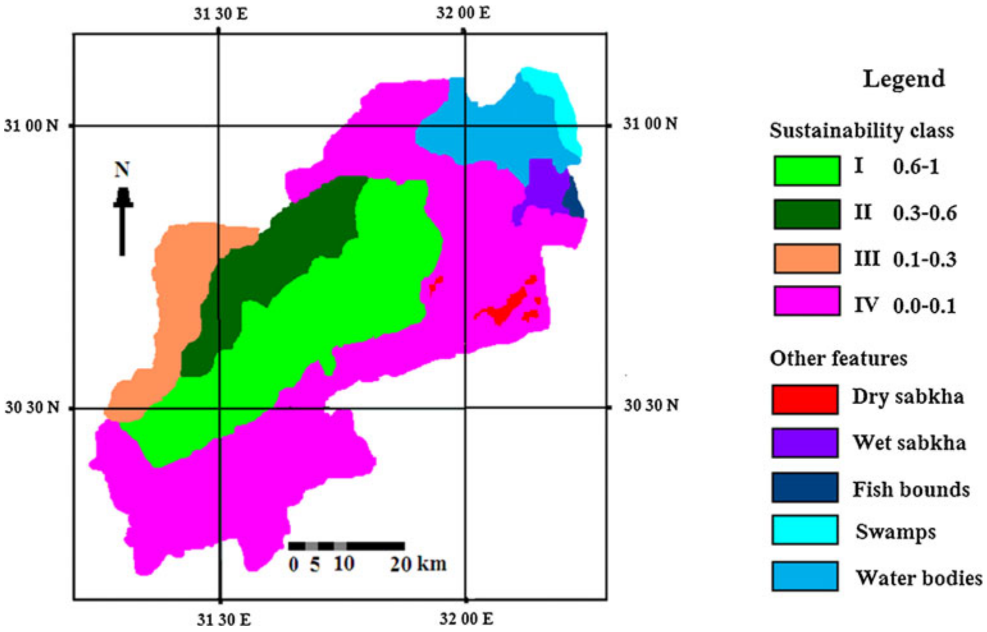

Fig. 9 Sustainability class in the studied area

formula: $$\text{Sustainability index(SUI)} = A \times B \times C \times D \times E$$

where

A=productivity, B=security, C=protection, D=economic viability, and E=social acceptability.

In general meaning, in the area under investigation, the land use management practices tend to be unsustainable as shown in Fig. 9 and Table 6. The output results indicated that the studied area includes four sustainability classes described as the following:

Class I Land management practices did meet sustainability requirements with a score ≥0.65, which are represented by map units (DB1, DB1, and TB) that occupy 1,208.48 km^2 (30.96 %) of the agricultural area.

Class II Land management practices were marginally above the sustainability threshold and represented by OB1 and OB2 units with values of 0.56–0.59, respectively, and occupied an area of 491.15 km^2 (12.58 %) of the agricultural area.

Class III Land management practices are slightly below the sustainability threshold. It existed in OM1 and OM2 map units with a value of 0.23 that occupies 335.87 km^2 (8.60 %) of the agricultural area.

Class IV Land management practices that did not meet sustainability requirements. It occurred in CF1, CF2, OS1, and OS2 units with values >0.1 and occupied 1,866.63 km^2 (47.86 %) of the agricultural area.

From the land sustainability point of view, obviously, only 30.96 % of the agricultural area or arable lands was

