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Sustainable Land Management Using Spatial Analyst in North Nile Delta Soil, Egypt

F.S. Moghanm[1], A.Y. Darwish[1*], Ekhlas M. Elwakel[1], M.I. El Shahawy[3], A. Shalaby[2]

[1]*Soil and Water Department, Faculty of Agriculture, Kafrelsheikh University, 33516,*

[2]*National Authority for Remote Sensing and Space Sciences, Cairo 1564 Egypt*

[3]*Soil, Water and Environment Institute, Agriculture Research Center, Kafr El-Sheikh, Egypt.*

SUSTAINABLE land management (SLM) in agriculture is a complex topic that incorporates many features, including biophysical, socioeconomic and environmental factors. To integrate land productivity, security, protection, economic viability and social acceptability indices, spatial analysis (ordinary Kriging) functions in a geographic information system (GIS) were employed to estimate the sustainability index. A SLM model was designed in ArcGIS to evaluate SLM, promote production services (productivity), reduce production risks (security), reduce the pressure on natural resources and protects soil and water degradation (protection). The model was designed to be economically viable (feasibility) and to be acceptable (susceptibility). This study aimed to evaluate sustainable agricultural land in Desouk district, north Nile Delta, Egypt, through a combination of five indices. The sustainability index data indicate that the area can be classified into three classes i.e., low and high class II areas above the threshold of sustainability and class III areas below the threshold of sustainability, representing 64%, 34% and 2% of the investigated area, respectively. It was found that most of the agricultural land in the study area tends to be marginally higher than the threshold for sustainability.

Keywords: GIS, Remote sensing, Soil, Sustainable land management.

Introduction

Sustainability indicators have proliferated as sustainability assessments have become increasingly common. As a result, there are now a wide range of sustainability assessment approaches, including indicators, product-related assessments and integrated assessment tools (Ness et al., 2007). Sustainable agricultural systems aim to develop new farming practices that are also safe and do not degrade the environment (Lichtfouse et al., 2009). Sustainable agriculture refers to practices that meet current and future societal needs for food and feed, ecosystem services and human health and that maximize the net benefits for people, without compromising the ability of future generations to meet their own needs by improving natural resources (Tilman et al., 2002). However, agricultural sustainable land management (SLM) is necessary to shorten the gap between planning practices and research regarding landscapes (Antonson, 2009). Crop yield is widely used as a sustainability indicator – this parameter not only quantifies production in terms of land area over time but also allows for the identification of gaps between experimental yield and farmer yield (El-Nahry, 2001 and Moghanm, 2015).

Biophysical elements (productivity, security and protection) and socio-economic aspects (economic viability and social acceptability) are used in Egypt to combat sustainability constraints that hinder agricultural development and to reduce these constraints to acceptable levels for mass production endeavors (Abdel Kawy & Darwish, 2014; Nawar, 2009; El Bastawesy et al., 2013 and Ali & Shalaby, 2013). As SLM becomes more important than land supply for development, it is important to determine whether current land management in Egypt is in the process of becoming more or less sustainable. Farmers, researchers and policy makers have become interested in

*Corresponding author: a.y.darwish90@gmail.com

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integrative measures of the current status of land quality and its changes over time (Hurni, 2000). There is a growing consensus that the long-term sustainability of agriculture and rural communities can be enhanced through locally based planning and management at the farm scale, including the farm recommendation unit and resource management (Eswaran et al., 2000).

The current study aimed to evaluate the sustainability of agricultural land in Desouk district, Kafr El-Sheikh governorate of the north Nile Delta, Egypt, through a combination of soil productivity, security, protection, economic viability and social acceptability indices.

Materials and Methods

Study area

The study area (Fig. 1) is located in the northwestern part of the Nile Delta in Egypt (31°00′36.9″–31°17′3.4″N,30°48′49.7″–30°35′39.5″E) with an area of approximately 319.5 km^2. Elevation of the study area ranged (3-5 meter). It has an arid climate, with annual rainfall of approximately 167 mm/year that falls mainly between October and March, and air temperatures of 12–23.4°C in winter and 26–45°C in summer. The mean evaporation reaches its maximum in August, at 7 mm/day. When the temperature is comparatively low, the minimum values are observed in January and December, and the highest value is recorded between June and September (Climatological Normal for Egypt, 2011).

