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Assessment of Agricultural Sustainability of Bahariya Oasis using Geo-Informatic techniques

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Abstract

Globally, Food security is considered one of the most issues for humanity due to rapid population growth thus sustainable natural resources assessment is required. Well assessment and management of soil can aid in achieving food security. Agriculture sector in Egypt is facing some obstacles related to sustainability. These include scarce land and water resources, degradation of environment and high rate of population growth. This study focuses on evaluating of agricultural sustainability development in Bahariya oasis, western desert of Egypt. Maps of physiographic and soils were produced using analysis of multispectral Sentinal-2 image with spatial resolution 10 m dropped over digital elevation model (DEM), A shuttle radar topography mission (SRTM) 1-arc-second v.30 DEM. Fifty soil profiles were dug to represent geomorphological units within study area. Soil productivity, environmental security, environmental protection, economic viability, and social acceptability of proposed management options were calculated within the study's landscapes using the Framework for Evaluating Sustainable Land Management (FESLM). The results revealed that the investigated area classified into lands that are marginally below the requirement of sustainability with an area of 534.34 km^2 and the rest of study area are not meet sustainability requirements. The sustainability challenges in the investigated area are associated with productivity, economic viability and social acceptability. This research suggests some practices to achieve sustainable development in the study area for instance practicing farmers on modern ways of well management and soil conservation, increase level of health and school care, facilitation of loans for farmers and increasing markets number. outputs from this study can provide decision makers with valuable data that help them to ensure achieving of sustainable management within study area.

Keywords: Agricultural sustainability; Remote sensing (RS); GIS; FESLM; Bahariya Oasis.

Introduction

Agriculture sustainability attempts to accomplish long-term agricultural output stability, environmental protection, and consumer safety by selecting the best methods to help farmers choose between different hybrids and types, soil fertility programmers, and soil-conservation culture (Gold 1999). Sustainable land management (SLM) in agriculture is not easy issue that includes many features, such as, biophysical, socioeconomic and environmental factors (Moghanm et al., 2018)

Assessment of planning is critical in closing the gap between planning practise and landscape research in order to achieve more sustainable land use (Antonson 2009). There have been many initiatives towards global environmental conservation since the Stockholm Declaration was adopted in 1972, as sustainable development is a significant concern of all nations given the need to maintain the global environment (Sohn 1973). Sustainable agriculture is also an agriculture of social values, one whose success is inextricably linked to vibrant rural communities, prosperous farm families, and nutritious food for all (Richard, 2005). The major restrictions of sustainability in Egypt are land and

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water shortage, degradation of environment, population exploration, in addition official arrangement (land tenure and farm fragmentation, agricultural management, infrastructure absence, and credit utilization and high rates of interest) (El-Nahry 2001; Mohamed and Gouda 2018).Sustainable agricultural technologies and modern information are essential for improving food production and decrease negative environmental impacts (Baroudy et al., 2020). In Egypt, a lack of necessary macro-control of land use, particularly legal guidelines and economic changes to market economy, as well as improper micromanagement, has resulted in a sharp conflict between land supply and demand. Furthermore, overpopulation has resulted in a heavy load on farmland, which has been used intensively without adequate protection, necessitating land use sustainability to solve this problem and reduce the heavy load. Integration of technologies, policies, and activities are required to achieve the sustainable land management (SLM) in the rural sector, particularly agriculture, in such a way that improves economic performance while sustaining the quality and environmental functions of the natural base (Abdel Kawy, 2013). Evaluation of sustainable land management was included five criteria include productivity, security, protection, viability, and acceptability (Dumanski, 1997). Crop yield is utilised as a sustainability indicator because it can track production per hectare over time and identify gaps between experimental and farmer yields (El-Nahry, 2001) Under Egyptian conditions, biophysical fundamentals and socioeconomic aspects (productivity, security, protection, economic viability, and social acceptability) are used to combat and implement sustainability restrictions that halt the development of agriculture or reduce it to acceptable levels of mass production efforts (Abdel Kawy et al., 2012; Nawar, 2009; El Bastawesy et al., 2013). The combined utilize of Remote Sensing (RS) and Geographic Information Systems (GIS) data helps decision-makers to organize land resources data and soil maps in the research area through giving the an essential information (Jalhoum et al., 2022). Within the Geographic Information System, the spatial analysis model is a very important technique for gathering, manipulating, and processing spatial variables (GIS). The interpolation techniques widely used in agriculture and some studies found that ‘‘kriging’’ is more precise in description of the data spatial structure and produce information with high accuracy about estimation error distributions (Leenaers et al., 1990; Deutsch and Journel, 1998; Mueller et al., 2004). The soils of study area are capable for projects of land reclamation because of its location and groundwater resources availability for irrigation (Elnaggar, 2017). The major goal of this study is to use a sustainable agricultural spatial model (SASM) integrated with GIS modeling to assess the current state of sustainable agriculture development in the Bahariya oasis in Egypt's western desert (productivity, security, protection, economic viability and social acceptability). The outputs from this study could be utilized by land managers to assess Agricultural sustainability development in drylands and can be used to other regions of a similar subject.

MATERIALS AND METHODS

The methodology brief of current research is illustrated in the Fig. (1)

Study area

The investigated area is situated in the middle of the Western desert of Egypt, occupying an area 2100 km2 between latitudes 27° 48' - 28° 30' N and longitudes 28° 35' - 29° 10' E as shown in Fig. (2), the area is categorized by a Mediterranean Sea climate with hot arid summer and little rain winter. The total rainfall is 3-6 mm/year. The study area soil temperature regime is *Thermic* and soil moisture regime as *Torric* or *Aridic*. The study area is characterized by an extremely arid condition, as, temperature varies from 10-20 ^{o}C and from 20-30 ^{o}C in winter and summer respectively, and average of annual precipitation is around 4 mm. The two main resources for irrigation and civic purposes are springs and wells. The depression surround on all sides by high scarps and having alot of isolated hills, (El-Kafrawy, 2013).

Production of geomorphologic map

Geomorphologic map was undertaken utilizing digital Sentinel-2 image acquired in (1-11-2021) integrated with DEM. Sentinel Application Platform (SNAP) and ENVI 5.3.The visual interpretation for the multispectral Sentinal-2 image with spatial resolution 10 m dropped over DEM (Fig. 3), A shuttle radar topography mission (SRTM) 1-arc-second v.30 DEM (USGS, 2005) acquired in 11/02/2000 and updated 06/08/2015 was used as the source data for study area elevation heights in System for Automated Geo-scientific Analyses (SAGA) V.7.6.1 to provide a 3D vision for the landform unit extract.

