

# Using GIS modeling to assess the agricultural sustainability in Kafr El-Sheikh governorate, Nile Delta, Egypt

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**Abstract** The evaluation of agricultural sustainability status helps in identifying specific indicators that constrain the achievement of sustainable agriculture. The agricultural sector in Egypt is facing major sustainability constraints such as scarce land and water resources, environmental degradation, and rapid population growth as well as institutional arrangement including land tenure and farm fragmentation, agricultural administration, lack of infrastructure, and credit utilization and high interest rates. This study aims to evaluate the agricultural sustainability in some areas in Kafr El-Sheikh governorate, north of the Nile Delta; the international framework for evaluating sustainable land management was used for realizing this objective. The map of the physiographic soils of the studied area was produced depending upon Landsat ETM<sup>+</sup> images analysis; the results indicate that the area includes three main landscapes, i.e., alluvial, lacustrine, and marine plains. The characteristics of productivity, security, protection, economic viability, and social acceptability in the different mapping units were assessed. The obtained results show that the studied area includes two different class types, the first are the lands that are marginally below the requirement of sustainability and the second are those lands that do not meet sustainability requirements. The former class is represented by the physiographic units of alluvial plain, whereas the latter class is represented by the physiographic units of the lacustrine and marine plains. The sustainability constrains in the studied area are related to the soil productivity, economic viability, and social acceptability.

**Keywords** Agricultural sustainability · Physiographic soils map · Kafr El-Sheikh governorate

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## Introduction

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 which help the producer to select hybrids and varieties, soil-conserving cultural practices, soil fertility programs, and best management programs (Gold 1999). 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. But 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). In Egypt, a sharp conflict exists between land supply and demands due to the lack of necessary macrocontrol of land use especially legal regulations and economic adjustments to market economy and also due to improper micromanagement. Overpopulation posed a 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. In Egypt, major sustainability variables could be identified as scarcity of land and water resources, environmental degradation, rapid population growth, as well as institutional arrangement including land tenure and farm fragmentation, agricultural administration, lack of infrastructure, and credit utilization and high interest rates (El-Nahry 2001).

The sustainable land management (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 decision supporting system, based on the framework of SLM, is an expert system technology which is used to evaluate the current condition of sustainability through the calculation of productivity, security, protection, viability, and acceptability indices (Smyth and Dumanski 1993). Spatial analyses model is a very important technique to gather, manipulate, and process the spatial variables within geographic information system (GIS). Spatial multi-agent 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 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 it 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 the one hand, and preserving natural resources and ecosystems, on which we and future generations depend. GIS and remote sensing offer a great potential to capture data through 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 main objective of the current work is to evaluate SLM through biophysics elements (productivity, security, and protection) and socioeconomic elements (economic viability and social acceptability) for the purpose of combating and tackling sustainability constraints that preclude the agricultural development or to reduce them to the acceptable levels of mass production.

## Materials and methods

### Study area

The studied area in Kafr El-Sheikh governorate is represented by an incorporating area of 3,165.18 Km<sup>2</sup>. It is located at the northern part of the Nile Delta and bounded by longitudes 310 00" and 310 30" E and latitudes 310 30" and 300 00" N (Fig. 1). This area belongs to the late Pleistocene, which is represented by the deposits of the neogene which is lowering its course at a rate of 1 m/1,000 years (Said 1993). Based on the Climatologically Normal for Egypt (2011) and the United States Department of Agriculture (USDA; 2010), the soil temperature regime of the studied area is defined as thermic and soil moisture regime as torric.

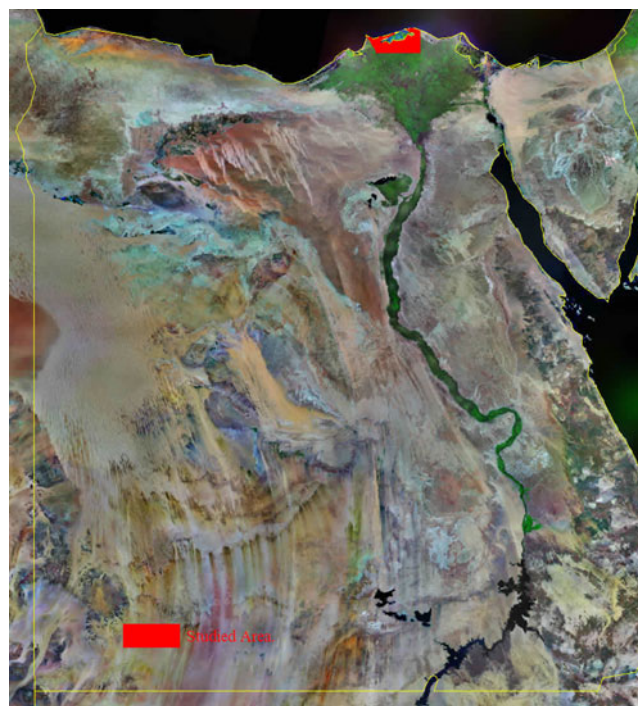
### Soil analyses

#### *Physical analyses*

Particle size distribution, bulk density, and soil compaction by soil core method were determined according to Klut (1986).

#### *Chemical analyses*

Electric conductivity (EC), soluble cations and anions, calcium carbonate (CaCO<sub>3</sub>), organic matter (OM), pH,



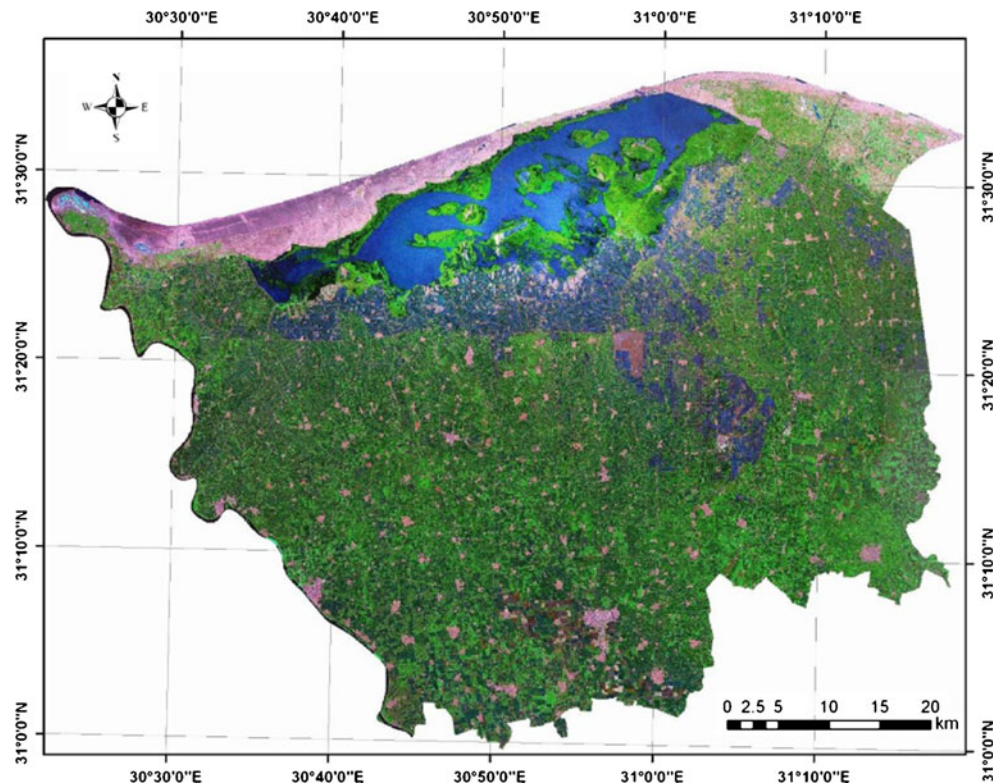
**Fig. 1** Location of the study area

Exchangeable  $\text{Na}^+$ , macronutrients, and cation exchange capacity were determined according to USDA (2004).