Soil sampling and laboratory analysis

The locations of soil profiles were selected according to landforms and physiographic map units. A total of 21 soil profiles were collected in the studied soils of the Desouk region to represent the different preliminary mapping units (Fig. 1). Water samples were collected from irrigation, drainage and the water table from the soil profile locations. Detailed socio-economic data about the studied area were collected through field questionnaires. Land surveys and laboratory analyses were conducted, and socio-economic data were generated. A database of the area was constructed with an attribute table using Arc-GIS 10.1 software. The soil profiles were morphologically described according to the FAO Guidelines for Soil Description (FAO, 2006). The collected soil samples were air dried, crushed and passed through a 2-mm sieve to obtain fine earth for analysis. Electrical conductivity (EC), calcium carbonate content, organic carbon content, pH, cation exchange capacity (CEC), and N, P and K contents were determined according to the United States Department of Agriculture methods (USDA, 2004).

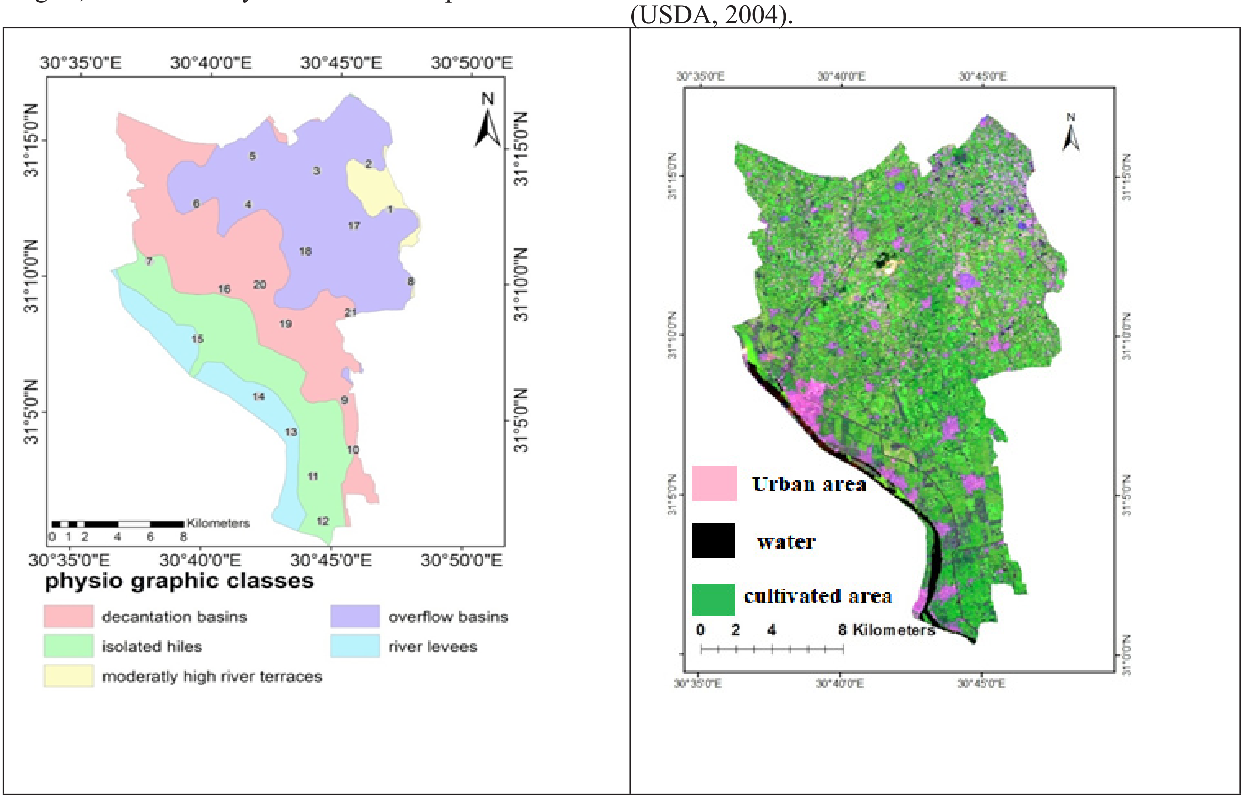

Fig. 1. Physiographic map and ETM$^+$ image of the study area.

