25 Egypt. J. Soil Sci. **Vol. 55,** No. 4, pp. 409 - 424 (2015)

Assessment of Sustainable Agricultural Land Management by Using GIS Techniques in North Delta, Egypt

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SUSTAINABLE Agricultural of Land Management (SALM) depends on a whole-system approach whose overall goal is the continuing health of the land and people. It concentrates on a long term solutions to problems instead of short term treatment of indicators. Assessment of (SALM) is determined by biophysical conditions, economic evaluation, social acceptability and environmental concerns that must be viewed in an integrated method. The current study aims to evaluate sustainable agricultural land management in North Delta Egypt, through integration land productivity, security, protection, economic viability and social acceptability. The spatial analysis function in geographic information system (GIS) was employed to estimate the sustainability index.

The obtained values of sustainability index indicate that the area could be classified into three classes, *i.e.* (Class II) areas above the threshold of sustainability, (Class III) areas below the threshold of sustainability and (Class IV) non-sustainable areas which representing 30.23 %, 58.24 % and 11.53 %, respectively of the investigation area. Results show that the most of agricultural land in the study area tends to be marginally below the threshold for sustainability (*i.e.* 58.24% of total area), this means attention should be paid to social and economic services.

Keywords: Sustainable Agricultural Land Management, GIS, North Delta, Egypt.

Sustainable Agricultural Land Management (SALM) is garnering increasing support and acceptance within mainstream agriculture. Sustainable agriculture depends on many environmental and social concerns. Sustainable development is defined as "development that meets the needs of the present without compromising the ability of future generations to meet their own needs" (Smith and Dumanski, 1993).

Sustainable agriculture is used to refer to practices that meet current and future societal needs for food and feed, ecosystem services and human health,

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maximizing the net benefit for people, without compromising the ability of future generations to meet their own needs by improving the natural resource (Tilman *et al.,* 2002). Sustainable agricultural systems aim at developing new farming practices that are also safe and do not degrade the environment (Lichtfouse *et al.,* 2009). On the other hand the SALM is necessary to shorten the gap between planning practice and research regarding landscape (Antonson, 2009). Crop yield is used as a sustainability indicator, which not only quantifies the production/ha over time but also allows to identify gaps between experimental yield and farmer yield (El-Nahry, 2001).

In this study the Bio-physic elements (productivity, security, protection) and socio-economic aspects (economic viability and social acceptability) are used under Egyptian conditions for the purpose of combating and tackling sustainability constraints that preclude the agricultural development or to reduce them to acceptable levels of mass production endeavors. (Abdel Kawy & Darwish, 2014, Nawar, 2009, El Bastawesy *et al.,* 2013 and Ali & Shalaby, 2013).

The aims of this study are to: (1) produce the physiographic map of the studied area, (2) evaluate sustainable utilization of agricultural land through integration of five factors (productivity, security, protection, economic viability and social acceptability) using spatial analysis in geographic information system (GIS), analytical tools for the determination of combating and tackling sustainable agricultural constraints and optimum land use planning in the North Delta Egypt.

Materials and Methods

Area of study

The studied area is located in the northern part of the Nile Delta- Egypt, between longitudes 30º45'00"and 31º10'00" east and latitudes 31º10'00" and 31º35'00" north, (Fig.1). It is located under typically arid and semi-arid climatic conditions; the annual rainfall distribution values occur in the cold season, *i.e.* November–February interval reaching about 167 mm/year. The maximum rainfall values are recorded in January and December. The mean annual evaporation reaches its maximum in August at 7 mm/day. The minimum values are observed in January and December when the temperature is comparatively low, whereas the highest value is recorded in the period between June and September. Air temperature ranges between 15.0 and 30.5º C in December and August, respectively. (Climatological Normal for Egypt, 2011).

Digital image processing and physiographic units

Image Landsat ETM^+ (path 177, row 038) acquired during the year 2013. The image was enhanced by using ENVI 5.1 software; improve the contrast and enhancing the edges according to Lillesand and Kiefer (2007). The atmospheric correction was done to reduce the noise effect. Image was radiometrically and geometrically corrected to accurate the irregular sensor response over the image and to correct the geometric distortion due to Earth's rotation (ITT, 2009). The digital elevation model (DEM) of the study area was extracted from the topographic maps scale 1:25000. The digital elevation model could be combined with land sat image ETM$^+$ to understand better view of the landscape. It can be employed to offer varieties of data that can assist in mapping of landforms and soil types. Information derived from a DEM (*i.e.* surface elevation, slope % and slope direction), could be used with the satellite images to increase their capabilities for soil mapping (Lee *et al*., 1988). The Landsat ETM$^+$ image and DEM were managed in ENVI 5.1 software to recognize the physiographic units and establish the soil database (Dobos *et al*., 2002).

Field studies and laboratory analyses

A semi detailed survey was carried out during the investigated area in order to gain an appreciation on soil patterns, landforms and the physiographic characteristics. A total of 42 soil profiles were collected in the studied area to signify the different preliminary mapping units (Fig.1). Water samples were collected from irrigation, drainage and water table sources closed to the soil profiles locations. Soils and water samples were analyzed (chemical and physical) following the procedure detailed by USDA (2004). Detailed socio-economic data about the studied area was collected during the field questionnaires and published report after CAPMAS (2011). The land surveying, laboratory analyses and socio-economic data were recorded in the attribute table of the physiographic map using Arc-GIS 10.1 software.