#### Geomorphology and soils mapping using GIS

Geomorphologic map was carried out using digital image processing of Land sat 7.0 ETM<sup>+</sup> image (path 177, row 38) dated 2010 (Fig. 2) executed using ENVI 4.7 software (ITT 2009). Image was stretched using linear 2%, smoothly filtered, and their histograms were matched according to Lillesand and Kiefer (2007). Image was atmospherically corrected using FLAASH module (ITT 2009). The different landforms were initially determined from the satellite image and the digital elevation model extracted from the contour map following the methodology developed by Dobos et al. (2002). The different soil units were represented by 10 soil profiles and 10 groundwater samples, the morphological descriptions of the soil profiles were carried out using FAO (2006). Keys of soil taxonomy (USDA 2010) were used to classify the different soil profiles. ArcGIS 9.3.1 and its spatial analyst extension (ESRI 2009) was used for mapping soil variables and building a “Sustainable Land use Management Spatial Model” (SLMSM; Malczewski 1999). The socioeconomic data were obtained from the Egyptian Environmental Affairs Agency (EEAA; 2009).

**Fig. 2** Enhanced Land sat ETM<sup>+</sup> image of the studied area



#### Evaluation of the sustainable land use management

Indicators of the international framework for evaluating sustainable land management (FESLM) were used as inputs for the designed SLMSM (Smyth and Dumanski 1993).

SLMSM was designed using the spatial geoprocessing tools of ARCGIS 9.3.1 (ESRI 2009). Table 1 illustrates sustainable land use management index, and associated values and classes.

#### Results and discussion

To assess sustainable land use management, the current work is multistage (Fig. 3) as discussed in the subsections below.

#### Geomorphology and soils

Satellite images interpretation indicated that the investigated area includes three main landscapes

- Alluvial plain
- Lacustrine plain
- Marine plain

The main physiographic soils units of the studied area are represented in Table 2 and Fig. 4. Some chemical and



**Table 1** Sustainability index and associated values and classes

Values	Land use/management status	Class
0.6 to 1.0	Meet the sustainability requirements	I
0.3 to <0.6	Marginally but above the threshold of sustainability	II
0.1 to <0.3	Marginally but below the threshold of sustainability	III
0 to <0.1	Do not meet the sustainability requirements	IV

physical analyses of the studied soil profiles and the EC of water samples are shown in Table 3.

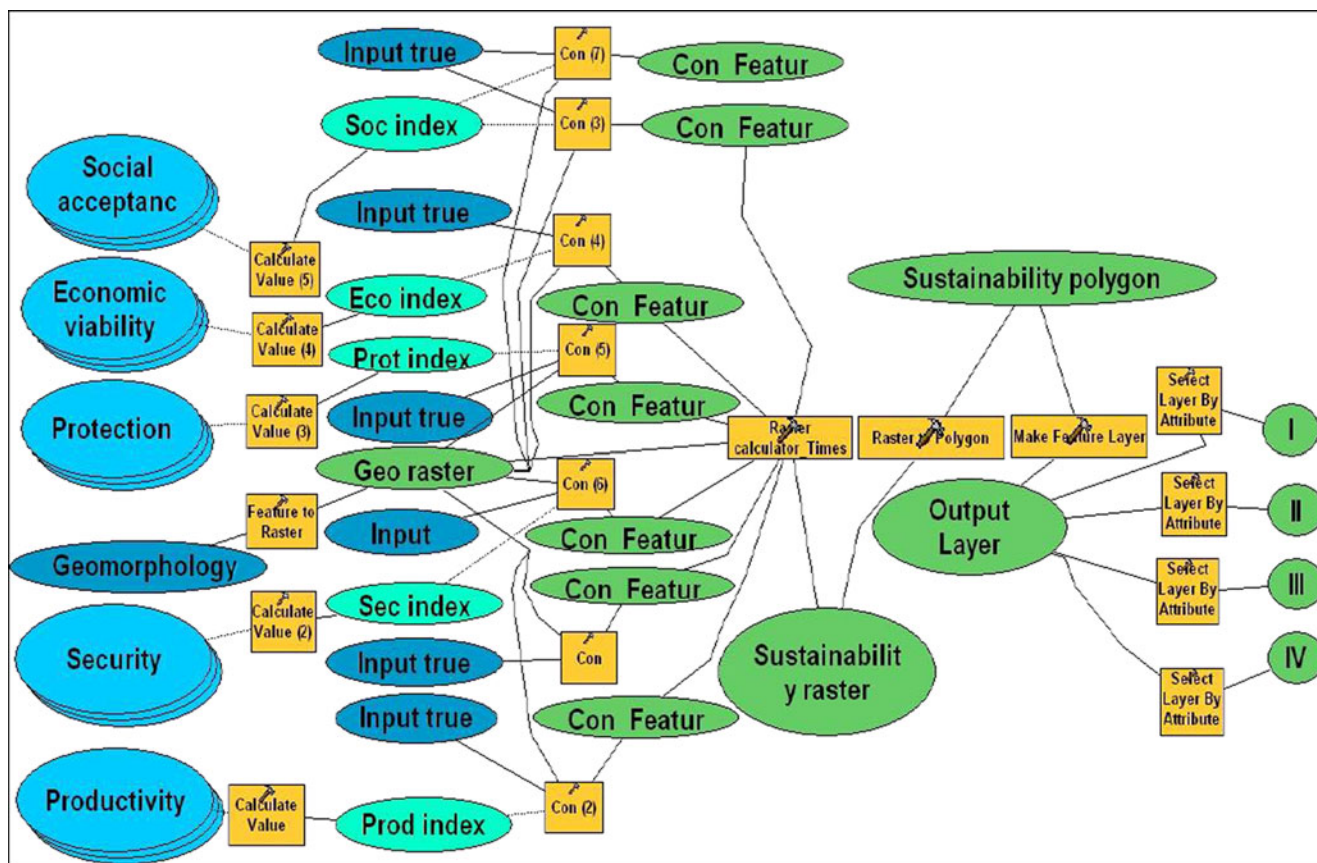
*Soils of lacustrine plain*

Soils of this landscape represents 19.35% of the total area and includes the dried lake bed (DL), dried fish ponds, wetlands (WL), and wet sabkha landforms. The main taxonomic units in this landscape are typic Natrargids and sodic Aquicambids. The obtained data showed that soil depth ranged between 60 and 80 cm. Soil texture class is clayey. Soils were compacted especially in wet sabkhas. Soil reaction (pH) values

are alkaline (8.50 and 8.70). The EC values are moderately ranging between 2.30 and 10.20 dS/m. The CaCO<sub>3</sub> content is low ranging between 8.30% and 12.30%. Organic matter content (OM%) is relatively sufficient for agricultural production under the aridity conditions recording a range of 0.86–1.51%. Cation exchange capacity is high, where it ranged between 30.90 and 48.60 mEq/100 g soils reflecting the high amount of clay content. Exchangeable sodium percentage (ESP) is high to very high where it ranges between 17.50 and 20.30. Finally, macronutrients represented by N, P, and K are in sufficient amounts.

