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Agricultural land sustainability Evaluation using Remote sensing and GIS in Nile Delta Area, Egypt

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Abstract

Sustainable agriculture has many constrains suppress it's continually this raise the importance of evaluating indicators status of agricultural sustainability. Land sustainability was evaluated in different areas in El-Monofia Governorate, through five indices (productivity, security, protection, economic viability and social acceptability).The area, lies between latitudes 30^{o} 20\` to 30$^{o}$ 50\` N, and longitudes 30^{o} 50\` to 31$^{o}$ 20\`E, The total of study area is about 33961 ha, This study found that more than 60% of the study are achieved sustainability index class II, while 38.7% of the area achieved sustainability index class I .There for agricultural land sustainability in El-Monofia Governorate requires much more governmental and public efforts through Attention to social and economic factors, Educate farmers to improve agricultural productivity and Using of precision agriculture as a technique maximize agricultural yield.

Keyword: Agricultural land, Sustainability Evaluation, Remote sensing, GIS, Nile Delta Area.

Introduction

Sustainable agriculture refers to agronomic systems that fulfil socioeconomic needs for feed and food, ecological processes, and human health while ensuring maximum net benefits to people while not negatively impacting populations' ability to meet their own needs through resource extraction improvement. **(WCED, 1987; USAID, 1988; Smyth and Dumanski, 1993; Tilman et al., 2002).** Sustainable agricultural systems create innovative agricultural technologies that are secured and environmentally friendly. **(Lichtfouse et al., 2009).** five criteria are needed i.e. productivity, security, protection, viability, and acceptability. **(Dumanski 1993; Smith and Dumanski, 1993; Dumanski, 1997, Rashed, 2020 and Mansour et al., 2022).** Agriculture is a complex system that combines social economy and natural ecology to provide adequate outputs **(Andzo-Bika and Kamitewoko, 2004; Li and Yan, 2012; Kokoye et al., 2013; Kumhálová and Moudr, 2014; Verburg, 2015; Rashed, 2016; Rasmussen, 2018 and Scown et al., 2019).** The fundamental factors of sustainable land management are profitability, safety, preservation, competitiveness, and tolerance. **(Dumanski, 1997).** The core of a new social compact between population as a whole and its agriculture is self-sustaining agriculture. However, putting sustainability into action is a difficult task. In many agricultural contexts, the notion of sustainability has yet to be enacted, therefore a full assessment that incorporates larger environmental, socioeconomic, and social elements is now required to accomplish sustainable farming **(Gliessman, 1998)**. To bridge the gap between landscape planning practitioners and scholars, sustainable resource use management is required **(Antonson, 2009).** Crop productivity is considered as a sustainability measure since it not only estimates yield per hectare throughout time and moreover enables for the identification of discrepancies among both research and commercial yields **(El-Nahry, 2001 and Mohamed et al, 2014).** Under Egyptian circumstances, physical and biological elements (performance, stability, and preservation) as well as socio - economic status aspects (commercial feasibility and public acceptance) are being used to counteract and address sustainability restrictions that obstruct agricultural production or to lowering them to reasonable standards for modern manufacturing pursuits**. (Nawar, 2009).** Because crop yields is culturally determined and its social component varies by location, it is more rational and appropriate to investigate it on a localized micro level **(Simon, 2000).** Agriculture and related villages can benefit from agricultural development and preparation, particularly the Field Recommendations and Allocation Category **(Eswaran et al., 2000). Matthews et al. (2008)** outline the creation of agricultural decision support system tools for examining alternate futures for agricultural sustainability. The model's key component is the simulation of future land-use changes in various scenarios, as well as the assessment of social, economic, and environmental repercussions.

The current study's goal is to assess the agricultural land sustainability in El- Monofia Governorate by incorporating five factors (productivity, security, protection, economic viability, and social acceptability) into a sustainable agricultural spatial model (SASM) using geographic information systems (GIS) and analytical tools for the purpose of combating and resolving sustainable agricultural constraints and optimum land use planning.

Materials and Methods

Study area description.

The study area is about 33961 ha, which is between the longitudes of 30°50` to 31°20`E, and between the two latitudes 30°20` to 30° 50` N. It was implemented as a case study in the Egyptian Delta, the area includes the centers of Shebin El-Koum, Barakat El-Sabaa, and Quesna in El-Monofia Governorate as shown in Fig(1),