Field survey and lab.Analyses

Truth check of the mapping units and consideration the certainty interpretation of DEM carried out by field studies and ground truth points. A total 50 soil profiles were chosen to represent different mapping units of investigated area Fig (4).

The profiles morphological description carried out by the basis outlined by FAO (2006). Representative soil samples have been collected and analyzed (Physical analyses i.e.: Particle size distribution, bulk density, and soil compaction by soil core method were done based on to Klut (1986), Chemical analyses i.e.: Electric conductivity (EC), soluble cations and anions, calcium carbonate ($CaCO_3$), organic matter (OM), pH, Exchangeable Na+, available nitogen (N), phosphorus(P) and potassium (K) and cation exchange capacity were measured relied on USDA (2004), key to soil taxonomy (USDA, 2010) was used for soil classification.

Spatial distribution of soil properties

To produce continuous information of data which collected at distinct locations (e.g., soil profiles), the spatial distribution of soil properties was used. Ordinary ‘‘kriging’’ model is an interpolation method, which estimates the unmeasured location depended on distance between the measured points and the unmeasured point and also overall geostatistical relations among the measured points (Ali and Moghanm, 2013). Ordinary ‘‘kriging’’ of Arc-GIS 10.4.1 software has been utilized to interpolate the soil characteristics within mapping units.

Evaluation of the agricultural sustainability in study area

Smyth and Dumanski (1993) developed the international Framework for Evaluating Sustainable Land Management (FESLM), which was used to assess sustainability in the study region. It has been chosen due to connect all land use aspects under study with the environmental, economic and social condition which collectively determine whether that the current agricultural management is sustainable or lead to sustainability in the future. It consists of technology, policies, and actions that integrate socio-economic principles with environmental concerns in order to satisfy the five Sustainable Land Management (SLM) pillars of productivity, security, protection, viability, and acceptability at the same time. The sustainability index (SI) considers the grand values of five criteria as sustainability pillars, viz.: productivity (A), security (B), protection (C), economic viability (D) and social acceptability (E), where: Sustainability Index (SI) = A x B x C x D x E

Productivity index:

The Productivity Index is calculated using following formula

$$V = A/100 \times B/100 \times C/100 \times D/100 \times E/100 \times F/100 \times G/100 \times H/100$$

Where: A = relative yield, B = OC%, C = pH, D = CEC, E= oxygen availability, F = EC, G = ESP and H = Texture.

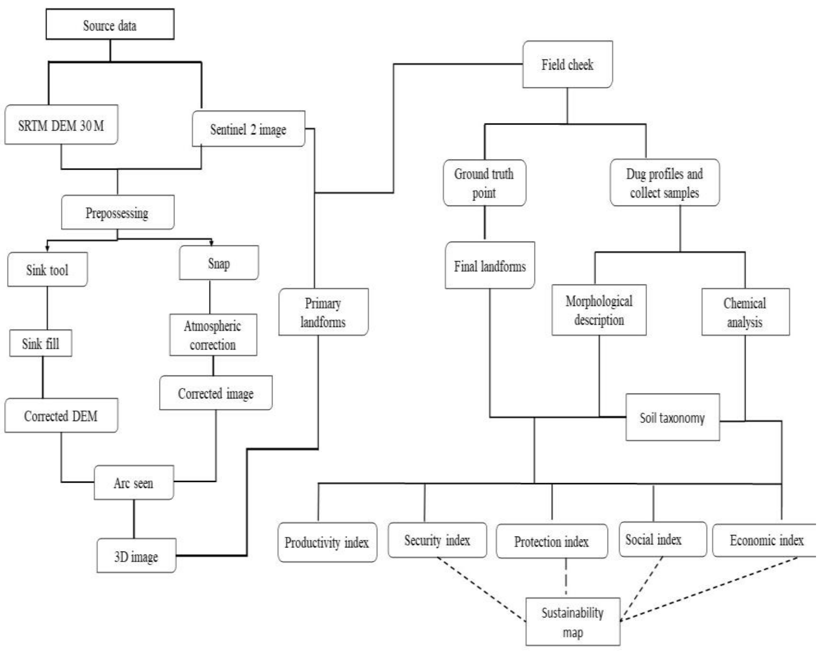


Fig. 1. The flowchart describes methodology of study area

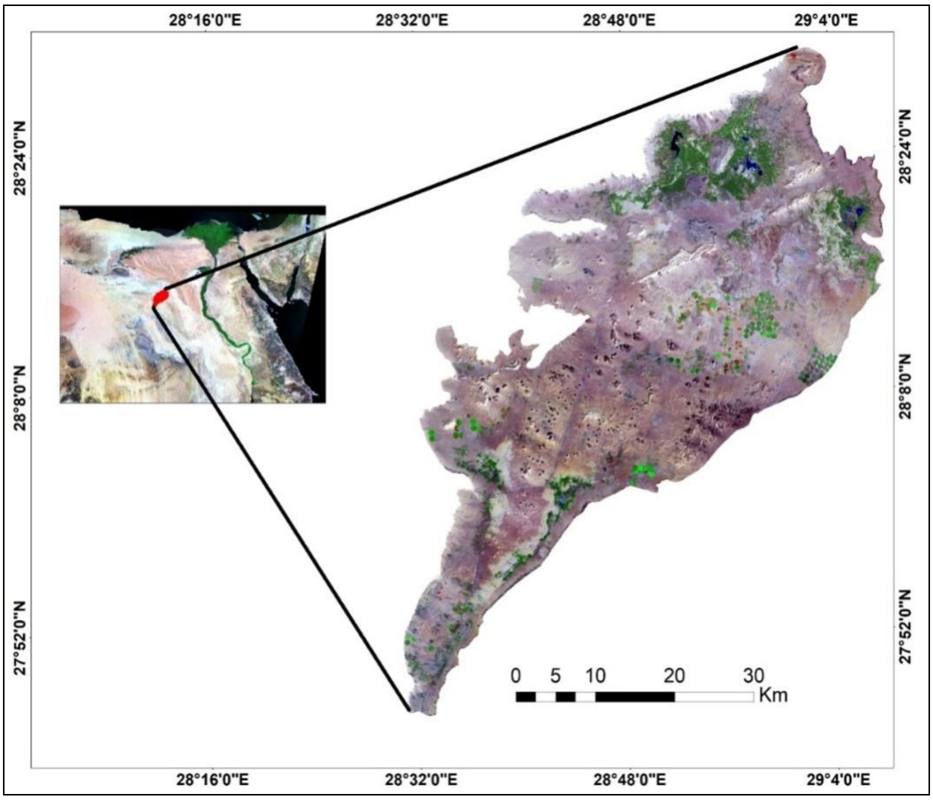


Fig. 1. The flowchart describes methodology of study area

Fig. 2. Location of the investigated area.