Assessment of SLM

To determine the condition of soil sustainability, we used the international framework for evaluating sustainable land management (FESLM) established by Smith and Dumanski (1993), as adapted for Egyptian conditions by El-Nahry (2001). The FESLM combines technologies, policies and activities aimed at assimilating socio-economic principles with environmental concerns and that contain the five supports of sustainable land management (productivity, protection, security, economic viability and social acceptability).

To evaluate the current sustainability status in the study area, the current land-use conditions, management practices, environmental factors, and economic and social conditions were recognized. An SLM model was developed using Arc-Map 10.1 software interpolation Inverse distance weighted (IDW) method. Figure 2 explains the input data required, the equations used and the outputs of the designed cartographic model. The model was designed for processing the database of land resource and socioeconomic data that characterize the physiographic map. The final outputs of the model are the productivity, security, protection, economic viability, social acceptability and sustainability indices of the studied area. Every indicator has a scale from 0.0 to 1.0. The actual values are affected by each other, and the sustainability index ranges between 0.0 and 1.0. The SLM was divided into four classes according to the obtained values of the sustainability index equations. These classes are C1, C2, C3 and C4 for sustainability index value ranges of 1–0.6, 0.6–0.3, 0.3–0.1 and 0.1–0, respectively.

Results and Discussion

Physiographic map

The landscape in the study area is a flood plain. The following five main landforms were identified: decantation basins, isolated hills, moderately high river terraces, overflow basins and river levees, which covered 27.9%, 22.4%, 26.5%, 19.6% and 3.6% of the total area, respectively (Fig. 1).

