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Assessment of Land Suitability and Water Requirements for Different Crops in Dakhla Oasis, Western Desert, Egypt

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Authors' contributions

This work was carried out in collaboration between both authors. Author MEF performed remote sensing and GIS works. Author ASA wrote the protocol and wrote the first draft of the manuscript. Both authors performed field and laboratory analysis, managing the analyses and read and approved the manuscript.

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ABSTRACT

Land reclamation projects in Egypt have been directed towards the Western Desert; however, such expansion requires devoting land and water resources to the optimum use. Hence, the current work aimed at assessing land suitability and water requirements for various crops in an area located west of Dakhla Oasis. The geomorphic features were identified after the processing of Landsat 8.0 satellite image and Digital elevation model (DEM) verified by field and ground studies. Samples of thirty-one soil profiles and eleven water wells were collected and analyzed. Land suitability was assessed using MicroLEIS software with an Almagra model. The main geomorphic units are plateau, pediplain, depression and sand sheets. About 97% of the soils are suitable (high, moderate and marginal) for maize, sunflower, soya bean, wheat, sugar beet, cotton, watermelon, alfalfa, potato, peach, citrus, and olive. Water requirements for each crop were calculated using FAO–Cropwat model as 816.33, 795.98, 1003.83, 550.78, 865.13, 1150.83, 797.87, 2113.47, 397.37, 1577.86, 1503.92 and 1163.96 mm, respectively. The area has water resources with high quality for irrigation, and thus it is considered promising for agricultural expansion

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Keywords: Land suitability; almagra model; dakhla oasis; western desert; GIS; remote sensing.

1. INTRODUCTION

Overpopulation, limited arable land, and water scarcity are the main problems facing Egypt [1]. Therefore, increasing the area of cultivated land is vital [2]. This is achieved via reclaiming more lands, particularly in the desert which occupy more than 96% of the total area of Egypt [3], but with limited scope for agricultural expansion in the Nile Valley and Delta [4]. Expansion of arable lands increases the national production and supports different developmental projects [5].

Major agricultural expansion, industry and civil activities are planned in the Western Desert [6,7], which covers 66.7% of the total area of Egypt having seven depressions; Siwa, Qattara, Fayum, Bahariya, Farafra, Dakhla, and Kharga, where the freshwater exist in the Oasis [8]. The Nubian Sandstone Aquifer (NSSA), the major ground water aquifer in Egypt, is in this desert [9]. Dakhla Oasis is situated in the heart of the Western Desert. It has high fertile lands and is the main Oasis which supports high population [10]. This is due to the large amount of groundwater presented in this locality, where the thickness of the NSSA ranges between 600 and 900 m. Therefore, this area should take a priority in the sustainable development project of southern Egypt [11]. The two main parameters should be under detailed study are soil suitability and water availability for crops [7]. Unless there are reliable information concerning land and water resources, agricultural expansion will not be positive [12].

Land suitability assessment plays an important role in planning and managing sustainable land use [13]. It provides useful information and helps in optimizing agricultural land use [14]. This is due to its impacts on appropriate land use and reasonable urban layout[15]. Remote sensing (RS) provides a cost-effective and quick technique to collect accurate data. Geographic Information System (GIS) can manipulate, analyze, and display the data, giving better results for RS image classification. Thus, a combined use becomes more realistic [16]. They are applied to an area for developing a strategy optimally fitting the local resources and potential productivity [17]. One of the most beneficial applications of GIS in planning land recourses is preparing land use maps [18]. Hence, the current work aimed at integrating RS and GIS for mapping agricultural land suitability for some soils located in the West of Dakhla Oasis, Western Desert, Egypt. Crop water requirements for each of the selected crops were also considered for sustainable land used planning.

2. MATERIALS AND METHODS

2.1 The Area of Study

The studied area covers 555.27 km^2 between longitudes 28°25'13.284" to 28°39'48.753"E and latitude 25°43'49.983" to 25°56'14.844"N (Fig. 1). Brookes [19] stated that the area is underlain by a sequence of sedimentary rocks of Cenomanian to Palaeocene eras. Dakhla shales and Quseir formation (variegated shale, mudstone, siltstone and flaggy sandstone) is forming most of the lithological units, while a small part in the area is developed on Duwi formation (mudstones, silicified limestones, and phosphorites). According to Egyptian Meteorological Authority EMA [20], the area receives very low annual rainfall of 0.5 mm. The mean annual temperature is 23.6°C and the maximum value reaches 40.3°C during July, while the minimum one decreases to 5.5°C during January. According to Soil Survey Staff [21], the soil temperature regime is Hyperthermic and the soil moisture regime is Torric.