*Soils of marine plain*

This landscape represents 9.07% of the total area and includes the sand sheets (S1 and S2), islands (I), and seasonally submerged land. The soils of this landscape are belonging to the typic Torripsamments subgreat group. The analytical data showed that depth of these sandy remnants soils ranged between 90 and 120 cm. Soil texture class is sand. Soil reaction (pH) values ranged between 7.80 and 7.90. The EC values are extremely high ranging between 16.10 and



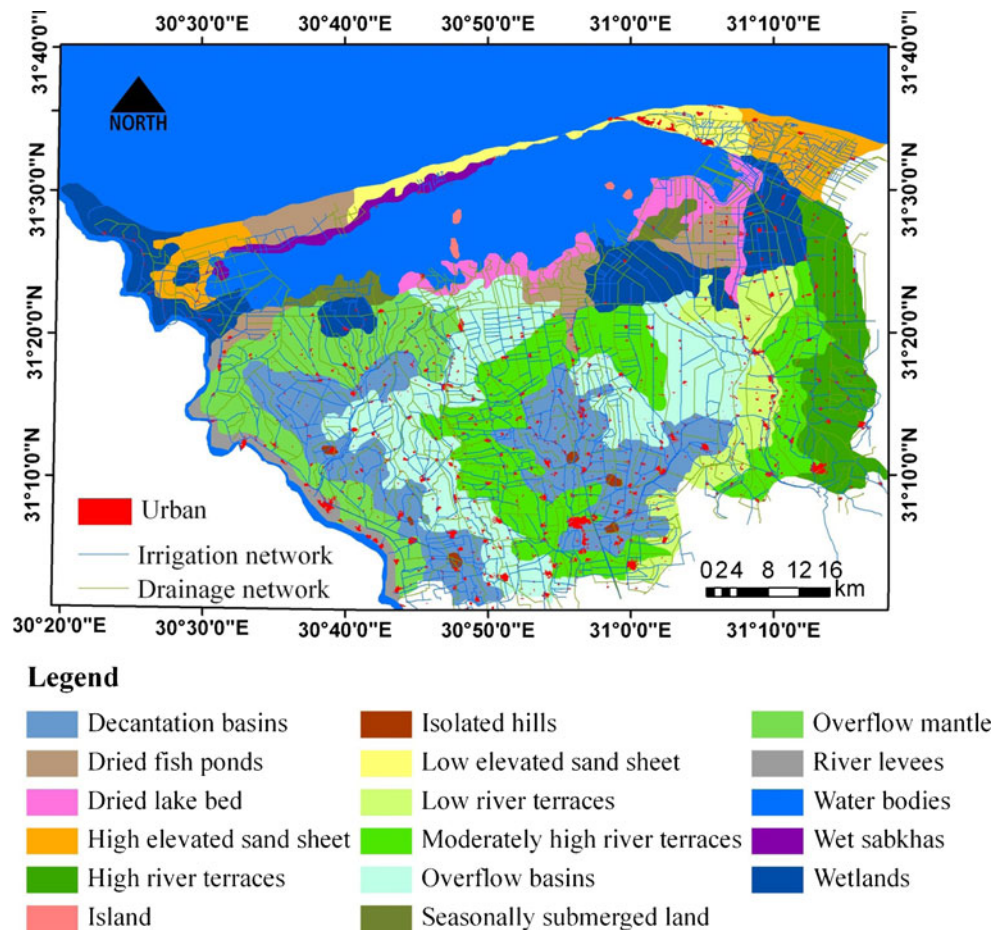
**Fig. 3** Sustainable land use management spatial model (SLMSM)

**Table 2** Legend of the physiographic soils map

Physiography	Landforms	Mapping unit	Area (km <sup>2</sup> )	Soil profile	%	Soil taxonomy
Flood plain	River terraces					
	High	T1	218.24	9	6.89	Vertic Torrifuvents
	Moderately high	T2	476.78		15.06	–
	Low	T3	173.44	4	5.48	Typic Aquisalids
	River levees	L	50.68	10	1.60	–
	Isolated hills	IH	10.54	–	0.33	–
	Overflow mantle	B1	292.41	3	9.24	Typic Torripsamments
	Overflow basins	B2	528.57	8	16.70	Typic Torrifuvents
Lacustrine plain	Decantation basins	B3	509.67	5	16.10	Typic Natrargids
	Dried lake bed	DL	115.00	6	3.63	Sodic Aquicambids
	Dried fish ponds	FD	152.25	–	4.81	–
	Wetlands	WL	304.83	7	9.63	Typic Natrargids
Marine plain	Wet sabkhas	WS	40.36	–	1.28	–
	Sand sheet					
	High elevated	S1	153.96	1	4.70	Typic Torripsamments
	Low elevated	S2	88.08	2	2.78	Typic Torripsamments
	Seasonally submerged land	SL	44.96	–	1.42	–
	Island	I	5.40	–	0.17	–

Total area=3,165.17 Km<sup>2</sup>

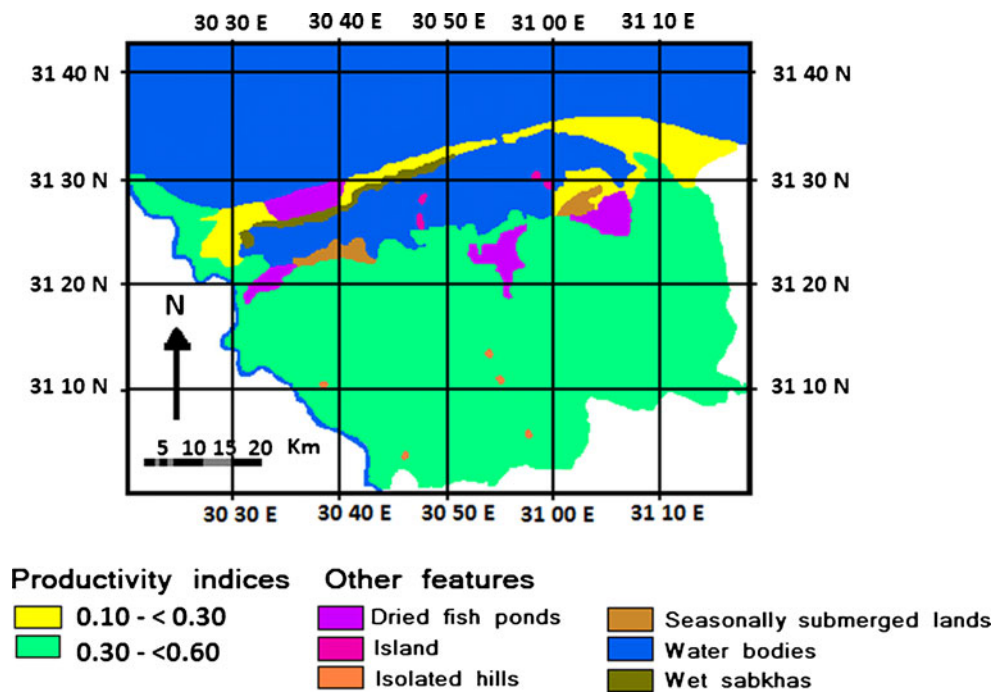
**Fig. 4** Physiographic and soils of the studied area