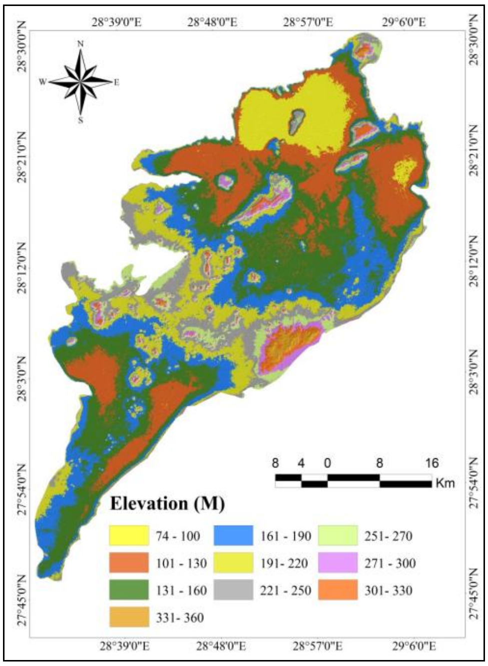


Fig. 3. Digital elevation of study area

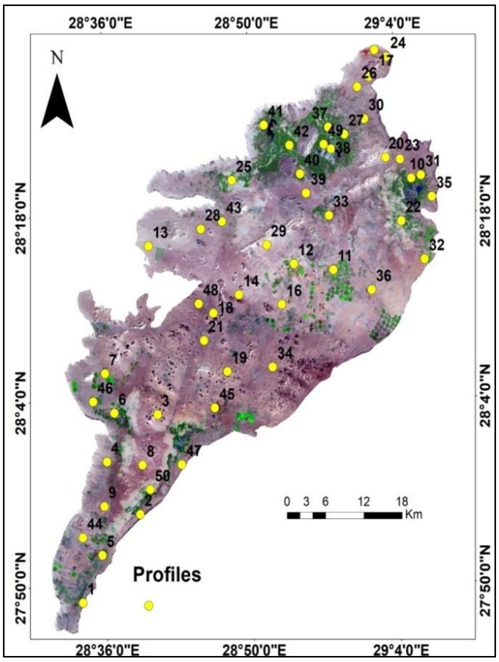


Fig. 4. Profile location of study area

Security index

The Security Index is calculated according to the formula:

$$V = A/100 \times B/100 \times C/100$$

Where: A = moisture availability, B = water quality and C = Biomass%.

Protection

The calculation of protection is as security, considering the value of the three indicators erosion hazards (A), flooding hazards (B) and cropping systems (C). Formula integrates these indicators $V = A/100 \times B/100 \times C/100$.

Economic viability

The value (V) of five indicators is used to calculate the Economic Viability Index according to SLM: 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 percentage of farm produce sold in market (E), using the following formula:

$$V = A/100 \times B/100 \times C/100 \times D/100 \times E/100.$$

Social acceptability

The SLM system uses the following formula to calculate the Social Acceptability index

$$V = A/100 \times B/100 \times C/100 \times D/100 \times E/100 \times F/100$$

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

The sustainability index (SI) considers the grand values of five criteria as sustainability pillars, viz.: productivity (A), security (B), protection (C), economic viability (D) and social acceptability (E), where: Sustainability Index (SI) = A x B x C x D x E.

Sustainable Agricultural Model

Sustainable agricultural model was established based on criteria of Smyth and Dumanski (1993) was used for sustainability evaluation in the study area. Model Builder in ArcGIS to identify and classify the investigated area based on agricultural use. Once the input of model was determined by the statistic model's sustainability evaluation the shapefiles with the source data were adapted to reveal the attributes that would be given consideration (Fig. 5). The values of sustainability index were classified as the shown in Table (1).

This model consists of several steps that use the result of one process as the input to another process (Shokr et al., 2021):

The first step: it is to creat a database for each parameter (productivity (A), security (B), protection (C), economic viability (D) and social acceptability (E)), and categorizing which datasets needed as inputs in adequate form (raster format).

The second step: Reclassifying (scaling) datasets reclassify each dataset to a common scale of values (i.e. from 1 to 5). Higher scale values are giving to more suitable attributes.

The third step: Weighting was done for each reclassified dataset using an evaluation scale that matches the scale used in reclassifying step (from 1 to 5). The evaluation scale value depends on the proposed rating for each characteristic.

Finally, using weighted overlay, the sustainability index was calculated by multiplying several indices. Each input dataset can be assigned a percentage influence; the total influence for all datasets must equal 100 percent. The cell values of each input dataset are multiplied by their influence percentages (weight).

Fig. 5. Model structure of Agriculture sustainability assessment

TABLE 1. The values of sustainability index

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

Results and Discussion

Digital soil maps units of study area

Landform units were identified Table (2) and Fig. (6). Plains occupy the north part in the Oasis. This landscape covers about 605 km2 (28.72%) of total area including ten landform units i.e. sand plain, high sand sheet, low sand sheet, alluvial fans, dunes, salt marsh dry sabkha, wet sabkha, playa and desert pavement representing (11.47%), (4.99%), (4.64%), (4.50%), (1.75%), (0.08%), (0.08%), (0.29%), (0.22) and (0.69%) of study area respectively. These soils are formed of erosion of hills and mountains with an elevation range from 91 to 201meter above sea level (a.s.l). Basins include overflow (118.78 km^2), decantation basins (26.07 km^2) and depression (127.73 km^2). Terraces occur at the edge of the decantation basins and subdivided into high, moderate and low terraces covering the majority of total area (35.92%). These landforms cover an area of 176, 167, 156 and 148 km^2. Pediment and reference terms are covering 174.30 km^2. Reference terms include rock land, rocky hill, urban area, Water body, mesa, foot slope and escarpment with an area about 298 km^2.