2.2 Digital Image Processing

Processing of a Landsat-8 operational land imager (OLI) satellite image (path 177, row 42) with a spatial resolution of 30 m dated to 27-03-2016, was executed using ENVI 5.1 Software [22]. Data were calibrated to radiance depending on image type, acquisition date, and time. The image was stretched using linear 2%, smoothly filtered, and their histograms were matched according to Lillesand et al. [23]. The image was atmospherically corrected using FLAASH module. Fusion methodology [24] was applied to produce an image covering the area of study.

2.3 Map Creation

A digital elevation model (DEM) of 30 m pixel size resolution, acquired from the Shuttle Radar Topographic Mission (SRTM) images on 27-03-2016, was the source for elevation heights of the study area (Fig. 2). The DEM was presented in 3D mode and was then overlaid by the OLI image to generate a 3D image [25], which was consequently used along with the ground truth

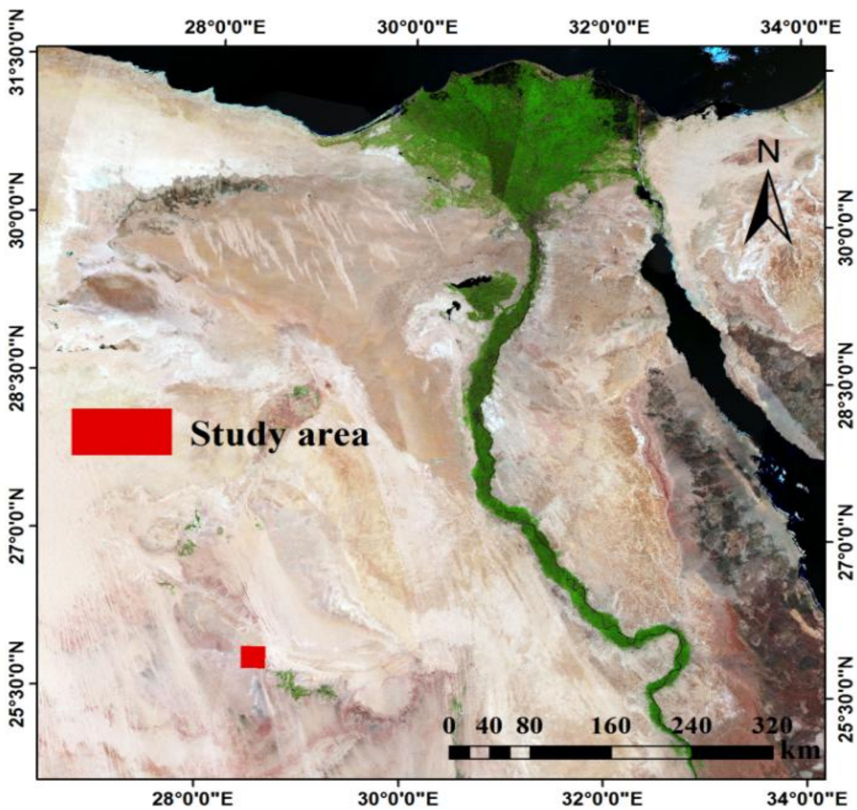

Fig. 1. Location map of the studied area

data to extract the different landforms of the area. The geomorphic units were described according to Zinck and Valenzuela [26]. The units were imported into a Geo-database as a base map to generate and display various maps using ArcGIS 10.2.2 software [27].

2.4 Field Work and Laboratory Analysis

Field and ground studies were done to identify the reality of digital image interpretation, obtain more details of the soil patterns, landforms and characteristic of the landscape. Thirty-one soil profiles were georeferenced using GPS and then dug (Fig. 3). The profiles were described according to the FAO guidelines [28]. Soil samples (151 sample) were collected from the profiles for laboratory analyses using the standard methods as outlined by Soil Survey Staff [29]. Soils were classified as per Keys to soil taxonomy [21]. Irrigation water samples were collected from eleven drilled water wells and subsequently analyzed. The depth of the drilled wells ranged in depth from 436 m to 1.08 km below the soil surface. Water quality for agriculture was evaluated according to the FAO guidelines for interpretations for irrigation [30].