**Table 3** some physical and chemical characteristics of the representative soil profiles

Profile no.	Mapping unit	Depth (cm)	Particle size distribution%			Texture class	pH 1:2.5	OM%	CaCO <sub>3</sub> %	EC <sub>(1:1)</sub> dS/m	EC <sub>w</sub> dS/m	CEC mEq/100 g. soil	ESP%	Available macronutrients (ppm)		
			C sand %	F sand %	Silt %									N	P	K
1	S1	0–20	8.12	89.53	1.41	0.94	7.90	0.30	11.40	21.30	0.90	3.00	7.00	0.20	0.50	2.10
		20–50	12.18	6.82	0.52	0.48	7.90	0.10	9.00	16.10		1.50	7.60	–	–	–
		50–90	13.46	85.20	0.78	0.56	7.90	0.10	10.80	18.20		1.60	6.40	–	–	–
2	S2	0–30	5.19	91.76	1.79	1.26	7.80	0.40	8.10	34.20	0.73	0.10	8.40	0.30	0.70	3.10
		30–80	6.14	91.66	1.10	1.10	7.80	0.10	4.30	29.60		1.00	7.10	–	–	–
3	B1	80–120	16.92	81.23	0.65	1.20	7.80	0.10	6.10	40.30		0.70	7.40	–	–	–
		0–20	4.96	91.89	1.31	1.84	7.90	0.30	0.90	6.40	1.20	0.80	7.10	0.60	1.80	5.80
		20–80	13.81	84.57	0.82	0.80	8.00	0.20	0.70	9.10		1.70	6.40	–	–	–
4	T3	80–100	3.92	94.90	0.46	0.72	7.90	0.10	0.30	8.80		0.80	7.50	–	–	–
		0–30	0.31	26.24	19.14	54.31	8.30	1.51	0.90	7.50	0.54	50.40	16.30	43.10	9.20	94.60
		30–60	0.48	19.19	30.17	50.16	8.30	1.00	1.10	10.80		38.20	18.30	–	–	–
5	B3	0–30	0.11	32.99	24.20	42.70	8.30	1.65	0.80	9.70	0.60	30.10	16.80	56.20	11.40	100.30
		30–120	0.65	10.32	29.32	59.71	8.40	0.92	1.10	8.30		41.70	18.40	–	–	–
6	DL	0–20	0.18	36.52	21.19	42.11	8.50	1.51	8.30	10.20	0.65	33.40	17.50	51.60	8.30	110.40
		20–80	0.56	31.42	28.10	39.92	8.60	1.23	4.80	5.60		30.90	19.80	–	–	–
7	WL	0–20	0.32	25.02	31.48	43.18	8.50	1.70	10.20	4.70	0.76	33.80	18.10	50.20	10.70	114.80
		20–60	0.67	18.98	19.16	61.19	8.70	0.86	5.70	2.30		48.60	20.30	–	–	–
8	B2	0–30	0.38	51.06	26.42	22.14	7.50	1.10	0.90	2.10	0.68	13.10	10.30	11.70	4.50	40.80
		30–80	0.54	62.91	21.29	15.26	7.60	0.46	0.70	3.10		9.80	9.80	–	–	–
9	T1/T2	80–130	0.26	68.14	20.18	11.42	7.90	0.10	0.60	4.90		6.40	10.50	–	–	–
		0–20	0.37	25.24	31.19	43.20	8.20	1.60	0.60	5.10	0.77	29.70	15.20	31.90	9.70	100.4
10	L	20–80	0.29	38.41	20.17	41.13	8.20	0.80	0.30	3.80		30.10	15.30	–	–	–
		80–120	0.31	41.99	18.42	39.28	8.20	0.47	0.80	2.70		28.60	16.00	–	–	–
		0–20	0.54	28.15	30.19	41.12	8.20	1.50	0.90	4.20	0.69	29.30	15.10	46.60	12.70	117.20
		20–70	0.35	22.98	31.46	45.21	8.30	0.98	0.40	1.60		33.80	15.00	–	–	–

**Fig. 5** Productivity index of the study area



40.30 dS/m. The CaCO<sub>3</sub> content is high, ranging between 4.30% and 11.40%. OM% is low, recording a range of 0.10–0.40%. Cation exchange capacity is very low reflecting the low amounts of clay and organic matter, where it ranges between 0.90 and 3.00 mEq/100 g soils. ESP is low where it lays around 8.00%. Finally, macronutrients represented by N, P, and K are insufficient in this landscape soils. Soils of this unit were classified into typical Torripsamments.

*Soils of alluvial plain*

This landscape represents 71.40% of the total area and includes the sequence of river terraces (T1, T2, and T3), river levees (L), isolated hills, and overflow mantle (B1), overflow basins (B2), and decantation basins (B3) landforms. The main taxonomic units in this landscape are typical Torrifluents, vertic Torrifluents, typical Torripsamments, typical Aquisalids, typical Natragids, and sodic Aquicambids. The obtained data

**Table 4** Productivity characteristics of the mapping units

Profile no.	mapping unit	A <sup>a</sup>	Nutrient availability							H	I	J
			B	C	D	E	F	G				
1	S1	0.41	0.20	7.9	1.0	0.2	0.5	2.1	90	18.50	7.0	
2	S2	0.50	0.25	7.8	1.1	0.3	0.7	3.1	120	34.70	7.6	
3	B1	0.68	0.21	7.9	0.8	0.6	1.8	5.8	100	15.40	7.0	
4	T3	0.64	0.80	8.3	50.4	43.1	9.2	94.6	60	29.15	16.8	
5	B3	0.74	0.90	8.3	30.1	56.2	11.4	100.3	120	18.00	17.6	
6	DL	0.64	0.32	8.5	33.4	51.6	8.3	110.4	80	7.90	18.6	
7	WL	0.60	0.32	8.5	33.8	50.2	10.7	114.8	60	3.50	19.2	
8	B2	0.71	0.64	7.5	13.1	11.7	4.5	40.8	130	3.40	10.2	
9	T1/T2	0.82	0.80	8.2	29.7	31.9	9.7	100.4	120	3.80	15.5	
10	L	0.51	0.71	8.2	29.3	46.6	12.7	117.2	70	7.90	15.0	

The productivity index considering the value (PRI) of ten indicators as determining soil productivity, viz.: relative yield % (A), organic carbon % (B), pH (C), CEC in meq/100 g soil (D), available nitrogen in ppm (E), available phosphorous in ppm (F), available potassium in ppm (G), soil depth in cm (H), EC per deciSiemens per meter (I), and ESP (J)