Some of soil properties of study area

The depth of water table is more than 200 cm. Soil texture class is differing between sandy, clay loam and sandy loam and sandy clay loam. OM % recording low ranges between 0.1 to 1.5%, the results are met with arid climatic condition, as it encourages organic matter decomposition. The mean weighted of pH values range between slightly alkaline (7.52) and strangely alkaline (8.8). Spatial distribution of ECe shows that the studied area has wide range of

ECe values, as it ranges from 1- 57.9 dS/m. The highest value found in moderately high terraces. Using low salinity in irrigation water to leach salts from the soil is the suggest management plan of the high saline soil (Zalacáin, et al., 2019, El Behairy et al., 2021). CEC is low where it ranges between 1.40 and 20.4cmole/kg soils reflecting low of clay content and organic matter. ESP vary from 1.8to 18.7%. The high sodium percentage can affect negatively in the soil properties i.e. soil structure, soil hydrology, reducing in crop productivity consequently reduction of agriculture sustainability. Adding agriculture gypsum to the soil is important to reclaim the soil which has more than 15 ESP (Chi, et al., 2012). Fig. (7) Show the interpolation maps of some soil properties. Based on morphological description and analytical data and using USDA (2010), the soils of study area could be classified into 7 sub great groups as a following: *Lithic Calcigypcids* (180.48 km^2), (8.52 %), *Lithic Haplocalcids* (103.16 Km^2), (4.87%), *Lithic Haplosalids* (4.74 Km^2), (0.23%), *Lithic Torriorthents* (86.21 Km^2), (4.07%), Typic *Aquisalids Typic Haplogypcides* (156.09 Km^2) (7.40%) respectively, *Typic Haplosalids* (104.51 Km^2) (4.95%), *Typic Haplocalcids* (223.40 km^2), (10.55), Reference terms (343.97 Km^2), (16.24%) and most of study area is a *Typic Torripsamments* (888.55km^2) (41.96%) Fig. (8).

Assessment of land sustainability

To assess the sustainability of the agricultural system in the study area, the following five indicators of the sustainable land management, were determined as the following:

Productivity index

This index related to soil status fertility, content and availability of nutrient for plants. Thus, chemical and physical characteristics are considered in soil productivity assessment. It was based on the relative yield, soil reaction (pH), salinity (EC), cation exchange capacity (CEC), oxygen availability and soil texture. The obtained data indicate that the land productivity index in plain landforms ranges from 0 to 0.6 so these landforms are located under three (class II) (Marginally but above the threshold of sustainability) For SP, LS and AF units, (class III) (Marginally but below the threshold of sustainability) for HS and DP units and (class IV) (do not Meet the sustainability requirements) for DS, WS, SM and P. The low values of the productivity in some mapping units are because of the lack of relative yield, CEC and high content of salinity, Table (3) and Fig. (9).

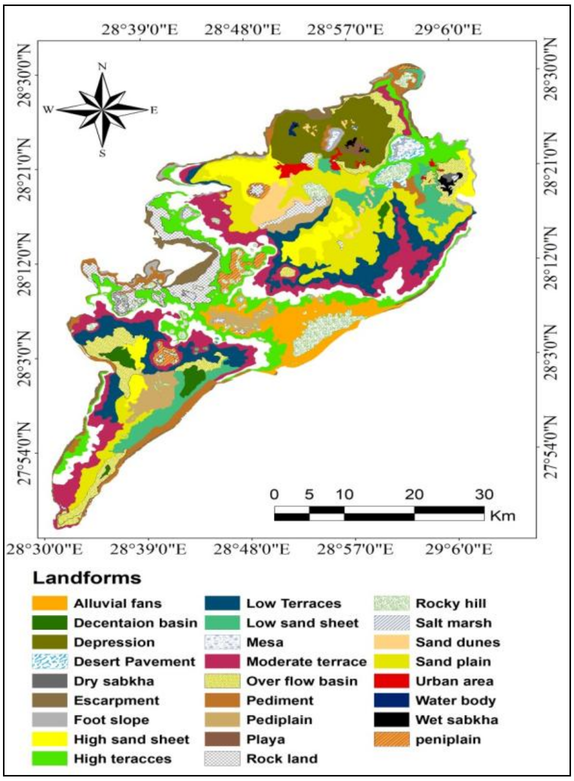
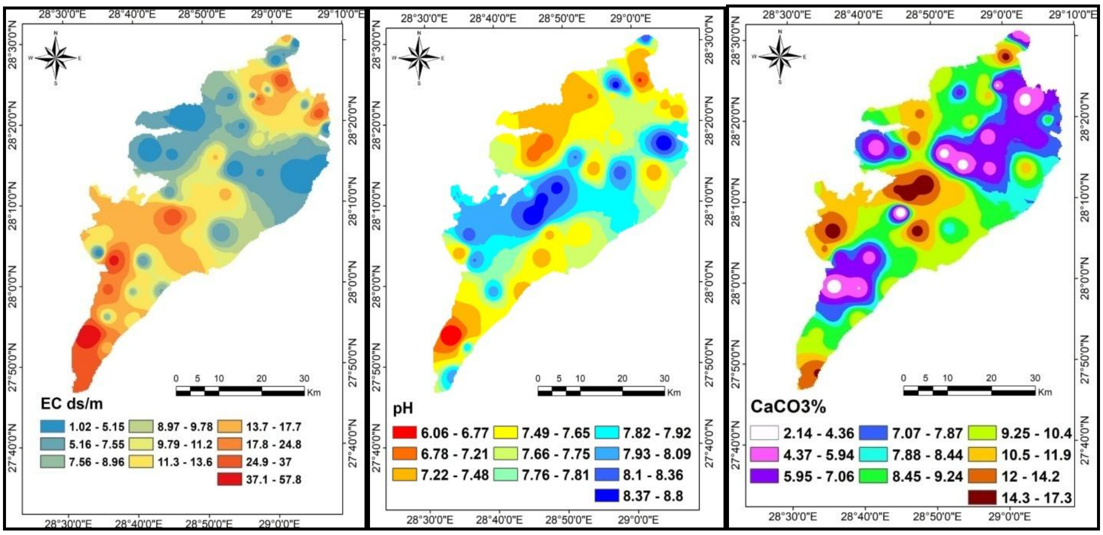