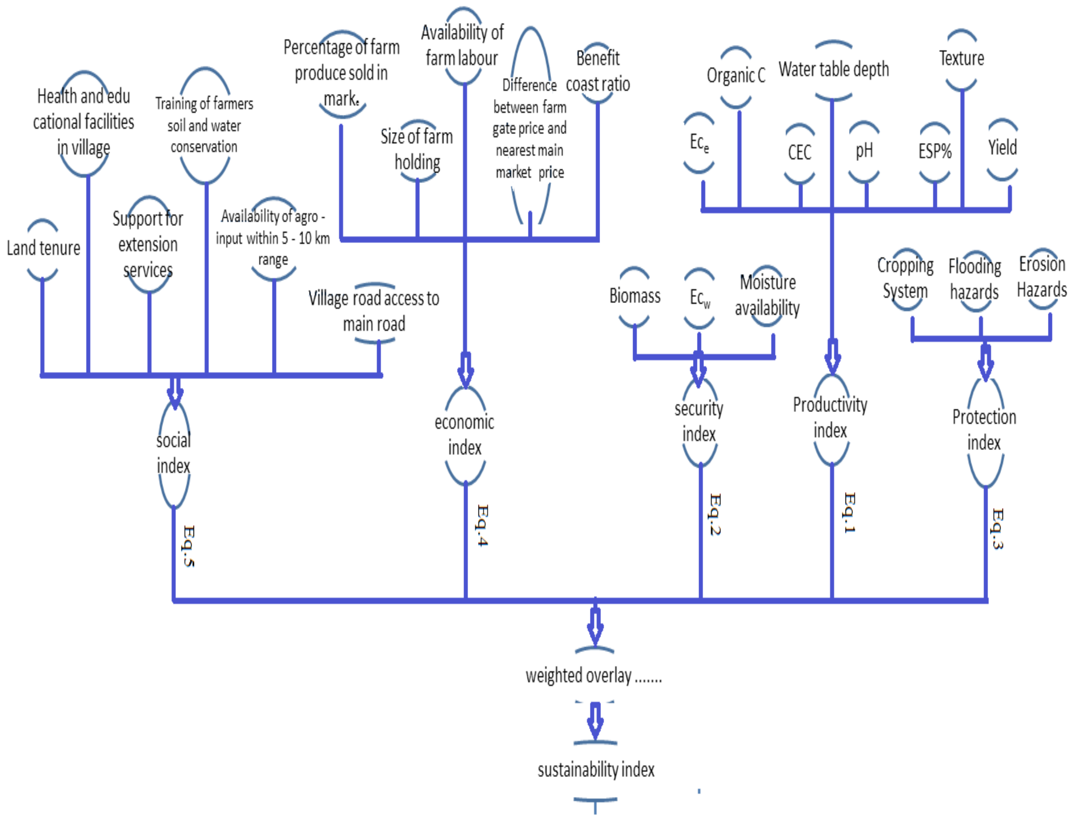

Fig. 2. Schematic diagram of the sustainable land management (SLM) model

Soil data

The soil data (Table 1) show that the water table depth ranged from 93 to 152cm in all soil profiles. The soil pH values ranged between 7.95 and 8.64 in the different soils. High values characterize the decantation basins. The soil EC was moderate to high (1.06–13.39 dS/m). Low values represent the soils of isolated hills.

The calcium carbonate and organic carbon contents were low in the studied soils ranging from 0.75%–4.5% and 0.28%–1.32%, respectively. The CEC was moderate to high in the soils (31.17–49.12 cmol/kg soil) but was low in the soils of isolated hills, and a high value characterized the overflow basins. The ESP was low to high and ranged between 2.77% and 24.06% with the highest values found in the overflow basins. The ranges of N, P and K contents were 56–308, 0.33–2.54 and 7.4–31.76 ppm, respectively. Low N values were found in the soils of river levees and isolated hills, and the high M values were found in overflow basins. Low P values were found in the soils of overflow basins and high P values were found in river levees. The low K values were found in the soils of isolated hills, and high K values were found in river levees.

Determination of agricultural SLM

Productivity index (A)

Soil productivity refers to the quantity of yield from agricultural processes. The productivity index was calculated using the following equation (El-Nahry, 2001 and Moghanm, 2015):

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

where A is relative yield %, B is texture, C is % organic carbon, D is soil pH, E is CEC, F is profile depth, G is salinity and H is alkalinity. The results revealed that the security index ranged from 0.77 to 0.90, as shown in Table 2 and Fig. 4. The higher index value refers to water quality, which is represented by moisture availability and biomass.

Security (B) and protection indices (C)

The security index depends on moisture availability (A), water quality (B) and biomass (C), whereas the protection index depends on erosion hazards by water and winds (A), flooding hazards (B) and cropping system (C) based on the following equations:

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

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

TABLE 1. Chemical analysis of studied soil samples

Profile No.	Organic Carbon (%)	pH 1:2.5	CEC (cmol/ kg soil)	Nutrient availability (ppm)			Water table /profile depth (cm)	EC (dS/m)	ESP (%)
				N	P	K			
1	0.54	7.97	49.12	168	0.5	14.16	105	13.39	9.24
2	0.65	8.16	36.07	168	0.69	26.28	110	11.20	5.34
3	0.97	8.21	39.36	168	0.75	18.54	102	5.00	8.07
4	0.74	8.49	44.98	84	0.33	14.24	140	3.41	9.47
5	0.86	8.27	34.50	112	0.66	22.26	112	5.31	11.81
6	0.87	8.41	37.75	252	2.1	17.5	99	3.46	9.53
7	0.52	8.51	44.26	168	0.91	13.8	155	1.85	5.44
8	0.67	8.33	34.99	196	2.38	20.44	94	3.02	6.72
9	0.48	8.43	34.63	112	0.86	19.38	150	2.00	6.22
10	0.43	8.27	37.31	168	2.54	14.62	130	1.275	3.36
11	0.64	8.18	31.89	224	1.35	13.9	135	1.06	2.77
12	0.51	8.45	31.17	56	1.05	7.4	160	1.64	4.21
13	0.94	8.39	32.43	280	1.49	22.22	93	7.02	13.51
14	1.05	8.57	35.48	56	0.72	13.98	128	1.99	4.65
15	1.32	8.54	37.88	140	0.94	31.76	110	1.64	5.20
16	1.09	8.64	42.62	196	0.64	18.48	140	2.50	8.72
17	1.15	7.95	44.23	308	0.44	17.98	120	10.47	24.06
18	1.03	8.24	36.46	168	0.69	21	144	1.13	3.22
19	0.44	8.64	35.46	140	0.91	20.46	145	2.89	6.92
20	0.37	8.57	41.38	196	0.91	14.58	134	4.47	9.16

The security index ranged from 0.77 to 0.90 (Table 2 and Fig. 4), and the higher index value refers to water quality as represented by moisture availability and biomass. The protection index depends on erosion hazards by water, wind, flooding hazards and the cropping system. The protection index was high (0.9) in all studied soils (Table 2 and Fig. 4). The higher index value refers to erosion and flooding hazards, which are expected to be lower in these areas.