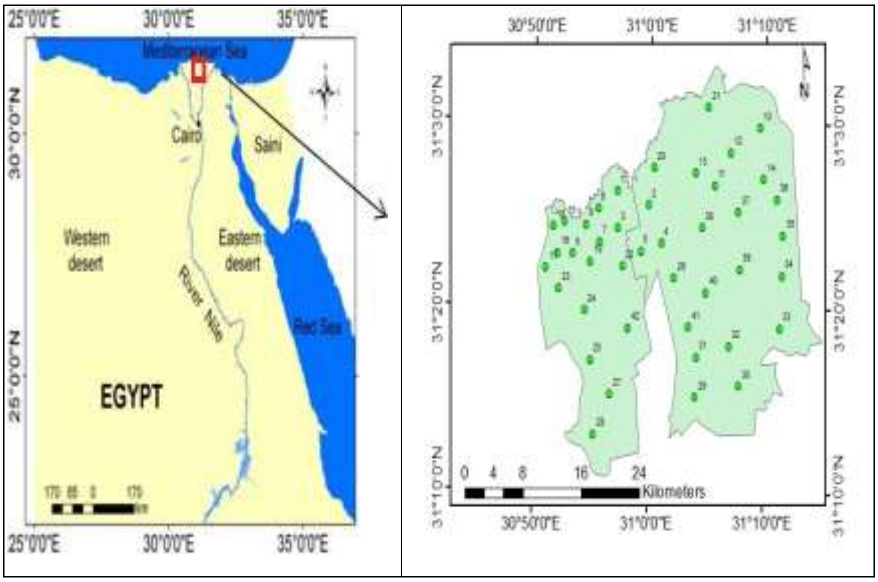

Fig. 1. Location of study area on Egypt map (to the left) and Location of soil profiles (to the right).

Assessment of sustainable agriculture

International Framework for Evaluating Sustainable Land Management (FESLM) (Smith and Dumanski, 1993) was used to recognize the current condition of sustainability, as well as having been modified and adapted for Egyptian conditions by El-Nahry (2001). FESLM combines technologies, policies and activities aimed at integrating socio-economic principles with environmental concerns. The FESLM involve the five supports of sustainable land management, which include productivity, security, protection, economic viability and social acceptability.

To define the current sustainability status and potentiality in the North Nile Delta, the current conditions of land use, existing management practices, environmental factors, and the present economic and social conditions were recognized. A (SALM) model was designed by using the Arc-Map 10.1 software. The designed model process the digital data stored in the land resources database which characterize the physiographic map. The outputs are the indices of productivity, security, protection, economic viability, social acceptability and sustainability index of the studied area. Each indicator has a scale from 0.0 to 1.0, the actual percentage being multiplied by each other, the resultant index of sustainability, also lying between 0.0 and 1.0. Sustainable agricultural land management (SALM) of the investigated area was divided into four classes according to the obtained values of sustainability index. These classes are S1, S2, S3 and S4 when the sustainability index is situated in the range of (1-0.6), (0.6-0.3), (0.3-0.1) and (0.1-0). respectively. Figure 2 illustrate the input data, equations and outputs of the designed cartographic model.

Productivity index (A)

Productivity refers to quantity of yield from agricultural operations. The productivity index was calculated using the following formula:

$$\text{Productivity Index} = \frac{A}{100} \times \frac{B}{100} \times \frac{C}{100} \times \frac{D}{100} \times \frac{E}{100} \times \frac{F}{100} \times \frac{G}{100} \times \frac{H}{100} \qquad \text{Eq. 1}$$

where: relative yield% (A), texture (B), organic carbon (C)%, pH (D), cation exchange capacity (E), profile depth (F), salinity (G), and alkalinity (H).

Security (B) and protection indices (C)

The security index depends on three factors, moisture availability (A), water quality (B) and Biomass (C). The protection index hinge on erosion hazards by water and winds (A), flooding hazards (B) and cropping system (C) using the following formulas:

$$\text{Security index} = \frac{A}{100} * \frac{B}{100} * \frac{C}{100} \qquad \text{Eq. 2}$$

$$\text{Protection index} = \frac{A}{100} * \frac{B}{100} * \frac{C}{100} \qquad \text{Eq. 3}$$