Fig. 6. Study area geomorphology map

TABLE 2. Geomorphologic units of study area

Landscape	Geomorphology	Land forms	Symbol	Area (km^2)	Area (%)
Plain	Sand plain	Sand plain	SP	241.78	11.47
	Sand sheet	High sand sheet	HS	105.13	4.99
		Low sand sheet	LS	97.86	4.64
	Alluvial fans	Alluvial fans	AF	94.91	4.50
	Sand dunes	Sand dunes	SD	36.95	1.75
	Salt marsh	Salt marsh	SM	1.78	0.08
	Sabkha	Dry sabkha	DS	1.76	0.08
		Wet sabkha	WS	6.06	0.29
	Playa	Playa	PL	4.74	0.22
	Desert Pavement	Desert Pavement	DP	14.46	0.69
Basin	Over flow basin	Over flow basin	OB	118.78	5.63
	Decantation basin	Decantation basin	DB	26.07	1.24
	Depression	Depression	D	127.73	6.06
Terraces	Alluvial terraces	High terraces	HT	197.28	9.36
		Moderate high terraces	MT	389.49	18.40
		Low Terraces	LT	180.49	8.56
Pediment	Pediment plain	Pediment plain	PP	73.03	3.46
	Pedi plain	Pedi plain	PL	71.76	3.40
	peniplain	peniplain	PN	30.14	1.43
Reference terms	Rock land	Rock land	-	89.10	4.23
	Rocky hill	Rocky hill	-	86.89	4.12
	Urban area	Urban area	-	13.00	0.62
	Water body	Water body	-	2.13	0.10
	Mesa	Mesa		1.55	0.07
	Foot slope	Foot slope		32.17	1.53
	Escarpment	Escarpment		73.18	3.47
Total	-	-		**2108.22**	**100%**



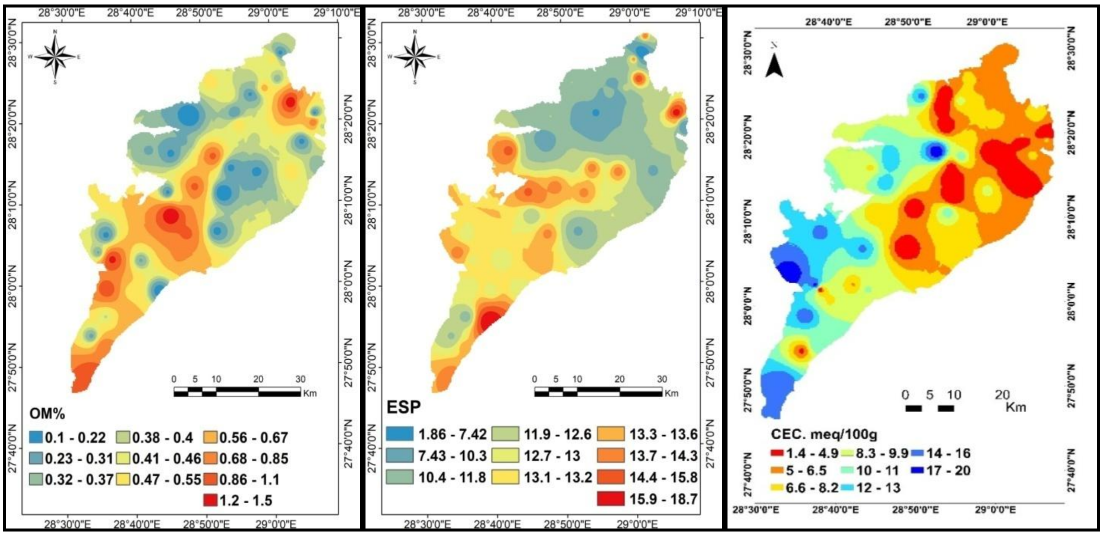


Fig. 7. Interpolation maps of some soil properties

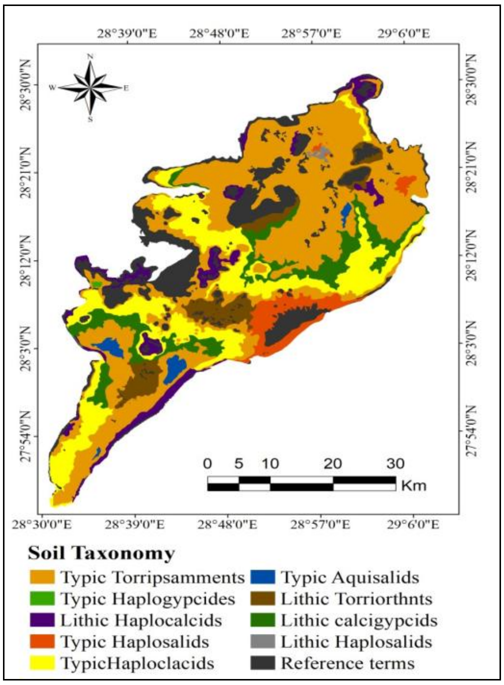


Fig. 8. Digital soil map of study area

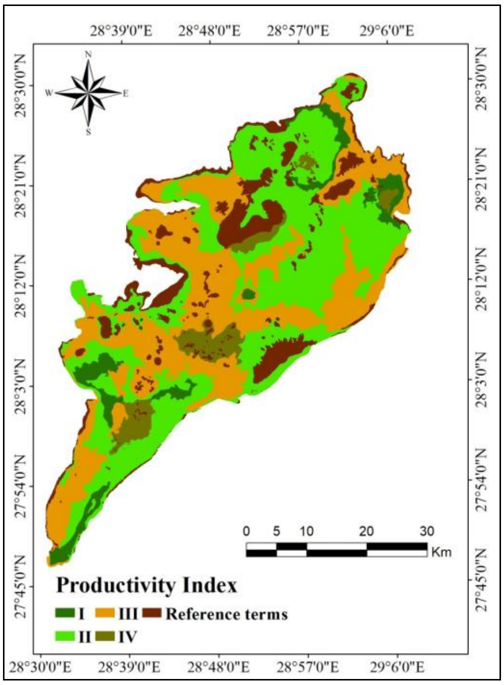


Fig. 9. Productivity map of study area

TABLE 3. Productivity characteristics and indices of the different mapping units in studied area