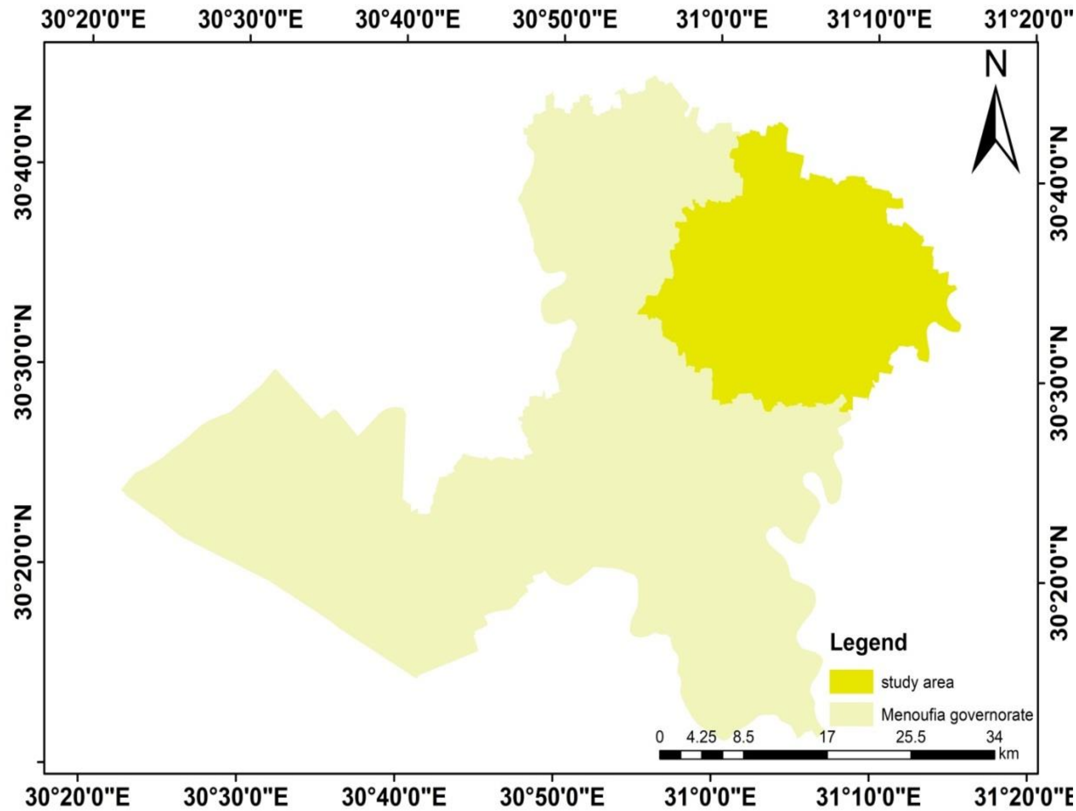

Fig.1. Location of the study area

Data acquisition

A detailed morphological description of soil profiles was recorded based on the guidelines of **FAO (2006).** Soil samples (Fig. 2) were taken from different layer of soil profiles and to represent the identified mapping units, the locations of these profiles were defined by using the GPS. Samples were taken from the same coverage most of the landform units. Soil samples were air-dried in the laboratory ground and sieved through a 2 mm sieve. Particle size distribution was determined according to **USDA (2004).** Electric conductivity (EC), soluble cations and anions, organic matter, pH, CEC and macro nutrients (NPK) were determined according to **Bandyopadhyay (2007).**The soil taxonomy were classified according to **USDA (2014).**

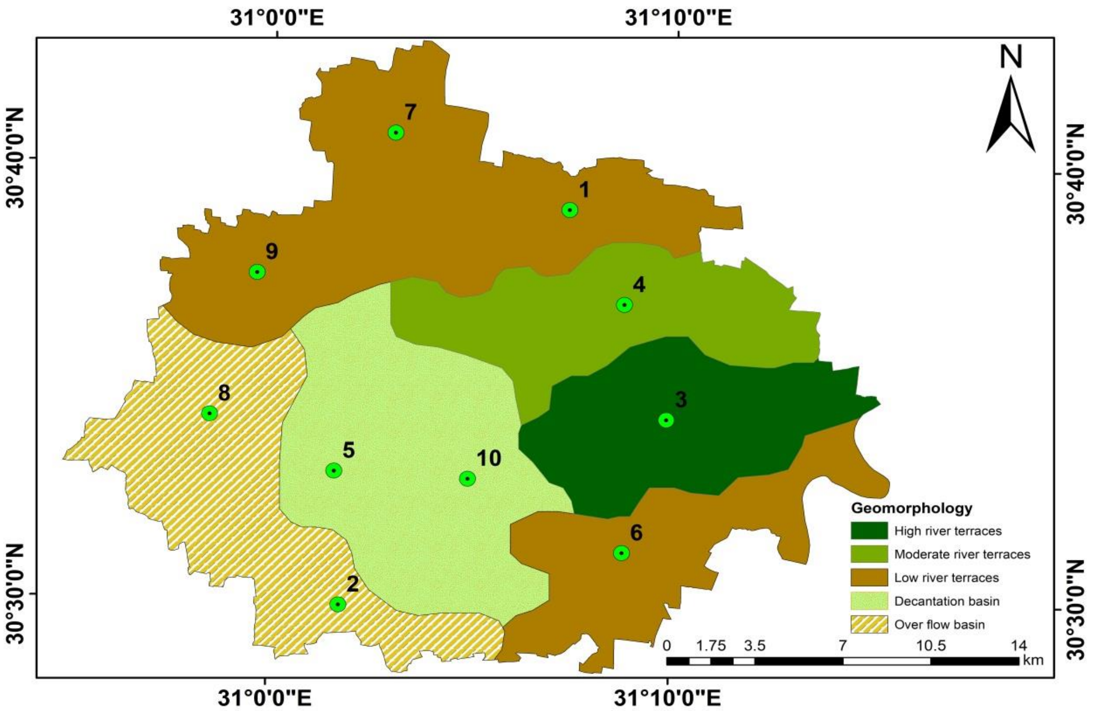

Fig.2. Location of soil profiles of the study are

Satellite Data:

Digital image processing of Landsat-8 OLI image in 2021 was executed using ENVI 5.2 and the ArcGIS 10.2 software's. The digital image processing included bad lines manipulation by filling gaps module designed using IDL language, data calibration to radiance according to **Lillesand and Kiefer (2007).** The Landsat-8 OLI image and the DEM were used to obtain the physiographic units and establish a soil database **(Dobos et al., 2000).** This study used the GIS for assessing and mapping of agricultural land sustainability in the investigated area.

Results and Discussion

Geomorphologic units of the studied area:

The main geomorphologic units in the study area can be observed into one landscape (flood plain) as shown in Fig (3). Flood plain which includes landforms of overflow basins (OB), decantation basins (DB) and river terraces: - high river terraces (RT1), moderately river terraces (RT2) and low river terraces (RT3), with areas about 9172, 10424, 6528, 6619 and 12418 ha, respectively.

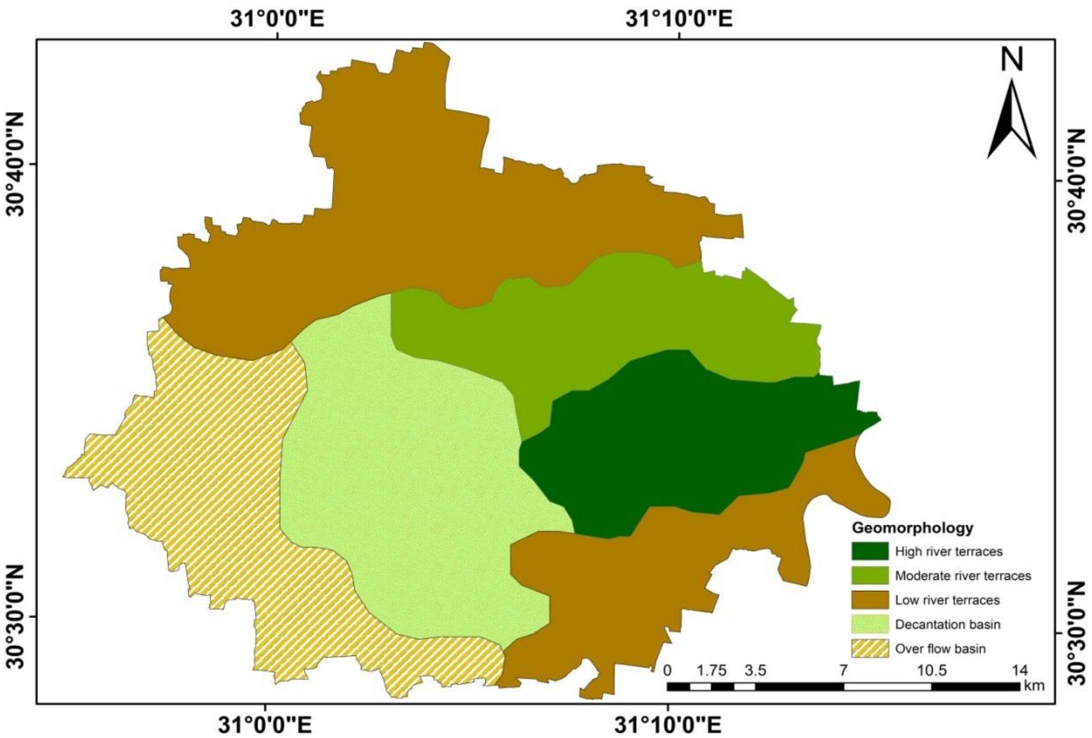

Fig. 3: Geomorphologic map of the studied area

Assessment of the land sustainability

Sustainability Index (**SI)** considers the 5 following criteria **(Dumanski and Smith 1993)**: productivity (A), security (B), protection (C), economic viability (D) land social acceptability (E) .The equation is: SI = (A x B x C x D x E)

Productivity Index (**PI**) according to the following equation (Eq. 1):

PI = A/100 x B/100 x C/100 x D/100 x E/100 x F/100 x G/100 x H/100 x I/100 x J/100

Where**,** A= relative yield (RY), B= organic carbon (OC) %, C= Soil reaction(pH), D=cation exchange capacity (CEC),E= oxygen availability, F= salinity (EC),G= Soil sodicity (ESP) , H=Texture ,I= Parent material and J= Rock Fragments.

Calculating the Security Index according to the following equation (Eq. 2):

Security Index = A/100 x B/100 x C/100

Where, A= moisture availability, B=water quality and C= Crop residues %.

Calculating the Protection Index according to the following equation (Eq. 3):

Protection Index = A/100 x B/100 x C/100

Where, erosion hazards including wind and water erosion (A), flooding hazards (B) and cropping systems (C). Formula integrates these indicators.