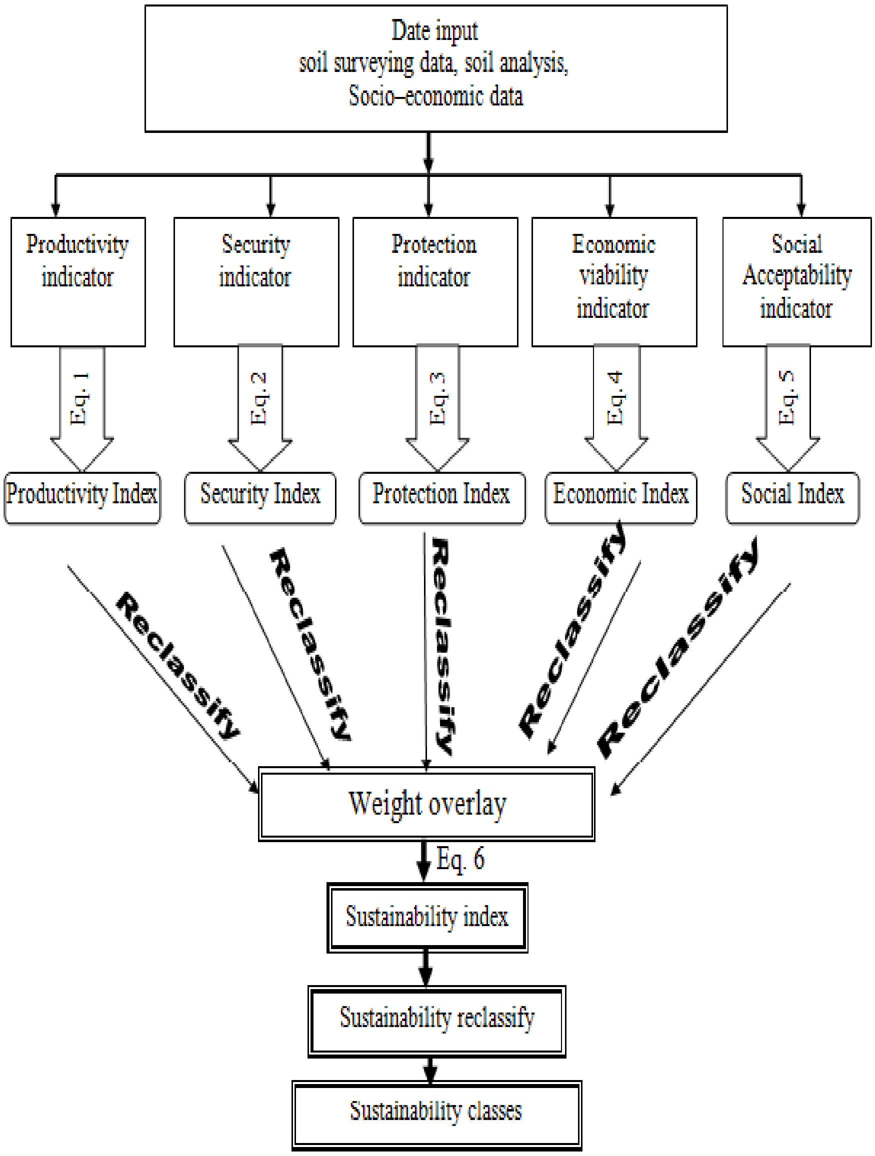

Fig. 2. Sustainable agricultural land management (SALM) model.

Economic viability index (D)

Economic evaluation depends on survey work, which should usually start early in the land evaluation processes. The economic viability index considering the value (V) of five indicators as determining economic viability, viz.: benefit–cost ratio (A), difference between farm gate price and the nearest main market price (B), availability of farm labor (C), size of farm holding (D) and percentage of farm produce.

$$\text{Economic index} = \frac{A}{100} * \frac{B}{100} * \frac{C}{100} * \frac{D}{100} * \frac{E}{100} \qquad \text{Eq. 4}$$

Social acceptability (E)

The social acceptability index was calculated using six factors: land tenure (A), support for extension services (B), health and educational facilities in the village (C), training of farmers on soil and water conservation (D), availability of agro-inputs within 5–10 km range (E) and village road access to main road (F).

$$\text{Social index} = \frac{A}{100} * \frac{B}{100} * \frac{C}{100} * \frac{D}{100} * \frac{E}{100} * \frac{F}{100} \qquad \text{Eq. 5}$$

Sustainability index

Sustainability index was calculated with the following formula:
Sustainability Index = A × B × C × D × E Eq. 6
where, A = productivity index, B = security index, C = protection index, D = economic index and E = social index.

Results and Discussion

Physiographic map

The main of landscapes in the study area are the fluvio lacustrine plain and flood plain. These landscapes contains ten landforms were recognizing, *i.e.* decantation basins, dried lake bed, high elevated sand sheet, high river terraces, low river terraces, moderately high river terraces, overflow basins, overflow mantel, seasonally submerged land and wet lands, which covered 7.94, 9.85, 0.22, 2.22, 12.05, 14.80, 22.24, 9.16, 2.15 and 19.37% of the total area, respectively (Fig. 3).

Sustainability indicators

Five factors were used to assess sustainable land management, including productivity, security, protection, economic viability and social acceptability using geographic information system.

Some soil analyses are shown in Table 1 and Fig.4. Soils of the studied area consisted of two main soil texture which differed from clay and silt clay. In addition, soil salinity varied from non-saline to very strongly saline. The obtained data revealed that these soils were characterized by alternative pattern of sedimentation and their sediments originated from different parent materials. i.e., fluvio lacustrine plain and flood plain. The studied soils were classified according to Soil Taxonomy (2010) into two orders the first was Entisols with sub great groups of Typic Torrifluvent and Vertic Torrifluvent. The second order was Aridisols with sub great groups of Typic Haplosalids, Aquallic Salorthids, and Typic Natrargids.