Mapping unit	Productivity characteristics								Productivity indices									
	A	B	C	D	E	F	G	H	A	B	C	D	E	F	G	H	V	Classes
SP	0.45	0.11	8.2	3.8	>200	4.9	13.8	S	85	95	95	90	100	95	100	95	0.6	II
HS	0.49	0.12	7.3	1.6	>200	2.2	13.8	S	70	90	100	80	90	80	80	85	0.25	III
LS	0.44	0.17	7.3	11	>200	2.5	13.78	SL	85	95	100	85	100	90	95	90	0.53	II
AF	0.68	0.11	7.52	1.42	>200	5.58	10	S	80	90	100	85	85	90	90	95	0.4	II
DP	0.4	0.81	7.7	7.7	>200	13.1	11.9	S	85	90	95	80	90	90	80	80	0.3	III
OB	0.47	0.17	7.3	11	>200	2.5	13.78	SL	95	95	100	90	95	100	90	90	0.63	I
DB	0.72	0.69	8.1	16.9	>200	43.9	12.9	SL	95	95	100	90	100	85	90	95	0.59	II
D	0.46	0.29	7.44	13.83	>200	7.7	11.8	LS	95	95	100	90	95	95	90	90	0.59	II
HT	0.56	0.35	7.4	8.5	>200	5.8	12.1	LS	80	85	95	85	85	95	85	80	0.3	III
MT	0.6	0.17	7.05	19.8	>200	5.71	11.65	SCL	90	90	80	80	90	90	90	80	0.3	III
LT	0.92	0.053	7.9	2.7	>200	14.9	13.7	S	80	80	90	80	100	90	90	90	0.34	II
PP	0.4	0.075	7.6	14.2	>200	2.2	18.7	SL	70	70	80	80	70	80	70	70	0.09	IV
PL	0.35	0.52	8.1	12.7	>200	14	12	SL	70	70	80	70	70	80	70	70	0.08	IV
PN	0.52	0.11	7.8	4.5	>200	5.8	12.8	S	80	90	85	85	85	90	90	90	0.32	III
SM	0	0.2	8.56	9.1	>200	34.76	9.9	SL	0	70	70	65	85	80	85	70	0.09	IV
DS	0	0.87	8.8	19.8	>200	36.6	11.9	SL	0	90	90	85	90	85	85	95	0	IV
WS	0	0.11	8.56	20.39	>200	50.65	5.54	SCL	0	90	90	90	85	80	90	90	0	IV
P	0	0.17	8.77	5.33	>200	27.08	7.8	SL	0	90	90	85	85	85	90	90	0	IV

Security and protection indices

Security index illustrates the relationship between water quality and biomass so, these parameters are used to show the statues of agricultural development in the investigated area. The results show that the security of about an area (730 km^2) meets the sustainability requirements, as the security index ranges from 0.50 to 0.81, and that the majority of the study area (1027.13 km^2) is marginally but above the sustainability threshold, while about 14 km^2 does not meet the sustainability requirements attributed by SM, DS, WS and P units as these values were < 0.1. The lack of moisture availability, biomass, degree of slop and erosion hazard are the major reasons of security values within study area. The security characteristics in the different mapping units in the study area was shown Table (4) and Fig. (10). The Protection index is classified into class (I) (0.63-0.81), class (II) (0.45-0.58), class (III) (0.29) and class (IV) (0.00). The low values are due to some erosion hazards and there is no cropping patterns system, Table (5) and Fig. (11).

Economic viability

Evaluation of economic index depends on a lot of factors related to the situation of local economic of each distract which differ from place to other. The agricultural economic situation includes a lot of factors such as inputs, outputs, external costs, marketing. The values (V) of five indicators were used to calculate the Economic Viability Index according to SLM: 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 percentage of farm produce sold in market (E). The obtained data indicate that the economic viability in SP and D units ranges between 0.62 and 0.65 so, these units are Meet the sustainability requirements. While, the economic viability index in DP, LT and LS mapping unit ranges between (0.55-0.58) therefore, these units are marginally but above the threshold of sustainability. While soils of, HS, AF, DP, HT and MT mapping units are located under class (III). In general, the soils of the pediment landscape and the DS, WS, SM, and P mapping units do not meet the sustainability requirements, which could be due to a decrease in the benefit to coasts ratio, a lack of farm labour, a small farm holding, and a low percentage of farm production in the market, as shown in Fig. (12). The features of economic viability in the research area are shown in Table (6).

Social acceptability

Evaluation of Social acceptability index is based on six social factors (land tenure, support for extension, health and educational facilities in village, training of farmers, availability of agro-input within 5- 10 km range and village road access to main road) which effects on sustainable agricultural and considered the major factors of agricultural development in the study area.

As demonstrated in Table (7) and Fig. (13), the soils of plain and pediment landscapes are marginally but below the sustainability threshold, i.e., the social acceptability index is (0.21 - 0.29), with the exception of SP, OB, D, and HD units, which are marginally but above the sustainability threshold. The rest of the area has a social acceptability index that meets the criteria for long-term viability. The low value of this index in the researched area is mostly due to a lack of health and educational facilities in the communities, as well as a lack of or insufficient soil and water conservation training for land users.

The Sustainability Index (SI)

Calculating according to the following formula considers the grand values of five criteria as sustainability pillars, viz.: Sustainability Index (SI) = A (productivity) x B (security) x C (protection) x D (economic viability) x E (social acceptability)

The results indicate that the studied area includes two sustainability classes as the following:

Soils of OB, DB and MT mapping units are marginally below the threshold for sustainability (Class III) as the range of SI index is from 0.11 to 0.15 with an area of 534.34 km^2 and all rest units are do not Meet the sustainability requirements Class IV (0.00-0.1), Fig. (14) and Table (8). Those areas are facing several obstacles that prevent the sustainable development under the current status

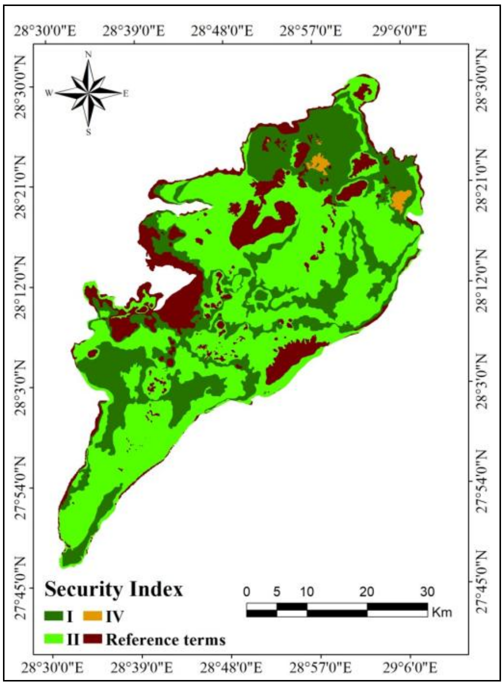


Fig. 10. Security map of investigated area

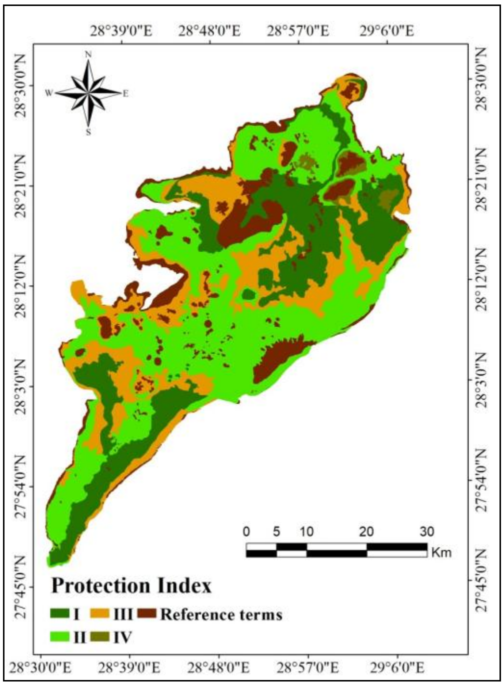


Fig. 11. Protection map of investigated area

TABLE 4. Security characteristics and indices of the different mapping units in studied area