Calculating the Economic Viability Index according to the following equation (Eq. 4):

Economic Viability Index = A/100 x B/100 x C/100 x D/100 x E/100

Where, benefit cost ratio (A), difference between farm gate price and the nearest main market price (B), availability of farm labour (C), size of farm holding (D) and and percentage of farm produce sold in market (E)

Calculation of Social Acceptability Index according to the following equation (Eq.5):

Social Acceptability Index = A/100 x B/100 x C/100 x D/100 x E/100 x F/100 x G/100

Where, A= Land tenure, B = Support for extension services, C = Health and educational facilities in village, D = Percentage of subsidy for conservation packages, E= Training of farmers in soil and water conservation techniques, F= Availability of agro-input within 5- 10 km range and G = Village road access to main road.

-SLMI was calculated for the different mapping units according to the following equation (Eq. 6):

Sustainability Index (SI) = A x B x C x D x E

Table 1. Class and rating limits of Sustainable Land Management Index (SLMI).

Value	Land use/management status	Class
0.6 to 1.0	Meets the sustainability requirements	I
0.3 to 0.6	Marginally but above threshold of sustainability	II
0.1 to 0.3	Marginally but below threshold of sustainability	III
0 to 0.1	Does not meet sustainability requirements	IV

Assessment of Productivity (A):

Productivity is the quantity of yield from agricultural operations **(Moghanm, 2015).** Table 2 shows characteristics of the productivity indicators. The parametric evaluation system of the index is given in Table 3 A and 3 B and fig.4. Each indicator has a scale of 0.0 to 1.0.

Table 2. Productivity characteristics of the landform units

Mapping unit	Relative yield	Organic carbon%	pH	CEC cmolc kg^{-1}	water table depth (cm)	Salinity (EC) dsm^{-1}	Texture	Available ($mgkg^{-1}$) N	P	K
RT1	0.88	0.90	8.00	37.14	90.00	0.52	Silty clay Loam	20.00	18.00	400.00
RT2	0.91	0.70	8.01	35.93	90.00	0.49	Clay loam	21.00	20.00	410.00
RT3	0.92	0.77	7.98	38.22	91.20	0.53	Silty clay Loam	21.50	17.00	422.50
DB	0.86	0.95	7.84	34.95	97.50	0.44	silty loam	19.50	21.50	435.00
OB	0.90	0.80	8.12	37.37	95.00	0.53	Silty clay loam	22.00	21.50	395.00

Table 3 A. Productivity indices of the landforms

Mapping unit	Nutrient availability												Depth of water table(cm)			EC dsm^{-1}		
	RV (%)			OC (%)			pH			CEC								
	S	R	V	S	R	V	S	R	V	S	R	V	S	R	V	S	R	V
RT1	10	10	100	10	10	100	10	10	100	10	10	100	10	9.5	95	10	10	100
RT2	10	10	100	10	10	100	10	9.5	95	10	10	100	10	9.5	95	10	10	100
RT3	10	10	100	10	10	100	10	10	100	10	10	100	10	9.5	95	10	10	100
DB	10	10	100	10	10	100	10	10	100	10	10	100	10	9.5	95	10	10	100
OB	10	10	100	10	10	100	10	9.5	95	10	10	100	10	9.5	95	10	10	100

RV (%) = Relative yield, S= score, R= rank, V: value = (SR), OC= organic carbon

Table 3 B. Productivity indices of the landforms

Mapping unit	Texture			Available ($mgkg^{-1}$)									Total
				N			P			K			
	S	R	V	S	R	V	S	R	V	S	R	V	
RT1	10	10	100	10	8.5	85	10	10	100	10	10	100	**0.80**
RT2	10	10	100	10	8.5	85	10	10	100	10	10	100	**0.76**
RT3	10	10	100	10	8.5	85	10	10	100	10	10	100	**0.80**
DB	10	10	100	10	8.5	85	10	10	100	10	10	100	**0.80**
OB	10	10	100	10	8.5	85	10	10	100	10	10	100	**0.76**