Table 6 Sustainability classes of the mapping units

Mapping Units	Prod.	Secu.	Prot.	Econ.	Soci.	Total value	Sustainability class	Area, km^2	%
CF1	0.48	0.50	0.58	0.27	0.34	0.01	IV	336.52	8.62
CF2	0.43	0.50	0.58	0.27	0.34	0.01	IV	105.24	2.69
OS1	0.29	0.44	0.34	0.23	0.21	0.002	IV	364.23	9.33
OS2	0.28	0.44	0.34	0.23	0.21	0.002	IV	404.51	10.36
OM1/OM2	0.46	0.90	0.90	0.61	1.00	0.23	III	335.87	8.60
T1/T2	0.50	0.90	0.90	0.58	0.43	0.09	IV	656.13	16.81
OB1	0.59	1.00	1.00	1.00	1.00	0.59	II	308.87	7.91
OB2	0.56	1.00	1.00	1.00	1.00	0.56	II	182.28	4.67
DB1	0.61	1.00	1.00	1.00	1.00	0.61	I	344.10	8.81
DB2/TB	0.63	1.00	1.00	1.00	1.00	0.63	I	864.38	22.15
Total								3,902.13	100

Prod productivity, *Secu.* security, *Prot.* protection, *Econ.* economic viability, *Soci.* social acceptability sustained or above the sustainability threshold. Meanwhile, 69.04 % of the total area was unsustainable or below sustainability threshold. Therefore, it is worthy to mention that the study area is in reality facing a great threat.

Conclusion

It is worthy to mention that sustainable land management in Egypt requires much more governmental and public efforts to be recovered. Adapted to the sustainable land use context, the integration between the five pillars of the FAO international framework for evaluating sustainable land management (FESLM) and the sustainable land use management spatial model (SLMSM) offers a quantified assessment for sustainable land management. Analysis of the results concluded that numerous limitations and constraints were observed that belong to soil productivity, social acceptability, and economic viability. The cornerstone for tackling sustainability constraints is adopting new technologies; improving agriculture, health, education, and infrastructure; supplying poor land users with nonrefundable loans, and offering more subsidies.

Recommendations

In order to overcome sustainability constraints, farm management, infrastructure, and social services should be improved to reach the standards of agricultural sustainability throughout: (1) improving soil and water resources following advanced techniques of management and conservation, (2) improving awareness levels on the sustainable issues of natural resources exploitation and enhancing livelihood options for land users and suppliers, (3) persuading decision makers to adopt effective rules to regulate marketing processes and ensure effective monitoring and flexible mechanisms, (4) persuading businessmen to insist on more investments on the traceability of the resources they procure from various middlemen, thereby, forcing all intermediary stakeholders to also comply with sustainability standards, (5) innovations in the materials and methods of production, appropriate technological interventions, and the introduction of strong backward linkages with suppliers, which are some of the measures that can reduce demand-driven pressure on sustainability.

References

Antonson H (2009) Bridging the gap between research and planning practice concerning landscape in Swedish infrastructural planning. Land Use Policy 26(2):169–177

Band LE (1986) Topographic partition of watershed with digital elevation models. Water Resour Res 22:15–24

Bell M, Hobbs B, Elliott E, Ellis H, Robinson Z (2001) An evaluation of multicriteria methods in integrated assessment of climate policy. J Multi-Criteria Dec Anal 10(5):229–256

Berger T (2001) Agent-based spatial models applied to agriculture: a simulation tool for technology diffusion, resource use changes and policy analysis. Science Direct J of Agricultural Economics 25(2–4):245–260

Brough PA (1986) Principle of geographical information systems for land resources assessment. Oxford University Press, Oxford. p, 194

Dobos E, Micheli E, Baumgardner MF, Biehl L, Helt T (2000) Use of combined digital elevation model and satellite radiometric data for regional soil mapping. Geoderma 97:367–391

Dobos E, Norman B, Bruee W, Luca M, Chris J, Erika M (2002) The use of DEM and satellite images for regional scale soil database. In: 17th World congress of soil science (WCSS), 14–21 August 2002, Bangkok, Thailand

Dumanski J (1993) Sustainable land management for the 21st century. Volume 1: workshop summary, compiled on behalf of the organizing committee. Proceedings of the International Workshop on Sustainable Land Management for the 21st Century. Uni. of Lethbridge, Canada, June 20–26 50 pp

Dumanski J (1997) Criteria and indicators of land quality and sustainable land management. ITC Journal 3(4):216–222