<sup>a</sup> Yield reduction of the community average

**Table 5** Productivity indices of the mapping units

Profile no.	Mapping unit	A	Nutrient availability							H	I	J	PI
			B	C	D	E	F	G					
1	S1	70	90	100	85	80	90	90	95	85	100	0.28	
2	S2	70	90	100	85	80	90	90	100	90	100	0.27	
3	B1	80	90	100	85	80	90	90	100	85	100	0.34	
4	T3	80	95	95	100	90	95	90	95	85	90	0.40	
5	B3	80	95	95	100	95	100	90	100	85	90	0.46	
6	DL	80	95	95	100	95	95	90	95	95	90	0.47	
7	WL	80	95	95	100	90	100	90	95	100	90	0.50	
8	B2	80	95	100	95	80	95	90	100	100	95	0.46	
9	T1/T2	90	95	95	100	85	95	90	100	100	90	0.53	
10	L	70	95	95	100	90	100	90	95	95	90	0.41	

$$PI = \frac{A}{100} \times \frac{B}{100} \times \frac{C}{100} \times \frac{D}{100} \times \frac{E}{100} \times \frac{F}{100} \times \frac{G}{100} \times \frac{H}{100} \times \frac{I}{100} \times \frac{J}{100}$$

showed that depth of this flood plain soils ranged between 60 and 130 cm. Soil texture class is sandy to clayey. Soil reaction (pH) values range between 7.9 and 8.50. The EC values is moderate ranging between 1.60 and 10.80 dS/m. The CaCO<sub>3</sub> content is low ranging between 0.30% and 1.10%. OM% recording a range of 0.30–1.70%. Cation exchange capacity is high, where it ranges between 0.80 and 50.40 mEq/100 g soils reflecting the high amount of clay content. ESP is high where it ranges between 6.40 and 18.30. Argilic horizon was identified clearly. Soil compaction was noticed in some fields with low management practices. Finally, macronutrients represented by N, P, and K are sufficient with some exceptions in this landscape soils. In general, water logging, compaction, salinity, and sodicity are the main constraints in most soils of the investigated area.

#### Sustainable land use management spatial model

To assess sustainable land use management of the agricultural system, five sustainability indicators (productivity, protection, security, economic viability, and social acceptability) were modeled in the following subsections.

#### Deriving indicator indices of the investigated area

Indicator indices could be calculated through a series of values for input criteria concerning (a) productivity, (b) security, (c) protection, (d) economic viability, and (e) social acceptability. Calculating a series of values for criteria was based on specified python expression resulting in five datasets for each input criteria.

**Table 6** Security and protection characteristics of the mapping units

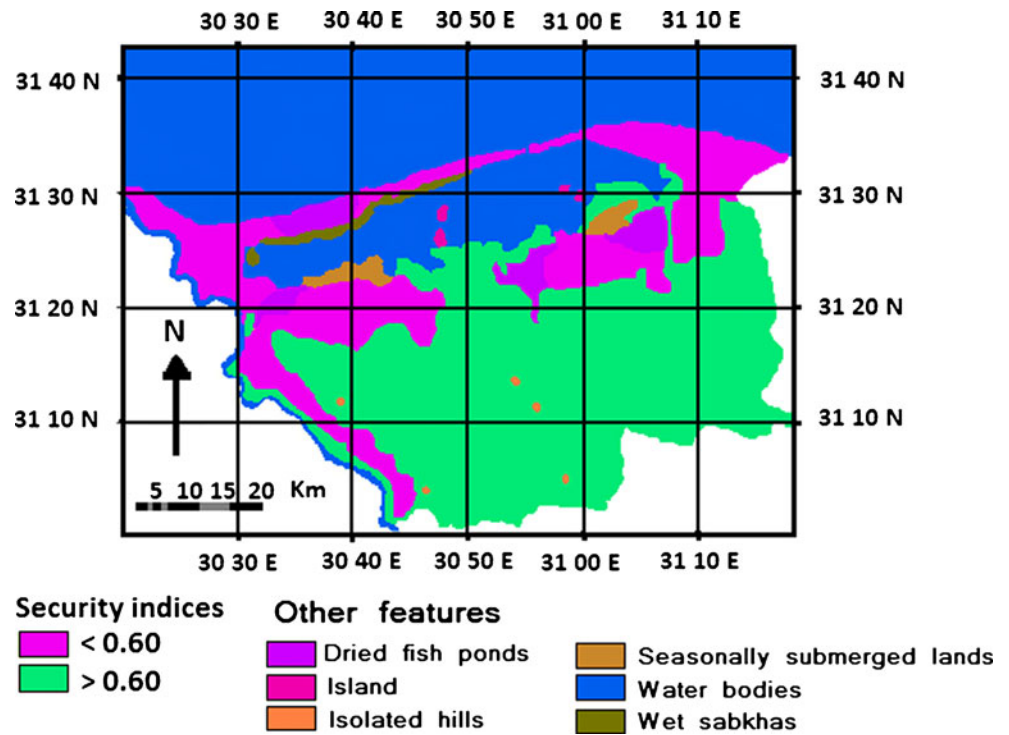
Profile no.	mapping unit	Security			Protection		
		A	B	C <sup>a</sup>	E	F	G
1	S1	<90	0.90	<16%/more than 1 year	Small gullies	Not	No cropping pattern
2	S2	<90	0.73	<16%/more than 1 year	Small gullies	Not	No cropping pattern
3	B1	<90	1.20	<16%/more than 1 year	No evidence	No	Double cropping pattern
4	T3	365	0.54	<16%/more than 1 year	No evidence	No	Double cropping pattern
5	B3	365	0.60	<16%/more than 1 year	No evidence	No	Double cropping pattern
6	DL	365	0.65	<16%/more than 1 year	No evidence	No	Double cropping pattern
7	WL	<90	0.76	<16%/more than 1 year	Small gullies	Not	Double cropping pattern
8	B2	365	0.68	<16%/more than 1 year	No evidence	No	Double cropping pattern
9	T1/T2	365	0.77	<16%/more than 1 year	No evidence	No	Double cropping pattern
10	L	365	0.69	<16%/more than 1 year	No evidence	No	No cropping pattern

The security index consider the value (SI) of three indicators, i.e., moisture availability per month/season (A), EC of irrigation water (B), and biomass%, (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 index of the natural resources (PI)