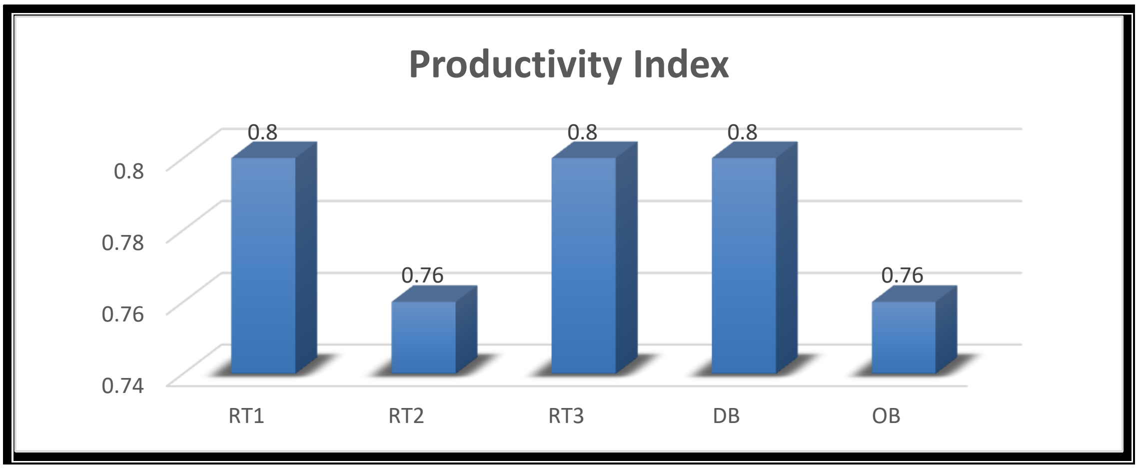

Fig.4: Productivity index of the study area

Assessment of Security and Protection indices (B and C).

Table 4 shows characteristics of the security and protection indicators on mapping unit level. The parametric evaluation system of the two indices was given in Table 5. Each indicator has a scale of 0.0 to 1.0. Figures 5 and 6 show that, security and protection practices in the flood plain (RT1, RT2, RT3, DB and OB mapping units) meet the requirements of sustainability (1.00) and representing (class I).

Table 4. Security and protection characteristics of the landform's units

Mapping unit	**Security characteristics**		**Protection characteristics**		
	Moisture availability (Day/Year)	**Crop residues %**	**Erosion hazards**	**Flooding hazards**	**Cropping system**
RT1	365	> 50 % > 3 years	No erosion evidence	No flooding evidence	Double cropping With Hedge row
RT2	365	> 50 % > 3 years	No erosion evidence	No flooding evidence	Double cropping With Hedge row
RT3	365	> 50 % > 3 years	No erosion evidence	No flooding evidence	Double cropping With Hedge row
DB	365	> 50 % > 3 years	No erosion evidence	No flooding evidence	Double cropping With Hedge row
OB	365	> 50 % > 3 years	No erosion evidence	No flooding evidence	Double cropping With Hedge row

Table 5. Security and protection indices of the landform's units

Mapping Unit	**Security index**							**Protection index**									
	Moisture availability (Day/Year			**Crop residues %**			**Total**	**Erosion hazard**			**Flooding hazard**			**Cropping system**			**Total**
	S	**R**	**V**	S	R	V		S	R	V	S	R	V	S	R	V	
RT1	10	10	100	10	10	100	1.00	10	10	100	10	10	100	10	10	100	**1.00**
RT2	10	10	100	10	10	100	1.00	10	10	100	10	10	100	10	10	100	**1.00**
RT3	10	10	100	10	10	100	1.00	10	10	100	10	10	100	10	10	100	**1.00**
DB	10	10	100	10	10	100	1.00	10	10	100	10	10	100	10	10	100	**1.00**
OB	10	10	100	10	10	100	1.00	10	10	100	10	10	100	10	10	100	**1.00**

Note: S= score, R= rank, (S*R) = value

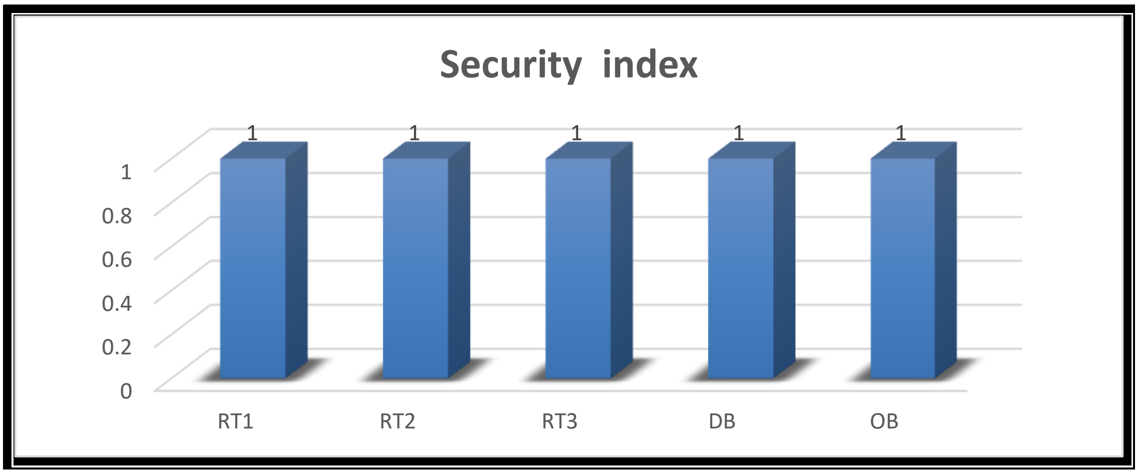

Fig. 5: Security index of the study area.