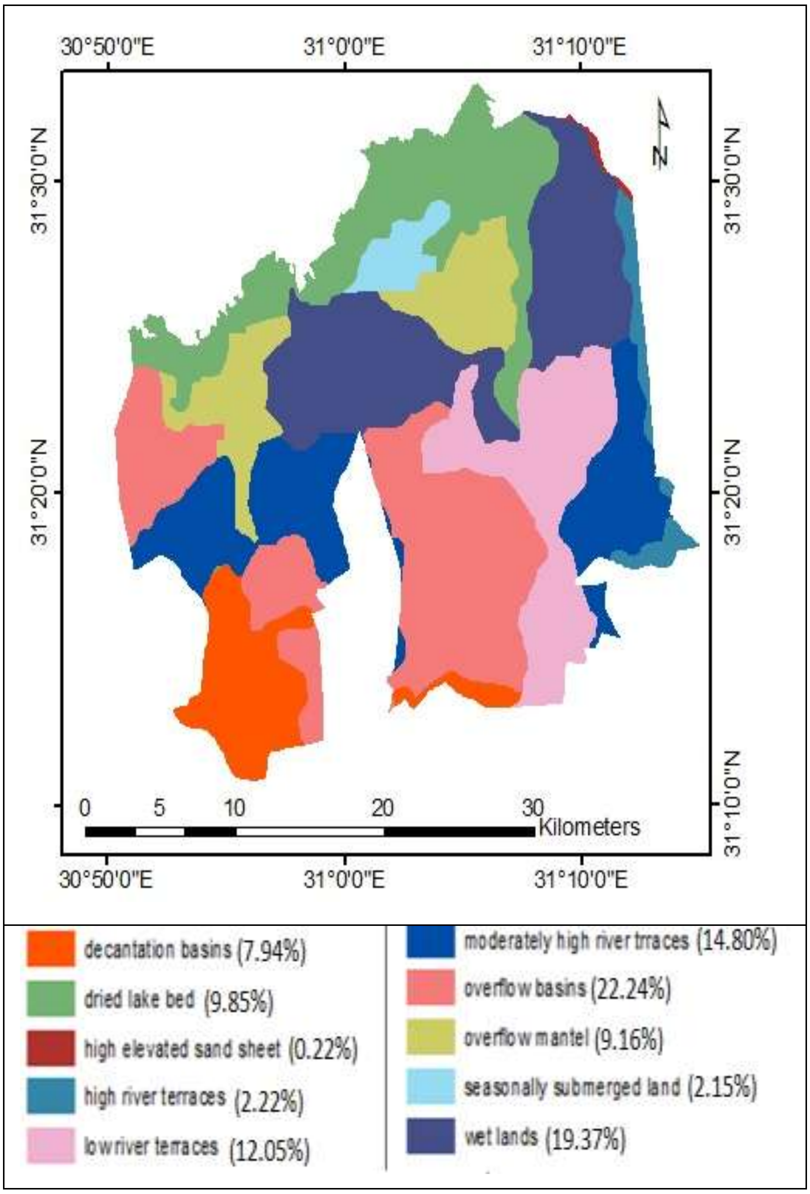

Fig. 3. Physiographic units of the study area.

TABLE 1. Some chemical and physical characteristics of the studied area.

Profile No.	Relative yield%	Nutrient availability			Watertable (cm)	EC (dSm^{-1})	ESP %	Texture
		Organic C %	p H 1:2.5	CEC meq/100g soil				
1	Very High	0.34	8.07	31.40	110	50.3	43.69	C
2	High	0.69	7.90	29.20	96	7.10	23.86	C
3	High	1.08	7.98	33.60	92	7.98	21.50	SiC
4	High	1.30	7.99	37.00	106	6.00	13.73	C
5	Medium	1.09	7.66	38.00	113	3.10	12.10	C
6	Very High	0.78	8.20	22.00	82	46.20	50.70	C
7	High	0.86	8.10	25.20	86	8.30	28.17	C
8	High	1.06	8.12	30.20	81	7.80	22.12	C
9	High	0.99	7.82	22.40	82	7.20	18.86	C
10	Very High	0.27	8.30	27.00	90	63.30	70.96	C
11	High	0.70	7.98	26.80	89	8.10	23.50	C
12	High	0.78	8.10	28.00	85	7.40	18.71	C
13	High	1.08	8.04	33.00	89	7.20	31.54	C
14	High	1.21	7.74	30.00	105	7.10	26.23	C
15	Very High	0.58	8.30	23.80	79	53.14	49.17	C
16	High	0.91	8.18	24.40	78	9.00	32.60	C
17	High	0.93	8.00	28.60	73	8.10	23.72	C
18	High	0.99	8.10	26.80	76	7.30	23.39	C
19	High	1.05	8.00	32.00	83	7.10	19.48	C
20	Very High	0.81	8.25	28.40	78	16.50	27.90	C
21	Very High	0.70	8.18	28.40	68	12.66	32.11	C
22	Medium	0.76	8.24	38.64	90	0.46	7.52	C
23	Very High	0.84	8.08	20.22	110	0.91	12.92	SiC
24	Very High	1.13	8.2	37.2	90	3.27	14.00	C
25	Very High	0.84	8.03	39.84	90	3.34	14.00	C
26	Medium	1.33	8.55	35.52	85	0.38	6.56	C
27	High	0.80	8.75	36.36	100	0.52	8.24	C
28	High	0.86	8.41	35.22	95	2.23	13.00	C
29	Very High	1.17	8.46	36.78	90	0.25	5.00	C
30	Very High	1.33	8.52	35.82	85	0.51	8.12	C
31	Very High	1.35	8.46	35.16	100	0.28	5.36	C
32	Very High	0.94	8.46	32.04	90	1.12	14.5	C
33	Very High	1.23	8.34	30.9	100	0.61	9.32	C
34	Medium	1.15	8.54	35.7	90	0.4	6.80	C
35	Medium	0.55	8.61	40.08	95	0.42	7.04	C
36	Medium	0.94	8.29	26.58	120	0.26	5.12	SiC
37	High	0.98	8.4	39.24	100	0.72	10.64	C
38	High	1.17	8.38	37.32	105	0.25	5.00	C
39	Medium	1.33	8.3	37.14	90	0.38	6.56	C
40	Medium	1.19	8.4	36.24	100	0.2	4.40	C
41	Medium	1.11	8.69	23.76	100	0.32	5.84	SiC
42	Medium	1.09	8.31	26.04	110	0.27	5.24	C