<sup>a</sup> Biomass%=percentage of crop residue plowed back to land



**Fig. 6** Security index of the studied area

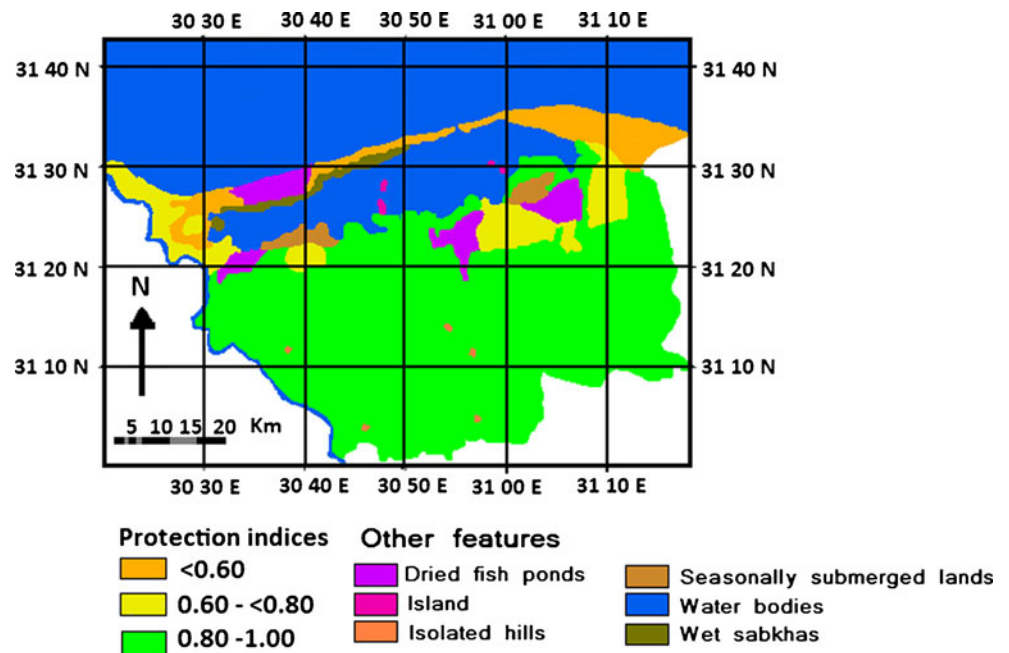


*Productivity* Results obtained from the first stage of executing SLMSM (getting productivity index from calculating series of values) indicated that the land productivity in the alluvial plain landforms are marginal but above the requirements of sustainability (class II), while it is marginal but below the requirements of sustainability (class III) in the lacustrine and marine plains. The low values of the productivity in the studied area are due to the decrease of relative yield, cation

exchange capacity, available nitrogen, and an increase of salinity. The spatial distribution of the productivity index is shown in Fig. 5, and Table 4 shows the productivity characteristics of the different mapping units in the studied area. The data of productivity indices are illustrated in Table 5.

*Security and protection indices* Table 6 represents the security and protection characteristics in the different

**Fig. 7** Protection index of the studied area



**Table 7** Security and protection indices of the mapping units

Profile no.	Mapping unit	Security				Protection			
		A	B	C	SI	E	F	G	PRI
1	S1	70	100	80	0.56	90	90	60	0.48
2	S2	70	100	80	0.56	90	90	60	0.48
3	B1	70	100	80	0.56	100	100	100	1.00
4	T3	100	90	80	0.72	100	100	100	1.00
5	B3	100	90	80	0.72	100	100	100	1.00
6	DL	100	90	80	0.72	100	100	100	1.00
7	WL	70	100	80	0.56	90	90	100	0.81
8	B2	100	90	80	0.72	100	100	100	1.00
9	T1/T2	100	100	80	0.80	100	100	100	1.00
10	L	100	90	80	0.72	100	100	60	1.00

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

mapping units in the studied area. Results obtained from the first stage of executing SLMSM were getting security and protection indices from calculating series of values, where security and protection practices in alluvial plain meet the requirements of the sustainability where their indices range between 0.72 and 0.80, and 0.81 and 1.00, respectively. On the other side, security and protection indices of lacustrine and marine plains are in general marginal but above the threshold of sustainability, which is due to moisture availability, biomass, erosion hazard, and the cropping system. The spatial distributions of security and protection indices in the studied area are represented in Figs. 6 and 7. The security and protection indices are shown in Table 7.

*Economic viability* Table 8 represents the characteristics of economic viability in the studied area. Results

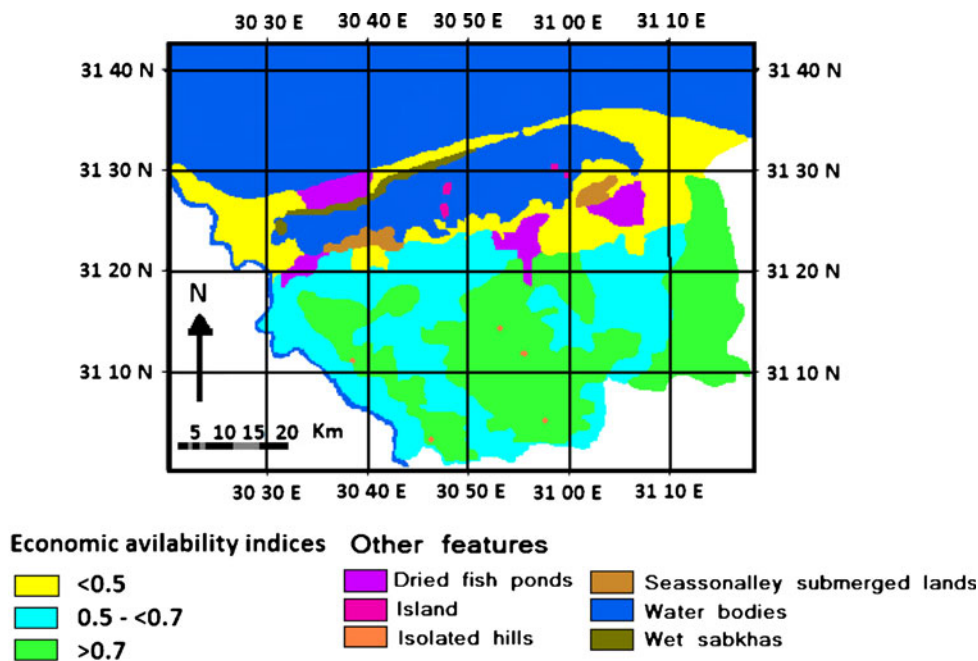
obtained from the first stage of executing SLMSM (getting economic viability index from calculating series of values) revealed that the economic viability of the different landforms in marine plain is marginal but above the requirements of the sustainability where the economic viability index in these areas ranges between 0.26 and 0.37. The rest of the area has an economic viability that meets the sustainability requirements where the economic viability index ranges between 0.58 and 0.66. The low economic viability in the studied area is due to the decrease of benefit to coasts ratio, low availability of farm labor, small size of farm holding, and low percentage of farm production in market. The distributions of economic viability index in the studied area are represented in Fig. 8. The economic viability indices are shown in Table 9.

**Table 8** Economic characteristics of the mapping units

Profile no.	Mapping unit	A	B	C	D	E	F	G
1	S1	1.00	17.32	25.20	1.00	1.00	31.50	20.00
2	S2	1.00	17.32	25.20	1.00	1.00	31.50	20.00
3	B1	1.30	30.16	11.70	3.00	2.00	31.50	30.00
4	T3	1.50	36.85	11.40	3.00	4.00	31.50	40.00
5	B3	1.75	46.18	11.40	3.00	4.00	31.50	53.71
6	DL	1.20	18.43	24.60	1.00	2.00	31.50	36.40
7	WL	0.90	16.76	24.80	1.00	2.00	31.50	30.00
8	B2	1.30	30.41	11.40	4.00	4.00	31.50	51.40
9	T1/T2	1.60	53.70	11.40	1.00	4.00	31.50	61.32
10	L	1.35	55.26	11.40	4.00	3.00	31.50	42.30

The economic viability index consider the value (EI) 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% (C), availability of farm labor man/feddan (D), size of farm holding in feddan (E), availability of farm credit% (F), and percentage of farm produce sold in market% (G)

**Fig. 8** Economic availability index of the studied area



*Social acceptability* Table 10 represents the characteristics of social acceptability in the studied area, which extracted from EEAA (2009) and field work. Results obtained from the first stage of executing SLMSM (getting social acceptability index from calculating series of values) indicated that the areas of marine plain is marginal but below the requirements of sustainability where the social acceptability index in these areas is 0.20, which is rather low. The social acceptability in the lacustrine plain and some parts of the alluvial plain is marginal but above the threshold of sustainability, where it ranges between 0.42 and 0.47. The social acceptability in the rest of the area is rather high as it reaches to value of 0.65, which meets the sustainability requirements. The low value of the social indicator in the studied area is mainly due to the shortage in health and educational facilities in the villages and the lack of training allocation for the land

users on soil and water conservation. Figure 9 represents the distribution of the social acceptability index all over the studied area. The social acceptability indices are shown in Table 11.