Economic viability index (D)

The economic viability index depends on five factors for determination of economic viability: the 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, as shown in the following equation:

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

The results obtained show that the economic viability index ranged from 0.72 to 0.90 (Fig. 4 and Table 2).

Social acceptability (E)

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

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

The social acceptability was 0.9 in all studied soils, and the high index values were the result of increased social services provided to citizens and high-income individuals.

Sustainability index

The sustainability index was evaluated through the following equation:

$$\text{Sustainability Index} = A \times B \times C \times D \times E \qquad \text{Eq. 6}$$

Where: A is the productivity index, B is the security index, C is the protection index, D is the economic index and E is the social acceptability index (Fig. 5 and Table 2).

TABLE 2. Values of the five sustainability indices for the studied area

Profile	Productivity	Security	Protection	Economic	Social acceptability	Sustainability	Class
1	0.62	0.81	0.9	0.81	0.9	0.33	C2
2	0.58	0.81	0.9	0.81	0.9	0.31	C2
3	0.69	0.77	0.9	0.81	0.9	0.35	C2
4	0.81	0.81	0.9	0.81	0.9	0.43	C1
5	0.69	0.77	0.9	0.81	0.9	0.35	C2
6	0.77	0.77	0.9	0.81	0.9	0.39	C2
7	0.86	0.81	0.9	0.9	0.9	0.51	C1
8	0.77	0.81	0.9	0.81	0.9	0.41	C1
9	0.77	0.9	0.9	0.72	0.9	0.40	C1
10	0.86	0.9	0.9	0.72	0.9	0.45	C1
11	0.9	0.9	0.9	0.72	0.9	0.47	C1
12	0.9	0.86	0.9	0.72	0.9	0.45	C1
13	0.66	0.86	0.9	0.72	0.9	0.33	C2
14	0.9	0.9	0.9	0.8	0.9	0.52	C1
15	0.9	0.9	0.9	0.8	0.9	0.52	C1
16	0.81	0.86	0.9	0.9	0.9	0.51	C1
17	0.65	0.81	0.9	0.81	0.9	0.35	C2
18	0.95	0.77	0.9	0.81	0.9	0.48	C1
19	0.73	0.81	0.9	0.81	0.9	0.39	C2
20	0.66	0.81	0.9	0.81	0.9	0.35	C2
21	0.73	0.9	0.9	0.81	0.9	0.43	C1

The locations of the profiles within the study area are shown in Fig. 1.