2.5 Land Suitability Evaluation

The Microcomputer Land Evaluation Information System (MicroLEIS) [31] with an Almagra model (Agricultural Soil Suitability) was used for land suitability appraisal. This automatized application of soil suitability method was used to evaluate agricultural crop suitability through matching land and soil characteristics with growth requirements for the selected crops (Fig. 4). In the current study, twelve traditional Mediterranean crops; wheat, maize, watermelon, potato, soybean, cotton, sunflower, sugar beet, alfalfa, peach, citrus, and olive were selected to be evaluated. The criteria used for evaluating land suitability were useful depth (cm), stoniness (%), texture, drainage, carbonate content (%), salinity (dS m^{-1}), sodium saturation (%) and soil profile development (Fig. 5). Weighted average value for each soil property was calculated by multiplying the parameter value of each horizon by horizon thickness and divided by the total profile depth. The weighted values were the input values for Almagra model in order to run suitability evaluation for the selected crops. Land suitability classes were calculated following a semi-quantitative procedure and the results were shown by the computer. The definitions of suitability classes, soil factors and the intensity of limitations are shown in Table 1.

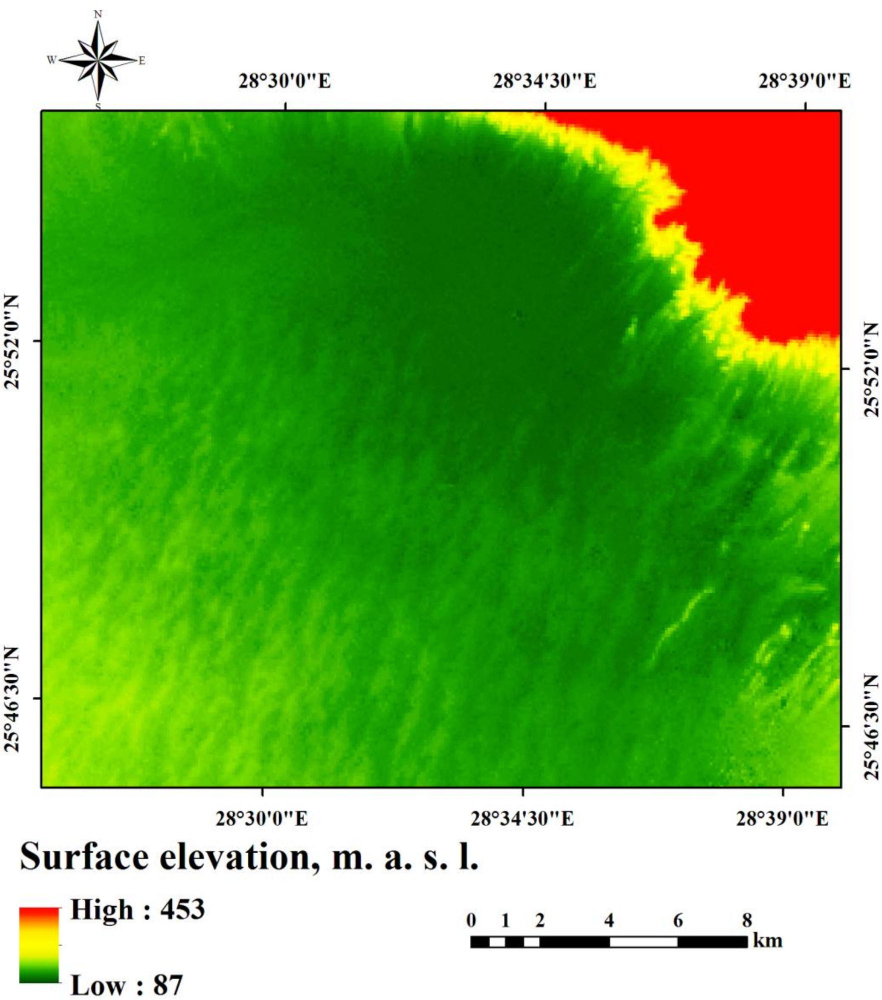

Fig. 2. Digital elevation model (DEM) of the studied area

Table 1. The suitability classes, limitations and soil factors used in Almagra model

Suitability classes		Limitation		Soil factor	
Symbol	**Definition**	**Symbol**	**Definition**	**Symbol**	**Definition**
S1	Optimum suitable	1	None	p	Useful depth
S2	High suitable	2	Slight	t	Texture
S3	Moderate suitable	3	Moderate	d	Drainage
S4	Marginally suitable	4	Severe	c	Carbonate
S5	Not suitable	5	Very severe	s	Salinity
				a	Sodium saturation
				g	Profile development