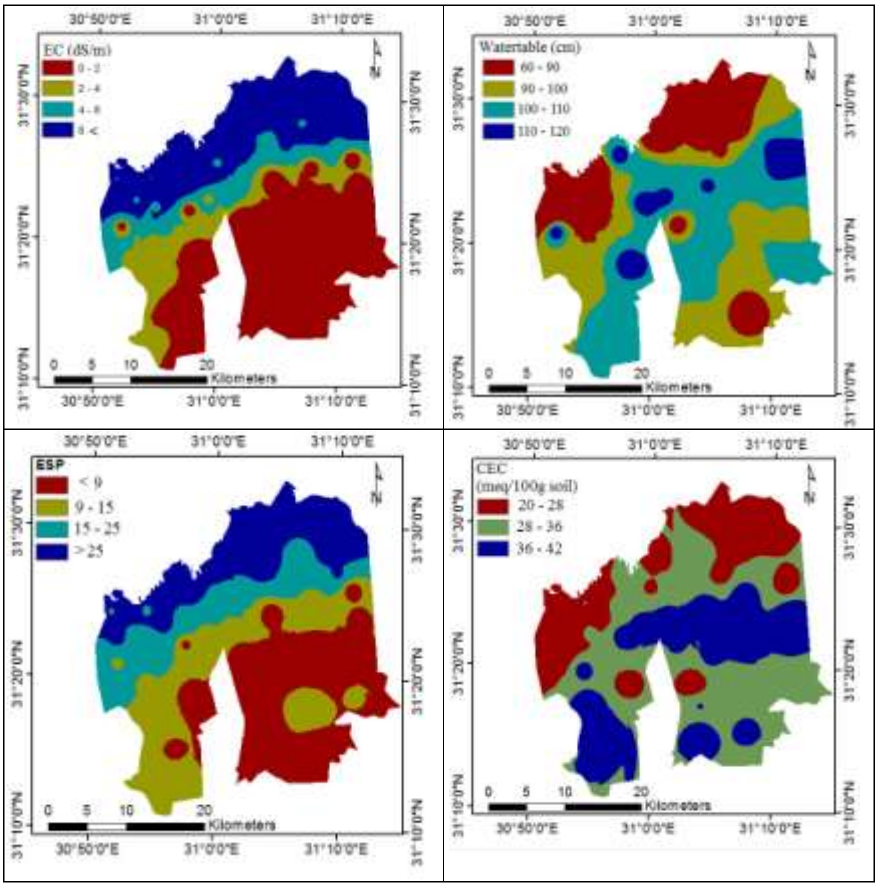

Fig. 4. Spatial distribution of EC, watertable, ESP and CEC.

To define the current sustainability status and potentiality in the studied area, the recent conditions of land use, existing management practices, environmental factors, and the existing economic and social conditions were recognized.

Results of land resources database were used to produce a set of thematic maps representing the soil productivity, land security, land protection, economic viability and social acceptability indices figures from (5 to 9). These maps were processed in a SALM model using simple equations (eq1 to eq6) to produce the sustainability indexes of the studied area.

A. Productivity index

Productivity index is associated with soil chemical and physical characteristics, as shown in Table 1 and Fig.4 , the results obtained indicated that soil productivity index in the study area ranging between 0.44 and 0.9 as shown in Table 2 and Fig.5. The main causes of such a decrease in soil productivity index are salinity and exchangeable sodium present ESP.