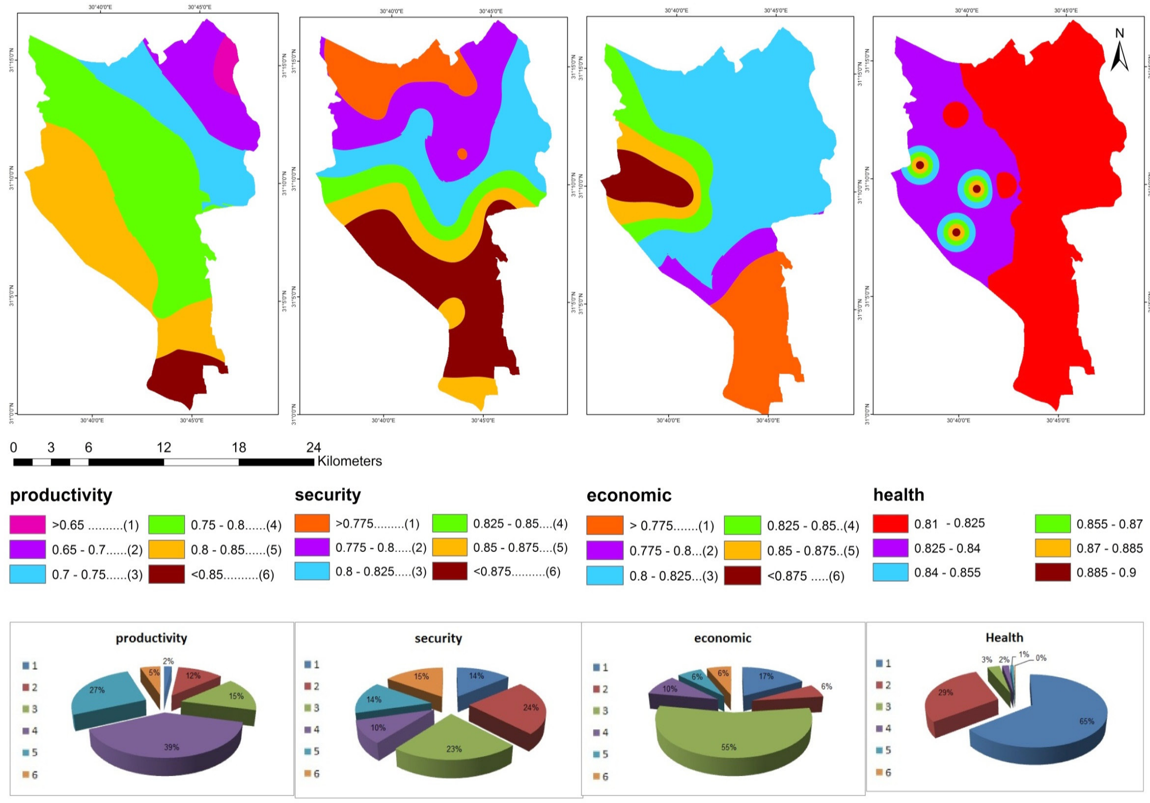

Fig. 4. Spatial distribution of sustainability indices in the study area.

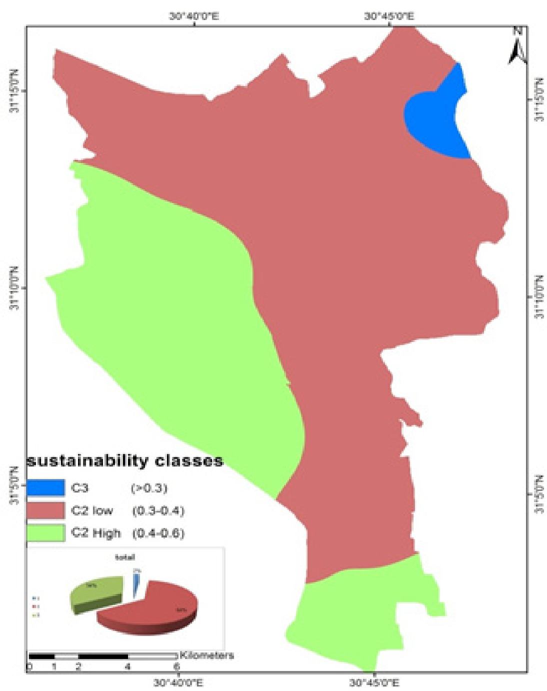

Fig. 5. Spatial distribution of sustainability classes in the study area

Productivity: The values of many factors changed dramatically between profiles, especially those of the salinity, relative yield, organic carbon and pH of the soil. Productivity is the factor most affecting the value of sustainability in the region under study. The main factor affecting on productivity factor of the study area is proximity or distance from Rashid branch, the evidence of productivity index increases west of study area and less as we turn east.

Security: The differences between security index values of different profiles were smaller than those of the productivity index values, and water availability and quality were the main factors influencing security values.

Protection: There were no large differences in the elements of the protection index (water and wind erosion hazards, flooding hazards and cropping system) and thus all the values of the protection index were 0.9 in all studied areas.

Economic criteria were based from a questionnaire circulated among farmers at the study sites and the proximity and distance from the main city were found to be the main factors for economic viability in the region under study.

The most influential factor in the productivity is the proximity of the region or beyond to the main city (Desouq city) where the types of the crops in the nearby areas is dependent on direct marketing projects with higher returns.