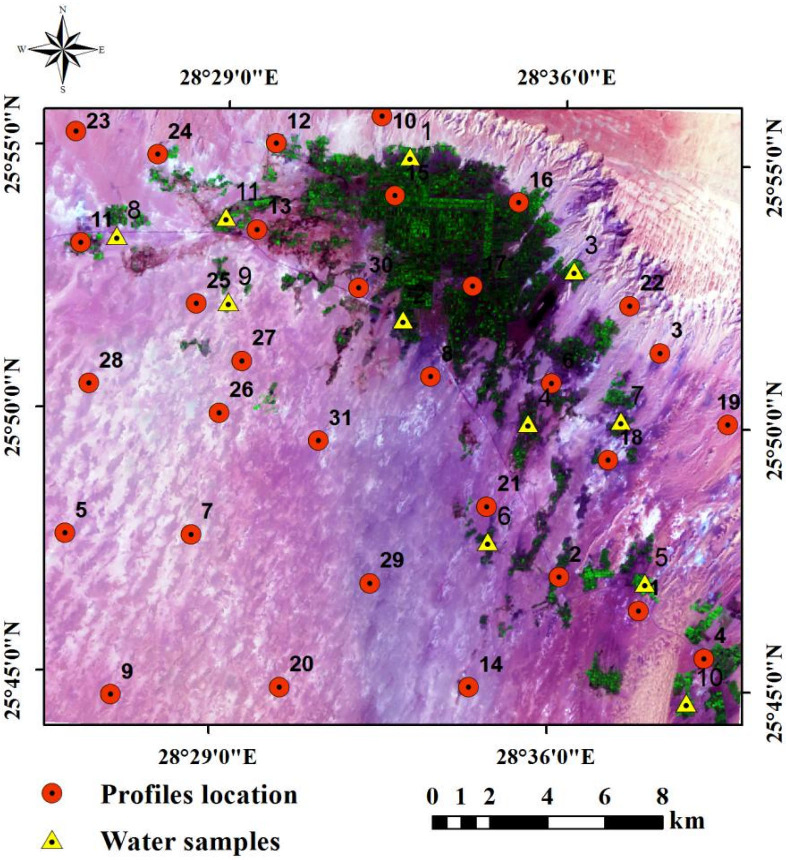

Fig. 3. Soil profiles and water samples in the studied area

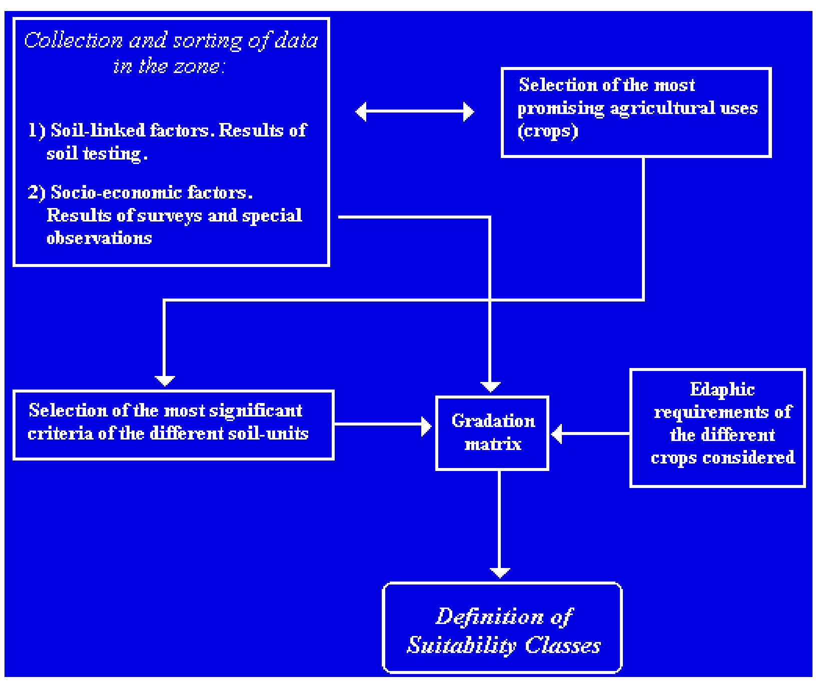

Fig. 4. Diagram showing the methodology followed in Almagra model

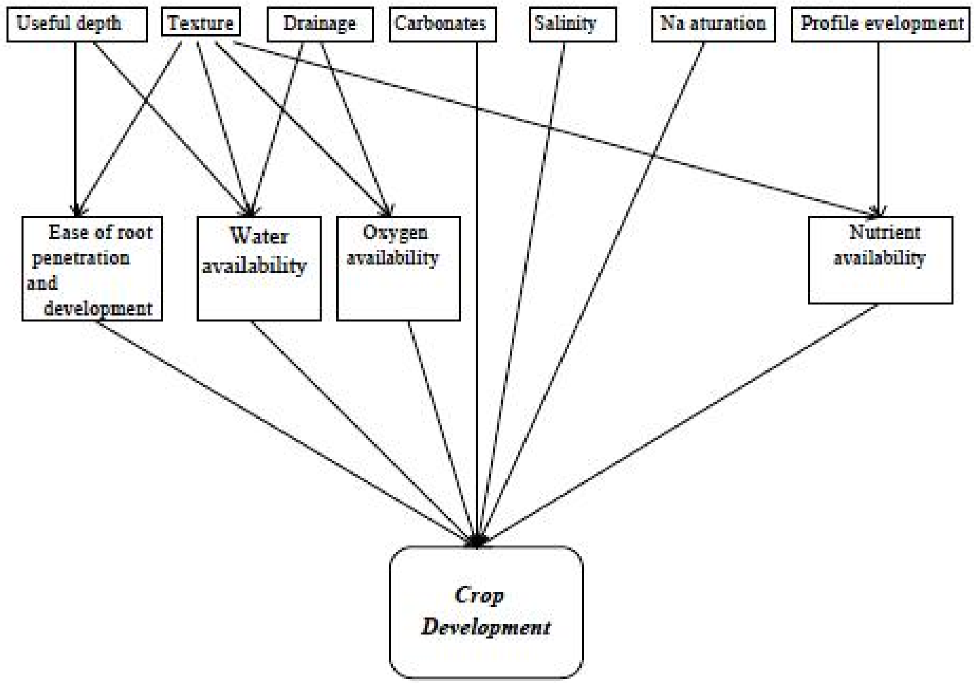

Fig. 5. Direct and indirect effects of the selected soil characteristics on crop production

2.6 Crop Water Requirements

Crop water requirements are commonly estimated with the FAO-56 methodology. This procedure based upon a two-step: first a reference evapotranspiration (ETo) is calculated from COPWAT 8.0 software using weather variables with the Penman-Monteith equation, then the ETo is multiplied by a tabulated crop-specific coefficient (Kc) adapted from Allen *et al.* [32] to determine the water requirement (ETc) of a given crop under standard conditions [33].

3. RESULTS AND DISCUSSION

3.1 Geomorphology of the Studied Area

The landforms and physiographic soil map legend are presented in Fig. 6 and Table 2. The main landscapes in the area are plateau, pediplain, depression, and Aeolian plain. The plateau covers 46.45 km^2 in the northeastern zone and represents 8.37% of the total area. It includes the landforms of summit (33.13 km^2) and escarpment (13.32 km^2). The pediplain occupies the smallest part, which