TABLE 2. Sustainability index evaluation of the studied area.

	productivity	security	protection	Economic viability	Social acceptability	Sustainability index	Sustainability class
1	0.47	0.77	0.7	0.57	0.44	0.06	VI
2	0.69	0.86	0.85	0.65	0.44	0.14	III
3	0.69	0.86	0.85	0.65	0.44	0.14	III
4	0.81	0.86	0.9	0.65	0.44	0.18	III
5	0.9	0.86	0.9	0.73	0.44	0.22	III
6	0.47	0.77	0.7	0.57	0.44	0.06	VI
7	0.63	0.86	0.85	0.65	0.44	0.13	III
8	0.69	0.86	0.85	0.65	0.44	0.14	III
9	0.69	0.86	0.9	0.65	0.44	0.15	III
10	0.44	0.77	0.7	0.57	0.44	0.06	VI
11	0.66	0.86	0.85	0.65	0.44	0.14	III
12	0.66	0.86	0.9	0.65	0.44	0.15	III
13	0.66	0.86	0.9	0.65	0.44	0.15	III
14	0.77	0.86	0.9	0.65	0.44	0.17	III
15	0.47	0.77	0.7	0.57	0.44	0.06	VI
16	0.59	0.86	0.85	0.65	0.44	0.12	III
17	0.63	0.86	0.85	0.65	0.44	0.13	III
18	0.66	0.86	0.9	0.65	0.44	0.15	III
19	0.69	0.86	0.9	0.65	0.44	0.15	III
20	0.52	0.86	0.7	0.57	0.44	0.08	VI
21	0.52	0.86	0.7	0.57	0.44	0.08	VI
22	0.81	0.86	0.9	0.9	0.69	0.39	III
23	0.65	0.86	0.85	0.65	0.62	0.19	II
24	0.69	0.86	0.85	0.65	0.62	0.20	II
25	0.65	0.72	0.85	0.65	0.62	0.16	II
26	0.81	0.9	0.9	0.9	0.69	0.41	III
27	0.73	0.86	0.85	0.65	0.62	0.22	II
28	0.73	0.86	0.85	0.65	0.62	0.22	II
29	0.72	0.86	0.85	0.73	0.69	0.27	II
30	0.68	0.86	0.85	0.65	0.62	0.20	II
31	0.72	0.9	0.9	0.73	0.69	0.29	II
32	0.65	0.9	0.9	0.73	0.69	0.27	II
33	0.72	0.9	0.9	0.73	0.69	0.29	II
34	0.81	0.9	0.9	0.9	0.69	0.41	III
35	0.77	0.86	0.9	0.9	0.69	0.37	III
36	0.81	0.9	0.9	0.9	0.69	0.41	III
37	0.73	0.9	0.9	0.9	0.69	0.37	III
38	0.86	0.9	0.9	0.9	0.69	0.43	III
39	0.86	0.9	0.85	0.9	0.69	0.41	III
40	0.86	0.9	0.85	0.9	0.69	0.41	III
41	0.77	0.86	0.85	0.9	0.69	0.35	III
42	0.9	0.86	0.85	0.9	0.69	0.41	III

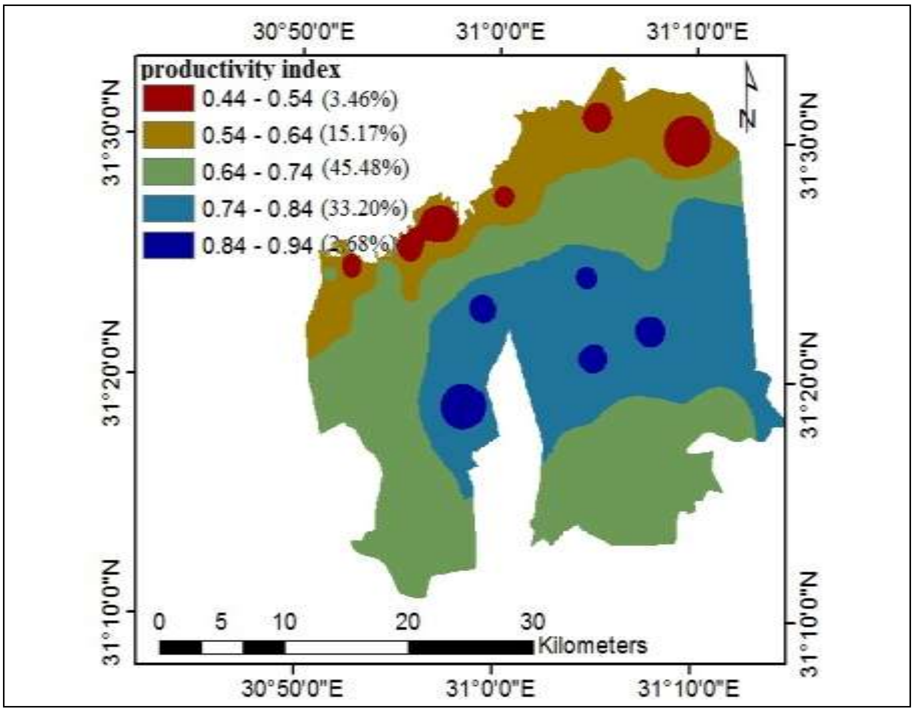

Fig. 5. Productivity index of the study area.

B. Security index

The security index includes the following factors: moisture availability degree, water quality and biomass. The results revealed that, the security index characterized by high index values in all soils in the study area, which have values higher than 0.7 as shown in Table (2) and Figure (6), the higher indices value refers to abundant in moisture contents, water quality and biomass.