Mapping units	Security characteristics			Security indices				Classes
	A	B	C	A	B	C	v	
SP	<210	0.3	<50 % < 3 years	80	90	90	0.64	II
HS	<210	0.4	<50 % < 3 years	70	90	80	0.50	II
LS	<210	0.5	<50 % < 3 years	80	80	80	0.51	II
AF	365	0.4	<50 % < 3 years	80	85	80	0.54	II
DP	365	0.3	<50 % < 3 years	70	95	80	0.53	II
OB	365	0.8	<50 % < 3 years	90	95	85	0.72	I
DB	365	0.9	<50 % < 3 years	90	95	90	0.76	I
D	365	1	<50 % < 3 years	85	95	100	0.80	I
HT	365	0.8	<50 % < 3 years	80	95	90	0.68	I
MT	365	0.9	<50 % < 3 years	70	85	90	0.53	II
LT	365	0.8	<50 % < 3 years	70	90	80	0.50	II
PP	<210	0.4	<50 % < 3 years	70	85	90	0.53	II
PL	<210	0.3	<50 % < 3 years	70	90	85	0.53	II
PN	<210	0.2	<50 % < 3 years	85	80	90	0.60	II
SM	<210	3.8	<50 % < 3 years	0	80	0	0	IV
DS	<210	4.7	<50 % < 3 years	70	80	0	0	IV
WS	<210	5.7	<50 % < 3 years	0	80	0	0	IV
P	<210	4.3	<50 % < 3 years	0	80	0	0	IV

TABLE 5. Protection characteristics and indices of the different mapping units in studied area

Mapping units	Protection characteristics			Protection indices				Classes
	A	B	C	A	B	C	V	
SP	No evidence	No flooding	No cropping patterns	90	90	100	0.81	I
HS	No evidence	No flooding	No cropping patterns	70	60	70	0.294	III
LS	No evidence	No flooding	No cropping patterns	70	100	90	0.63	II
AF	No evidence	No flooding	No cropping patterns	70	80	90	0.504	II
DP	No evidence	No flooding	No cropping patterns	70	90	0	0	III
OB	No evidence	No flooding	No cropping patterns	90	80	90	0.648	I
DB	No evidence	No flooding	No cropping patterns	100	90	90	0.81	I
D	No evidence	No flooding	No cropping patterns	80	70	80	0.448	II
HT	No evidence	No flooding	No cropping patterns	80	80	70	0.448	II
MT	No evidence	No flooding	No cropping patterns	80	80	90	0.576	II
LT	No evidence	No flooding	No cropping patterns	70	60	70	0.294	III
PP	No evidence	No flooding	No cropping patterns	70	60	70	0.294	III
PL	No evidence	No flooding	No cropping patterns	80	85	85	0.578	II
PN	No evidence	No flooding	No cropping patterns	70	60	70	0.294	III
SM	No evidence	No flooding	No cropping patterns	80	90	0	0	IV
DS	No evidence	No flooding	No cropping patterns	85	80	0	0	IV
WS	No evidence	No flooding	No cropping patterns	90	70	0	0	IV
P	No evidence	No flooding	No cropping patterns	80	90	0	0	IV

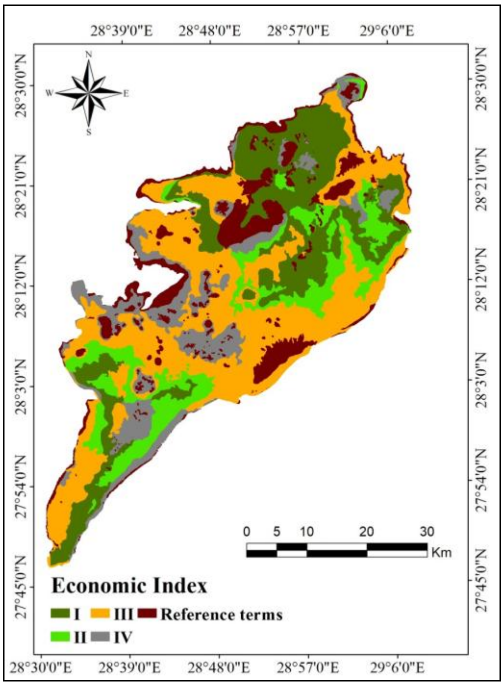


Fig. 12. Economic map of study area

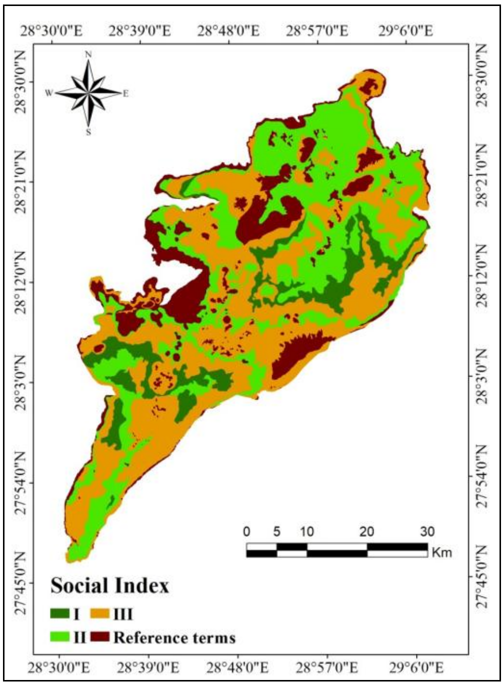


Fig. 13. Social map of study area

TABLE 6. Economic viability characteristics and indices of the different mapping units in studied area