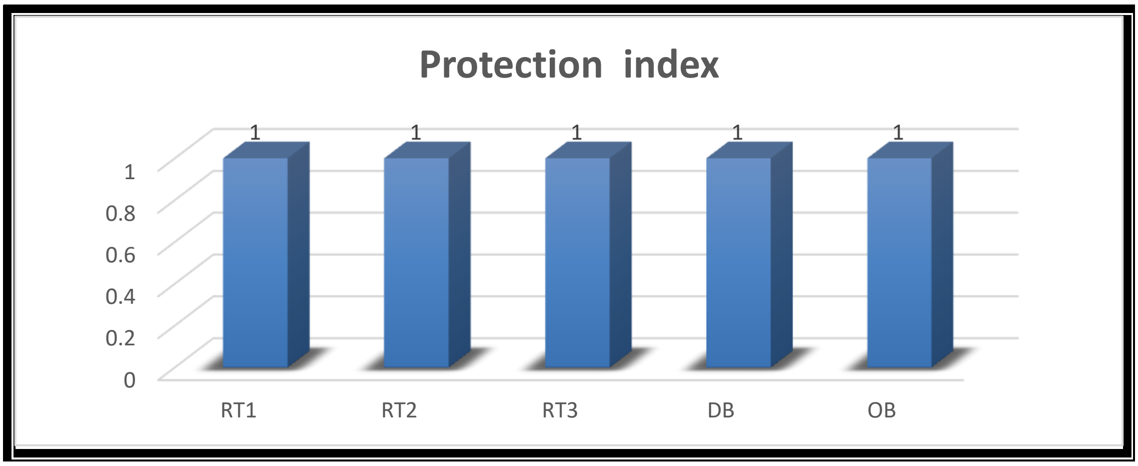

Fig.6: Protection index of the study area

Economic viability Assessment (D)

Table 6 shows characteristics of the economic viability indicators on mapping unit level. The parametric evaluation system of the index was given in Table 7. Each indicator has a scale of 0.0 to 1.0. Figure 7 shows that, the economic viability index ranged from 0.64 to 1.00. Economic viability practices in all flood plain mapping units meet the requirements of sustainability ranging between 0.60 and 1.00 and representing (class I).

Table 6. Economic Viability characteristics of the landform's units

Mapping Unit	Benefit cost ratio	Difference between farm gate price and nearest main market price %	Availability of farm labor	Size of farm Holding	Percentage of farm product sold in market
RT1	1.78	78	3	1.21	90
RT2	1.91	82	3	1.27	90
RT3	1.86	63	2	0.80	70
DB	1.57	53	3	0.89	90
OB	1.77	62	2	1.61	80

Table 7. Economic Viability Indices of the landform units

Mapping unit	Benefit cost ratio			Difference between farm gate price and nearest main market price %			Availability of farm labor			Size of farm Holding Fadden			Percentage of farm product sold in market			Total
	S	R	V	S	R	V	S	R	V	S	R	V	S	R	V	
RT1	10	10	100	10	10	80	10	10	100	10	10	100	10	10	100	**1.00**
RT2	10	10	100	10	10	80	10	10	100	10	10	100	10	10	100	**1.00**
RT3	10	10	100	10	8	80	10	9	90	10	9	90	10	10	100	**0.64**
DB	10	9	90	10	8	80	10	10	100	10	9	90	10	10	100	**0.64**
OB	10	10	100	10	8	80	10	9	90	10	10	100	10	10	100	**0.72**

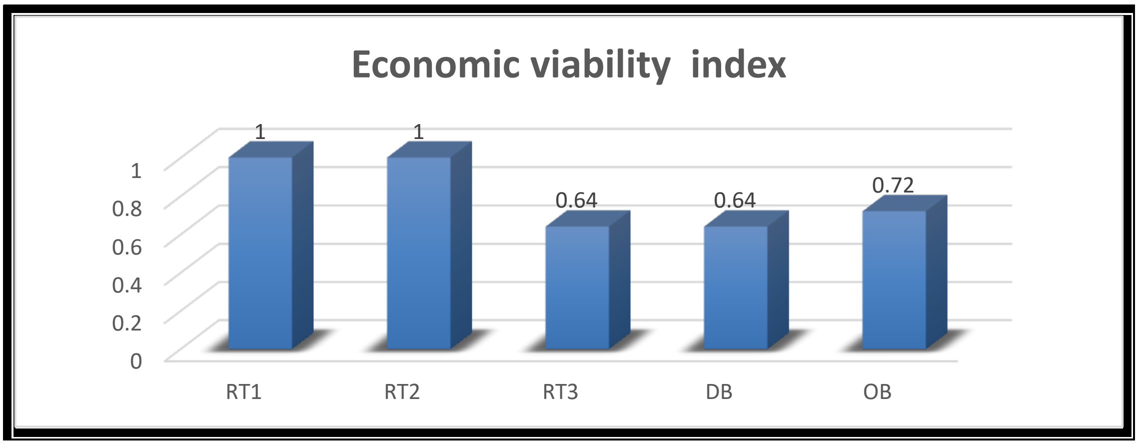

Fig. 7: Economic Viability index of the study area

Social Acceptability Assessment (E)

Table 8 shows characteristics of the social acceptability indicators on mapping unit level. The parametric evaluation system of the index was given in Table 9. Each of these seven indicators is on a scale from 0.0 to 1.0. Figure 8 shows that, the social acceptability index in the flood plain is higher, the economic viability index ranged from 0.72 to 0.90, meeting the sustainability requirements (class I).