C. Protection index

Protection index is included: erosion hazards by water and winds, flooding hazards, and cropping system. The results revealed that, protection index is characterized by high index values in all soils in the study area, which have values higher than 0.7 as shown in Table 2 and Fig7, the higher indices value refers to soil erosion hazard and flooding which are expected to be lower in these areas.

D. Social acceptability index

The current work is attentive on six factors to evaluate the social acceptability as follows: land tenure, support for extension services, health and educational facilities in the village, training of farmers on soil and water conservation, availability of agro inputs within 5–10 km range and village road access to main roads, education and health facilities. Therefore, the obtained results showed that social acceptability ranged between 0.44 and 0.69, (Fig. 8 and Table 2), values of low indices refer to poor social services provided to citizens and also low income individuals.

E. Economic viability index

Economic viability means that market operation is sustainable regarding current and projected revenues. The results obtained revealed that the study area are suffering from lack of markets, however there is a big difference between farm gate price and the nearest main market also benefit cost ratio is different. The estimated economic viability index ranged between (0.57-0.9) as shown in Fig.9 and Table 2.

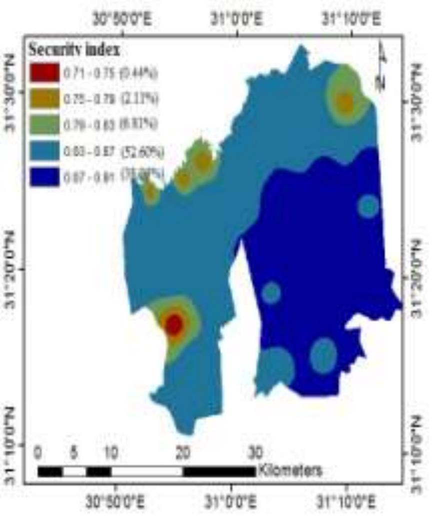

Fig. 6. Land security index.

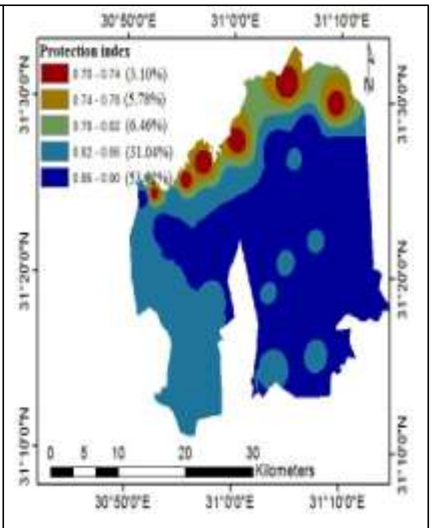

Fig. 7. Land protection index.

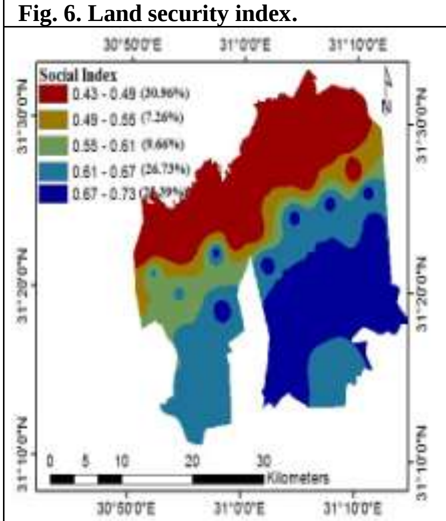

Fig. 8. Social acceptability index.

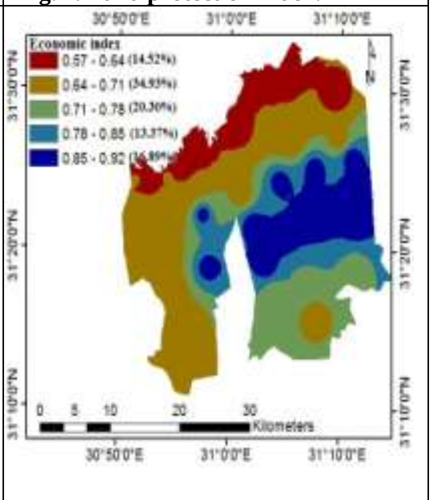

Fig. 9. Economic viability index.

Sustainability assessment

The estimated sustainability index (Fig. 10) shows that there is a significant variation in sustainability across the region. Soil mapping units with high relative sustainability are easily distinguishable from those with relatively low sustainability. Assessment of sustainable Agricultural Land Management in the investigated area resulted in three sustainability classes, which reflect the degree of agriculture sustainability recorded as follows:

1. Class II – 0.6-0.3 (30.23% of investigation area)
2. Class III – 0.1-0.3 (58.24% of investigation area)
3. Class IV – 0.1-0.0 (11.53% of investigation area)

Based on the obtained values of sustainability index the area could be classified into three classes *i.e.* (Class II) Areas marginally above the threshold of sustainability representing about 30.23 %, (Class III) Areas marginally below the threshold of sustainability representing about 58.24 % and (Class IV) non-sustainable areas representing about 11.53 % of investigation area.