Conclusion

This paper shows that the use of geographical information system extension spatial and statistical analyst, to create high resolution soil maps and models of land capacity, for sustainability is an effective tool to support decision-making in the study area. This method is effective and can be used continuously for its dynamic and ability modification data. The model has proved to be a sensitive way to assess sustainability, as it has the potential to show differences in sustainability and each of its factors across the entire study area, making it an effective tool that can be used by decision-makers to develop strategies that support land sustainability over time. During the statement of changes in the unit of the land under different agricultural practices over time. This paper also showed that the study area is mostly in the first rank of the categories of sustainability, where the ranks of the first, second and third ratios of 64% and 34% and 2% respectively.

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الادارة المستدامة للاراضى باستخدام التحليل المكانى فى أراضى شمال دلتا النيل – مصر

فرحات سعد مغنم[١] ، أحمد درويش[١] ، إخلاص الوكيل[١] ، محمد الشهاوى[٢] و عادل شلبى[٣]
[١] قسم الاراضى و المياه – كلية الزراعة – جامعة كفرالشيخ [٢] معهد بحوث الاراضى و المياه و البيئة – مركز البحوث الزراعية – محطة بحوث سخا [٣] الهيئة القومية للاستشعار عن بعد و علوم الفضاء – القاهرة -مصر

الإدارة المستدامة للأراضي (SLM) في الزراعة هي موضوع معقد يشتمل على العديد من السمات ، بما في ذلك العوامل البيوفيزيائية والاجتماعية والاقتصادية والبيئية عن طريق دمج دليل إنتاجية الأرض والأمن والحماية والجدوى الاقتصادية والقبول الاجتماعي. يستخدم التحليل المكاني بإستخدام نظم المعلومات الجغرافية (GIS) لتقدير مؤشر الاستدامة.للأراضى موضع الدراسة وقد تم تصميم نموذجٍ SLM في نظام ArcGIS لتقييم مدى قدرة الأرض على الإستدامة ، وتعزيز خدمات الإنتاج ،والحد من مخاطرٍ الإنتاج والحد من الضغط على الموارد الطبيعية وحماية التربة وتدهور المياه). وقد صمم النموذج ليكون مجديا اقتصاديا ويكون مقبولا تحت الظروف المصرية. تهدف هذه الدراسة إلى تقييم الأراضي الزراعية المستدامة في منطقة دسوق ، شمال دلتا النيل، مصر ، من خلال المؤشرات الخمس سالفة الذكر وقد أنتهت الدراسة إلى أن استخدام التحليل الإحصائي والمكانى لإنشاء خرائط دقيقة للتربة ونماذج SLM أنتجت أداة فعالة لدعم القرار لتقييم الاستدامة في منطقة دسوق. الادارة المستدامة للاراضى هي وسيلة سهلة الاستخدام لمراقبة الاستدامة حيث أنها تستخدم طريقة سهلة خطوة بخطوة قادرة على إنتاج الخرائط التي تظهر الاختلاف في الاستدامة في جميع أنحاء المنطقة وكذلك الظروف الفيزيائية الحيوية والاجتماعية والاقتصادية. أثبت اختبار النموذج (SLM) أنه طريقة حساسة لتقييم الاستدامة. إن قدرة النموذج على إظهار الاختلافات في الاستدامة والظروف الأساسية في جميع أنحاء المنطقة يمكن أن تساعد متخذى القرار على تخطيط مبادرات الاستدامة وإجراءات الإدارة الأخرى ، مما يجعلها أداة لدعم أتخاذ القرار إذا ما استخدمت هذه الأداة بانتظام ، فقد تكون مفيدة أيضًا في مراقبة الاستدامة وتقييم كفاءة استراتيجيات الاستدامة من خلال توضيح التغيرات في استدامة وحدة التربة مع مرور الوقت. وبالتالي ، فقد دعمت هذه الورقة تقييمات الاستدامة في منطقة الدراسة من خلال إنتاج أداة تحليل قائمة على معايير GIS متعددة المعايير ، وهي عبارة عن تقييم استدامة متكامل تمامًا ، وهو سهل الاستخدام وواضح ومفيد لمساعدة اصحاب القرار على اتخاذ قرارات لتعزيز الاستدامة. وقد أشارات بيانات مؤشر الاستدامة إلى أن المنطقة يمكن تصنيفها إلى ثلاث فئات وهى الأولى اوالثانية والثالثة ، والتي تمثل 64٪ و 34٪ و 2٪ من منطقة الدراسة على التوالى.