Table 8. Social Acceptability characteristics of the landform units.

Mapping unit	Land tenure	Support for extension services	Health and educational facilities in village	% of subsidy for conservation packages	Training of farmers in soil and water conservation techniques	Availability of agro-input within 5- 10 km range	Village road access to main road
RT1	Full ownership	Full extension support	Adequate	74	Adequate training	Available.	full access
RT2	Full ownership	Full extension support	Adequate	78	Adequate training	Available.	full access
RT3	Long term user rights	Moderate extension support	Adequate	63	Adequate training	Available.	full access
DB	Full ownership	Moderate extension support	Adequate	83	Sufficient training	Available.	full access
OB	Long term user rights	Moderate extension support	Adequate	66	Sufficient training	Available.	full access

Table 9. Social Acceptability Indices of the landform units

Mapping unit	Land tenure			Support for extension services			Health and educational facilities in village			Percentage of subsidy for conservation packages			Training of farmers in soil and water conservation techniques			Availability of agro-input within 5- 10 km range			Village road access to main road			Total
	S	R	V	S	R	V	S	R	V	S	R	V	S	R	V	S	R	V	S	R	V	
RT1	10	10	100	10	10	100	10	10	100	10	10	100	10	9	90	10	10	100	10	10	100	**0.90**
RT2	10	10	100	10	10	100	10	10	100	10	10	100	10	9	90	10	10	100	10	10	100	**0.90**
RT3	10	9	90	10	9	90	10	10	100	10	10	100	10	9	90	10	10	100	10	10	100	**0.72**
DB	10	10	100	10	9	90	10	10	100	10	10	100	10	10	100	10	10	100	10	10	100	**0.90**
OB	10	9	90	10	9	90	10	10	100	10	10	100	10	10	100	10	10	100	10	10	100	**0.81**

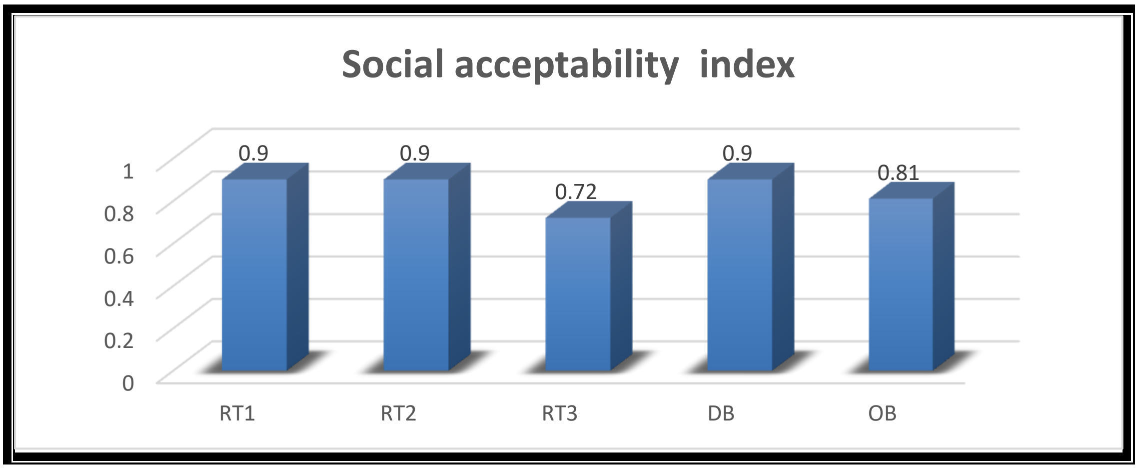

Fig. 8: Social Acceptability index of the study area.

The Sustainability Index (SI).

The study is based on Sustainable Land Management (SLM) model and the SLM indices (productivity, security, protection, economic viability and social acceptability). Mathematical formula expressing sustainability index as a resultant of the various criteria. Each index is valued on a scale from 0.0 to 1.0. Thus, the 5 indices are multiplied by one another. The resultant of sustainability index also lying between 0.0 and 1.0. Tables 10 and 11 show values of the factors of sustainability index, parametric evaluation system and distribution of sustainability index of the study area. Figure 9 shows that, sustainability index in the investigated area fall into two sustainability index classes, which assess the degree of agriculture sustainability. Class I and II exist in the flood plain soils. Most of El- Monofia area 61.30% (20814 ha) consists of good classes (II) in terms of Marginally but above threshold of sustainability: RT3, DB and OB mapping units of flood plain. The remaining 38.70% (13147 ha) of study area has average class (I) in terms of land management practices meets the sustainability requirements: RT1 and RT2 mapping units of flood plain.

Table 10. Sustainability index and classes of the landform units

Maping unit	Productivity index	Security index	Protection index	Economic viability index	Social acceptability index	Total value of sustainability index	Sustainability class
RT1	0.80	1.00	1.00	1.00	0.90	0.72	**I**
RT2	0.76	1.00	1.00	1.00	0.90	0.68	**I**
RT3	0.80	1.00	1.00	0.64	0.72	0.36	**II**
DB	0.80	1.00	1.00	0.64	0.90	0.46	**II**
OB	0.76	1.00	1.00	0.72	0.81	0.44	**II**

Table 11. Distribution of land sustainability index of the study area .