Mapping unit	Economic viability characteristics					Economic viability indices						
	A	B	C	D	E	A	B	C	E	F	V	Classes
SP	1.81	30	1	2.1	20	80	90	100	100	90	0.648	II
HS	1.6	32	1	2.1	20	80	70	90	70	80	0.282	III
LS	1.7	30	1	2.1	70	90	80	90	90	100	0.583	II
AF	1.95	40	3	4.2	20	70	80	80	80	80	0.287	III
DP	1.6	32	1	0.42	20	70	80	80	80	80	0.287	III
OB	1.7	40	1	0.42	80	90	95	90	90	90	0.623	II
DB	1.8	35	4	6.3	80	100	90	90	90	80	0.583	II
D	1.8	40	4	6.3	80	90	80	90	100	95	0.615	II
HT	1.9	40	4	6.3	70	70	80	80	80	80	0.287	III
MT	1.6	40	3	4.2	70	70	80	70	80	90	0.282	III
LT	1.5	30	1	4.2	20	80	100	95	90	80	0.547	II
PP	1.5	31	1	0.84	20	70	0	80	80	80	0	IV
PL	1.4	32	1	0.42	20	0	80	80	80	80	0	IV
PN	1.8	33	1	0.42	20	0	90	80	80	80	0	IV
DS	1.4	32	1	0.84	20	0	0	80	90	0	0	IV
WS	1.8	33	1	0.42	20	0	0	90	80	0	0	IV
SM	1.8	33	1	0.42	20	0	0	80	90	0	0	IV
P	1.8	33	1	0.42	20	0	0	80	90	0	0	IV

TABLE 7. Social acceptability characteristics and indices of the different mapping units in studied area

Mapping unit	Social acceptability characteristics						Social acceptability indices								
	A	**B**	**C**	**D**	**E**	**F**	**A**	**B**	**C**	**D**	**E**	**F**	**G**	**V**	**Classes**
SP	No	Low	Non	No	not available	limited	85	90	80	90	100	95	100	0.52	II
HS	No	Low	Non	No training	not available	limited	85	80	80	80	80	80	80	0.22	III
LS	No	Low	Non	No training	not available	limited	85	80	80	80	80	80	80	0.22	III
AF	No	Low	Non	No training	not available	full access	85	80	80	80	80	80	80	0.22	III
DP	No	Low	Non	No training	not available	limited	85	80	90	80	80	80	90	0.28	III
OB	No	Low	Shortage	No training	shortage	limited	90	90	95	90	95	100	90	0.59	II
DB	No	Low	Shortage	No training	shortage	full access	90	90	95	100	90	95	100	0.66	II
D	No	Low	Shortage	No training	shortage	full access	85	80	90	80	80	90	90	0.52	II
HT	No	Low	Shortage	No training	shortage	full access	85	80	90	90	100	90	95	0.47	II
MT	No	Low	Shortage	No training	shortage	full access	85	80	90	80	90	90	80	0.32	III
LT	No	Low	Shortage	No training	shortage	limited	85	100	95	85	100	95	100	0.65	II
PP	No	Low	Non	No training	not available	limited	85	80	80	80	80	80	90	0.25	III
PL	No	Low	Non	No training	not available	limited	85	80	80	80	80	80	90	0.25	III
PN	No	Low	Non	No training	not available	limited	80	80	80	80	80	80	80	0.21	III
SM	No	Non	Non	No training	not available	No access	90	80	80	90	90	70	70	0.23	III
DS	No	Non	Non	No training	not available	No access	80	80	90	80	80	80	70	0.21	III
WS	No	Non	Non	No training	not available	No access	80	80	70	90	80	80	90	0.23	III
P	No	Non	Non	No training	not available	No access	90	90	80	70	90	80	90	0.29	III

TABLE 8. Agriculture sustainability classes of the mapping units

Mapping units	Productivity	Security	Protection	Economic	Social	Final sustainability	Classes
SP	0.602	0.648	0.810	0.608	0.523	0.100	III
HS	0.247	0.608	0.294	0.282	0.223	0.003	IV
LS	0.528	0.512	0.630	0.583	0.223	0.022	IV
AF	0.400	0.544	0.504	0.287	0.223	0.007	IV
DP	0.301	0.532	0.220	0.287	0.282	0.003	IV
OB	0.625	0.727	0.648	0.692	0.592	0.120	III
DB	0.623	0.769	0.810	0.583	0.658	0.149	III
D	0.594	0.807	0.648	0.626	0.517	0.100	III
HT	0.592	0.658	0.648	0.637	0.632	0.108	III
MT	0.582	0.635	0.676	0.682	0.651	0.111	III
LT	0.569	0.604	0.684	0.665	0.652	0.110	III
PP	0.098	0.535	0.294	0	0.251	0	IV
PL	0.098	0.535	0.578	0	0.251	0	IV
PN	0.304	0.612	0.294	0	0.210	0	IV
DS	0.090	0	0	0	0.229	0	IV
WS	0	0	0	0	0.206	0	IV
SM	0	0	0	0	0.232	0	IV
P	0	0	0	0	0.294	0	IV

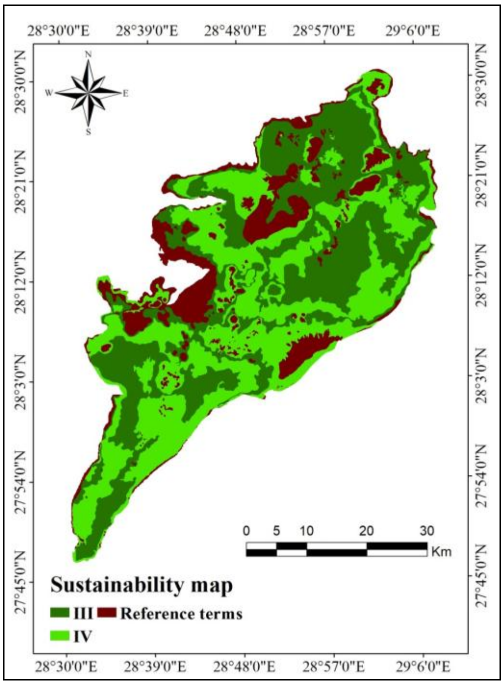


Fig. 14. Sustainability map of study area

Conclusion

The worldwide framework for evaluating sustainable land management (FESLM) provides an integrated methodology for quantitative agricultural sustainability evaluation, as well as the capacity to use the results in GIS to generate sustainability maps. Based on the findings of this study, it can be inferred that agricultural sustainability in the study area has various problems, including soil productivity, social acceptability, and economic viability. To increase the agricultural sustainability criteria in the researched area Farm management, infrastructure, and social services must all be enhanced in order to meet the norms of agricultural sustainability in the examined region. The proposed recommendation are practicing farmers on modern ways of well management and soil conservation, increase level of health and school care, facilitation of loans for farmers and increasing markets number. These recommendations can apply by government and decision makers to farmers and their activities that can be used in the future.

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