The obtained data referto the most of agricultural land of the study area tends to be marginally below the threshold for sustainability which covered 58.24% of total area with value sustainability index between 0.3 and 0.1. The economic viability and social acceptability limit the sustainability in these areas due to the small farm sizes, low benefit to cost ratio, and the low levels of education and the land conservation cultural.

Non-sustainable areas (sustainability index less than 0.1) the sustainability is mainly limited by the soil productivity (0.44 - 0.52), land security (0.77 – 0.86), social acceptability (0.44) and economic (0.57). This area is located in north of the study area, neighborhood Lake Boroullos.

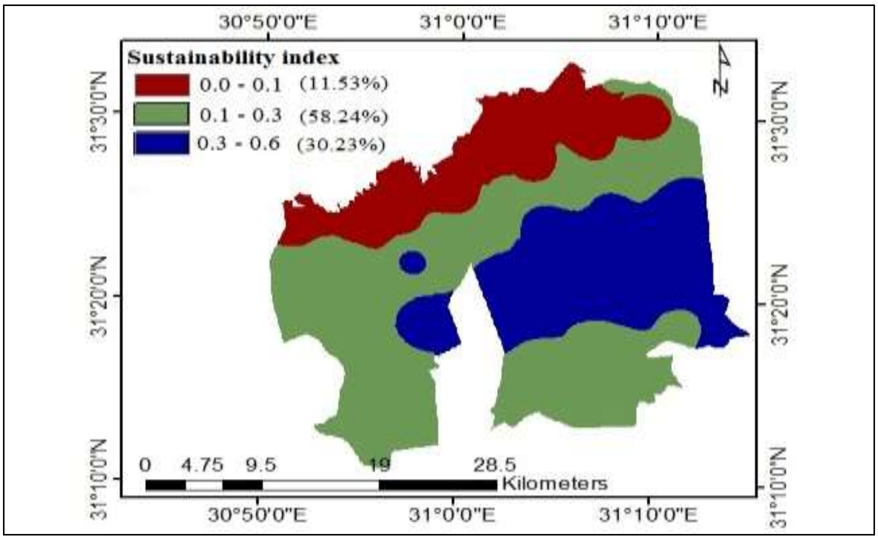

Fig. 10. Agricultural sustainability indices in the study area.

Conclusion

The assessment of sustainable agricultural land management in the North Nile Delta, Egypt has been performed on the basis of land productivity, security, protection, economic viability and social acceptability, following the sustainable agricultural land management model (SALM). The investigated area is classified into three classes, *i.e.* Class II, III and IV. Class IV has sustainable value <0.1 and occupied an area about 11.53% of the total area. This class refers to land management practices do not meet sustainability requirements (non-sustainable). Unfortunately the results reflected the existing reality of sustainable agricultural. Class II areas above the threshold of sustainability represent about 30.23 %, class III areas below the threshold of sustainability represent about 58.24 %. Obtained data will be a good tool for classifying and evaluating the different soils for sustainable agricultural purposes. The northern part of the study area needs more development and attention to education and health.

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(*Received* 20/12015;
accepted 22/2/2015)

تقييم أستدامة إدارة الأراضي الزراعية باستخدام تقنيات نظم المعلومات الجغرافية في شمال الدلتا – مصر.

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أستدامة إدارة الأراضي الزراعية (SALM) يعتمد على أستدامة النظام كله والذى يهدف الى استدامة القدرة الانتاجية للاراضى والاستدامة الصحية للناس. مؤشرات استدامة أدارة الاراضى الزراعية تعتمد على حلول طويلة الامد بدلا من الحلول على المدى القصير. تقييم أستدامة إدارة الأراضي الزراعية تحددها الظروف الطبيعية والحيوية والتقييم الاقتصادى والقبول الاجتماعى والاهتمامات البيئية التي يجب أن ينظر اليها بشكل متكامل. تهدف الدراسة الحالية الى تقييم أستدامة إدارة الأراضي الزراعية فى منطقة شمال الدلتا – مصر من خلال التكامل بين أنتاجية الارض والامن والحماية والجدوى الاقتصادية والقبول الاجتماعى. معادلات التحليل المكانى (spatial analysis) فى برنامج نظم المعلومات الجغرافية (GIS) تم استخدامها فى تقدير مؤشر الاستدامة.

القيم التي تم الحصول عليها من مؤشر الاستدامة تشير إلى أن المنطقة يمكن أن تصنف إلى ثلاث فئات وهي (الدرجة الثانية) وهى تمثل مناطق فوق عتبة الاستدامة، و(الدرجة الثالثة) مناطق تحت عتبة الاستدامة و(الدرجة الرابعة) المناطق غير المستدامة والتي تمثل 30.23 ٪، 58.24٪ و 11.53٪ على التوالي من المساحة الكلية المدروسة. تبين النتائج أن معظم الأراضي الزراعية في منطقة الدراسة يميل إلى أن يكون أقل هامشيا عن عتبة للاستدامة (أي 58.24٪ من المساحة الكلية) ، وهذا يعني الانتباه إلى تحسين الخدمات الاجتماعية والاقتصادية لمنطقة الدراسة.