(LSI)	Grade	Class	Mapping unit	Area (ha)	Area %
0.6–1	**I**	Meet the sustainability requirements	**RT1 and RT2**	13147	38.70
0.3–0.6	**II**	Marginally but above the threshold of sustainability	**RT3, DB and OB**	20814	61.30
0.1–0..3	**III**	Marginally but below the threshold of sustainability	---------------------	-----	----
0–0.1	**IV**	Do not meet the sustainability requirements	---------------------	----	----

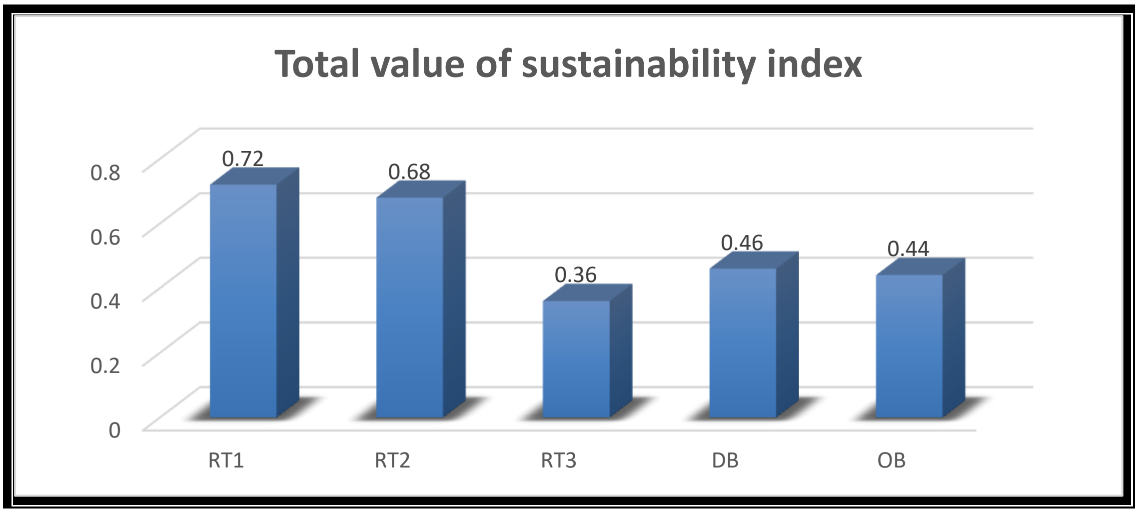

Fig. 9: Sustainable land management index of the study area.

Conclusion

Sustainable agriculture has many constrains suppress its continually, this raise the importance of evaluating indicators status of agricultural sustainability. Water resources and scarce land are major sustainability constraints this in addition to impact of anthropogenic activities and environmental sensitivity to degradation. These are main constrains facing sector of agricultural in Egypt. Assessment of agricultural land sustainability, depending on five factors (productivity, security, protection, economic viability and social acceptability). This study found that more than 60% of El-Monofia Governorate achieved sustainability index class II, while 38.7% of the area achieved sustainability index class I. Therefore, agricultural land sustainability in El-Monofia Governorate requires much more governmental and public efforts through: 1- Attention to social and economic factors; 2- Educate farmers to improve agricultural productivity and 3- Using of precision agriculture as a technique maximize agricultural yield.

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تقييم الاستدامه الزراعيه باستخدام الاستشعار من بعد ونظم المعلومات الجغرافية في منطقة دلتا النيل – مصر

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للزراعة المستدامة العديد من القيود التي تمنعها باستمرار ، وهذا يزيد من أهمية تقييم حالة مؤشرات الأستدامة الزراعية والموارد المائية والأراضي النادرة هي قيود الرئيسية للأستدامة هذا بالإضافة إلى تأثير الأنشطة البشرية وحساسية البيئة للتدهورو هذة هي المعوقات الرئيسية التي تواجه قطاع الزراعة في مصر.حيث تم تقييم استدامة الأراضي الزراعية اعتمادًا على خمسة عوامل (الإنتاجية ، والأمن ، والحماية ، والجدوى الاقتصادية ، والقبول الأجتماعي).و توصلت هذه الدراسة إلى أن أكثر من 60٪ من محافظة المنوفية حققت مؤشر الأستدامة من الدرجة الثانية ، بينما حققت 38.7٪ من المنطقة مؤشر الأستدامة من الدرجة الأولى. لذلك ، تتطلب استدامة الأراضي الزراعية في محافظة المنوفية مزيدًا من الجهود الحكومية والعامة من خلال: 1- الاهتمام بالعوامل الاجتماعية والاقتصادية. 2- توعية المزارعين لتحسين الإنتاجية الزراعية 3- استخدام الزراعة الدقيقة كأسلوب لتعظيم العائد الزراعي.