EEAA (2009) Environmental description report Sharkiea governorate statistics bureaus. Environmental Press, Egyptian Environmental Affairs Agency

Egyptian Meteorological Authority (2011) Climatologically normal for Egypt. The normal for Sharkiea governorate station (1960–2011). Ministry of Civil Aviation: Meteorological Authority, Cairo, Egypt. Accessed Aug 2007

El-Baroudy AA (2011) Monitoring land degradation using remote sensing and GIS techniques in an area of the middle Nile Delta. Egypt Catena 87:201–208

El-Nahry AH (2001) An approach for sustainable land use studies of some areas in northwest Nile Delta Egypt. PhD thesis, soil science, Dept. Faculty of Agric, Cairo University

ESRI (2009) Arc Map version 9.3.1. User manual. ESRI: ESRI product, California 92373–8100, USA

FAO (2006) Guidelines for soil description, 4th edn. Rome, FAO, ISBN 92-5-105521-1

FAO (2009) Country support tool. For scaling-up sustainable land management in Sub-Saharan Africa. Food and Agriculture Organization of the United Nations, Rome

Gafsi M, Bruno L, Nguyen G, Patrice R (2006) Towards sustainable farming systems: effectiveness and deficiency of the French procedure of sustainable agriculture. Agricultural Systems No. 90, 226–242

Gold M (1999) Sustainable agriculture: definitions and terms. SRB 99–02, USDA National Agricultural Library (NAL)

Gold M (2007) Sustainable agriculture: definitions and terms. SRB 99–02 USDA National Agricultural Library (NAL) http://www.nal.usda.gov/afsic/pubs/terms/srb9902.shtml. Accessed August 2007

Hayashi K (2000) Multicriteria analysis for agriculture resource management: a critical survey and future perspectives. Eur J Oper Res 122:486–500

ITT (2009) ITT corporation ENVI 4.7 software. 1133 Westchester Avenue, White Plains, NY, 10604, USA

Klut A (ed) (1986) Methods of soil analysis (part-1) physical and mineralogical methods. American Society of Agronomy and Soil Science Society of America, Madison

Lal R, Pierce M (1991) Soil management for sustainability. Soil and Water Conservation, Ankeny

Lillesand TM, Kiefer RW (2007) Remote sensing and image interpretation, 5th edn. Wiley, New York

Malczewski J (1999) GIS and multi-criteria decision analysis. Wiley, New York

Munda G (2005) Multiple criteria decision analysis: state of the art surveys. International Series in Operations Research & Management Science 78(VII):953–986. doi:10.1007/0-387-23081-5_23

Said R (1993) The River Nile geology and hydrology and utilization. Pergamon press, Oxford

Smyth AJ, Dumanski J (1993) FESLM: an international framework for evaluating sustainable land management, World Soil Resources Report 73: Food and Agriculture Organization (FAO). Land and Water Development Division, Rome

TerrAfrica (2006) Regional sustainable land management brochure, Washington DC, USA

USAID (1988) The transition to sustainable agriculture: an agenda for A.I.D. committee for Agric. Sustainability For Developing countries, Washington D.C

USDA (2004) Soil survey laboratory methods manual, soil survey investigation. Report no. 42, U.S. Department of Agriculture: Natural Resources Conservation Service (NRCS), third edition, version 4.0

USDA (2010) Keys to soil taxonomy, United State Department of Agriculture: Natural Resources Conservation Service (NRCS), third edition

USGS Geological Survey (1998) USGS fact sheet. No. 102-96

Weibel R, Heller M (1991) Digital terrain modelling. In: Maguire DJ, Goodchild MF, Rhind DW (eds) Geographical information systems: principles and applications. Longman, London, pp 269–297

Woodfine A (2009) Using sustainable land management practices to adapt and mitigate climate change in sub-saharan Africa. Resource guide version 1.0. TerrAfrica-Regional Sustainable Land Management

Zink JA, Valenzuala (1990) Soil geographic database: structure and application examples. ITC 3:270–294