*Performing a conditional statement*

A conditional statement if/else evaluation on each of the input cells of the geomorphologic raster map was performed. The outputs were the true values of indicators indices in raster format belonging to the different mapping units in the investigated area.

*Getting sustainability index*

Sustainability index were obtained by multiplying indices of the five indicators according to the following formula:

**Table 9** Economic availability indices (EI) of the mapping units

Profile no.	Mapping unit	A	B	C	D	E	F	G	EI
1	S1	70	90	90	80	80	90	80	0.26
2	S2	70	90	90	80	80	90	80	0.26
3	B1	80	100	100	100	90	90	90	0.58
4	T3	90	100	100	100	90	90	90	0.66
5	B3	100	100	100	100	90	90	100	0.81
6	DL	80	90	90	80	90	90	90	0.37
7	WL	70	90	90	80	90	90	90	0.33
8	B2	80	100	100	100	90	90	100	0.65
9	T1/T2	90	100	100	100	90	90	100	0.73
10	L	80	100	100	100	90	90	90	0.58

Economic viability index (EI)=  
 $A/100 \times B/100 \times C/100 \times D/100 \times$   
 $E/100 \times F/100 \times G/100$

**Table 10** Social characteristics of the mapping units

Profile no.	Mapping unit	A	B	C	D	E	F	G
1	S1	Not official	Low	Non	20	Not available	Not available	Non
2	S2	Not official	Low	Non	20	Not available	Not available	Non
3	B1	Long term	Moderate	Shortage	36	Not available	Not available	Limited
4	T3	Long term	Moderate	Shortage	36	Not available	Limited	Limited
5	B3	Full	Moderate	Shortage	36	Not available	Limited	Full access
6	DL	Not official	Low	Non	20	Not available	Limited	Non
7	WL	Not official	Low	Non	20	Not available	Not available	Non
8	B2	Full	Moderate	Shortage	36	Not available	Limited	Limited
9	T1/T2	Full	Full	Shortage	36	Not available	Available	Full access
10	L	Long term	Full	Shortage	20	Not available	Available	Limited

The social acceptability index consider the value (SOI) 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 main road (G)

Sustainability index =  $A \times B \times C \times D \times E$ , where  $A$ =productivity,  $B$ =security,  $C$ =protection,  $D$ =economic viability, and  $E$ =social acceptability.

*Converting sustainability units from raster to polygon in a geodatabase file*

Sustainability units were converted from raster to polygon to get the areas of the sustainability units for assessment purposes.

*Creating sustainability layers and selecting classes*

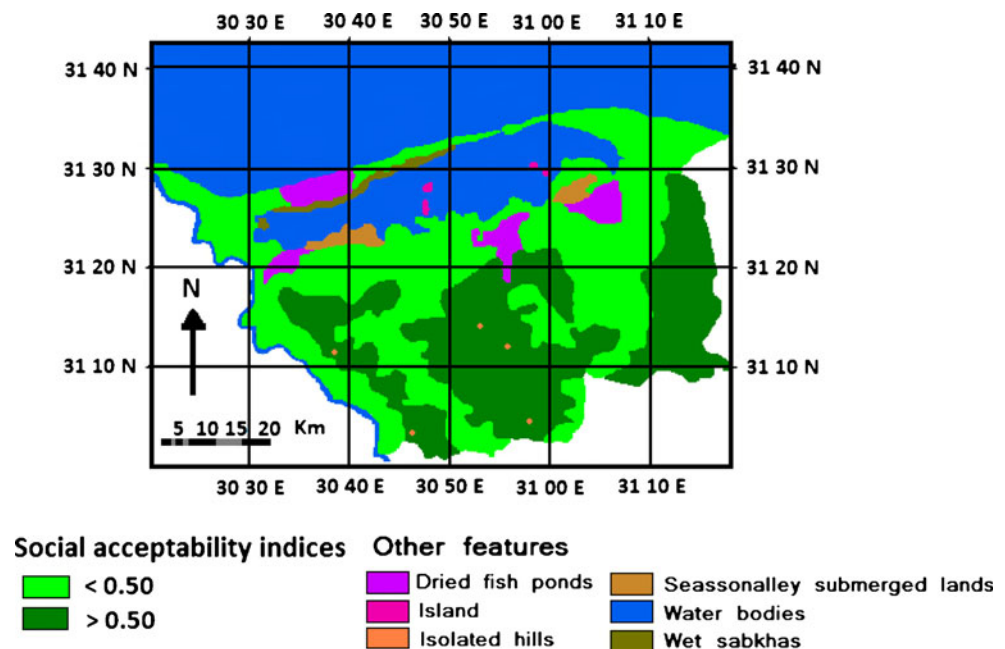
Sustainability layers were created to query sustainable land management classes.

*Model products accuracy assessment*

However, quantitative assessment was executed for SLMSM map products to identify and measure the map errors that are derived from the model. In these assessments, map data were compared with ground truth data obtained from two sources, field measurements and observations on farming system level and from laboratory analyses. The overall accuracy assessment of thematic maps recorded 98.34%.

In general, land use management practices tend to be unsustainable as shown in Figs. 10 and 11, and Table 12. The results indicated that the studied area includes two sustainability classes as the following:

**Fig. 9** Social acceptability index of the studied area





**Table 11** Social acceptability indices (SAI) of the mapping units

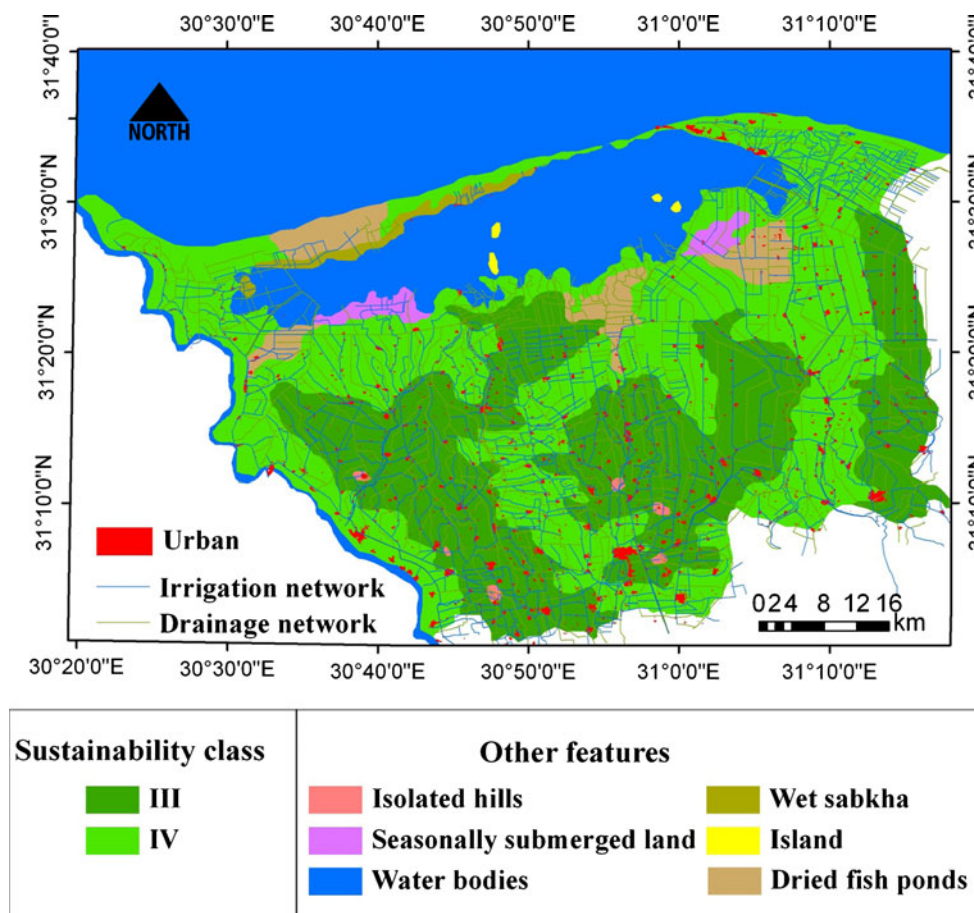
Profile no.	Mapping unit	A	B	C	D	E	F	G	SAI
1	S1	80	80	80	80	80	80	80	0.20
2	S2	80	80	80	80	80	80	80	0.20
3	B1	90	90	90	90	80	90	90	0.42
4	T3	90	90	90	90	80	90	90	0.42
5	B3	100	90	90	90	80	100	100	0.58
6	DL	80	80	80	80	80	80	80	0.20
7	WL	80	80	80	80	80	80	80	0.20
8	B2	100	90	90	90	80	90	90	0.47
9	T1/T2	100	100	90	90	80	100	100	0.65
10	L	90	100	90	80	80	90	90	0.42

Social acceptability index (SAI)  
 $= A/100 \times B/100 \times C/100 \times D/100 \times E/100 \times F/100 \times G/100$

- Class III Land management practices are marginally below the threshold for sustainability as occurred in the units with values range (0.1–0.2), i.e., T1, B2, and B3.
- Class IV Land management practices do not meet sustainability requirements as occurred in the units with values range (0.003–0.07), which include S1, S2, B1, DL, WL, L, and T3.

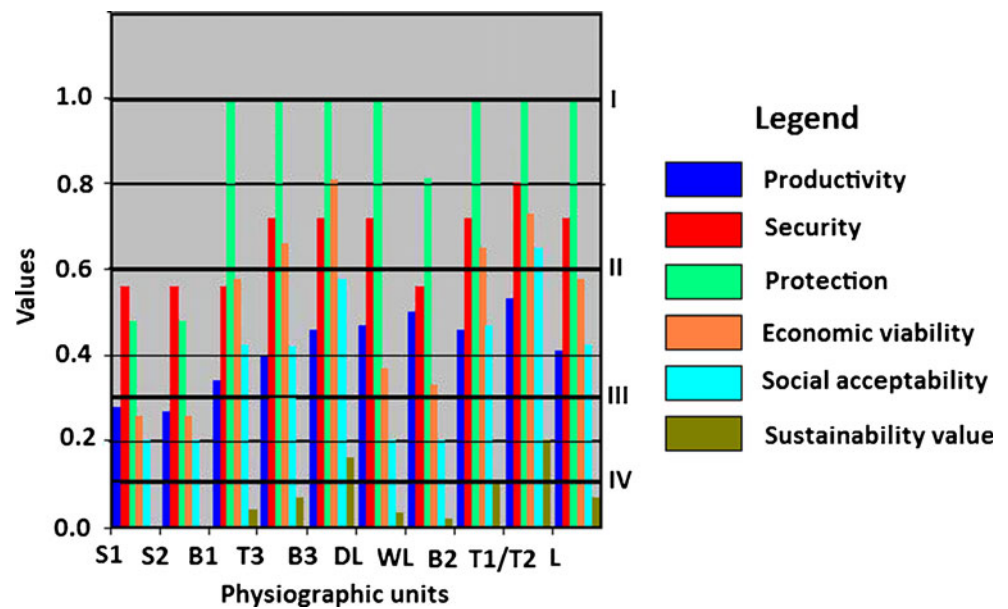
**Conclusion**

Results based on the present work demonstrate that the investigated area is facing numerous constrains such as soil productivity, social acceptability, and economic viability which could hinder the agricultural sustainability in the region. The land productivity in the alluvial plain landforms is marginal, while it is marginal but below the requirements



**Fig. 10** Sustainability class in the studied area

**Fig. 11** Sustainability values at the studied area



of sustainability in the lacustrine and marine plains. The low values of the productivity in the studied area are due to the decrease of relative yield, cation exchange capacity, available nitrogen, and an increase of salinity. In the soils of lacustrine and marine plains, the security and protection are in general marginal but above the threshold of sustainability, which is due to moisture availability, biomass, erosion hazard, and the cropping system. The low economic viability in the studied area is due to the decrease of benefit to coasts ratio, low availability of farm labor, small size of farm holding, and low percentage of farm production in market. The low value of the social indicator in the studied area is mainly due to the shortage in health and educational facilities in the villages and the lack of training allocation for the land users on soil and water conservation. To overcome such constrains, farm man-

agement, infrastructure, and social services must be improved to reach the standards of agricultural sustainability. The FESLM offers an integrated model for quantitative assessment of the agricultural sustainability; it gives the capability of using the results in the GIS to produce the thematic maps.

### Recommendations

To overcome sustainability constrains, farm management, infrastructure, and social services should be improved to reach the standards of agricultural sustainability throughout: (1) improving land and water resources following advanced techniques of management and conservation; (2) improving awareness levels on the sustainable issues of natural

**Table 12** Sustainability classes of the mapping units

Profile no.	Units	Productivity	Security	Protection	Economic viability	Social acceptability	Total value	Sustainability class
1	S1	0.28	0.56	0.48	0.26	0.20	0.003	IV
2	S2	0.27	0.56	0.48	0.26	0.20	0.003	IV
3	B1	0.34	0.56	1.00	0.58	0.42	0.04	IV
4	T3	0.40	0.72	1.00	0.66	0.42	0.07	IV
5	B3	0.46	0.72	1.00	0.81	0.58	0.16	III
6	DL	0.47	0.72	1.00	0.37	0.20	0.03	IV
7	WL	0.50	0.56	0.81	0.33	0.20	0.01	IV
8	B2	0.46	0.72	1.00	0.65	0.47	0.10	III
9	T1/T2	0.53	0.80	1.00	0.73	0.65	0.20	III
10	L	0.41	0.72	1.00	0.58	0.42	0.07	IV

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

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 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 are some of the measures that can reduce demand-driven pressure on sustainability.

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