represents 2.87 % of the total area, covering 15.91 km^2. The depression covers the greatest part, 60.80% of the total area, and occupies 337.62 km^2 in the middle part of the area. The included landforms within this landscape are depression edge (130.21 km^2) and depression floor (207.41 km^2). The Aeolian plain covers 155.29 $km^2$and represents 27.97% of the total area. The landforms in this landscape are sand sheets (low and moderate), covering 119.28 and 36.01 km^2, respectively.

3.2 Soils of the Study Area

3.2.1 Soils of the pediplain

As shown in Table 3, the soils are gently sloping (2.72-2.76%) and moderately deep to deep (70-110 cm). Soil texture is gravelly and very gravelly sandy loam. According to Soil Survey Staff [34], the soils are slightly to moderately alkaline and slightly to strongly saline since pH ranged from 7.61 to 7.88, while EC ranged from 7.22 to 23.90 dS m^{-1}. Soil organic matter varied from 0.92 to 1.25 g kg^{-1}. Calcium carbonate and gypsum varied from 154.10 to 548.20 g kg^{-1} for the former and from 52.32 to 61.46 g kg^{-1} for the latter. CEC ranged from 7.80 to 11.60 cmolc kg^{-1} soil. ESP varied from 2.21 to 8.92, indicating none-sodic soils. The main soil subgroup is Typic Torriorthents.

Table 2. Physiographic legend and soils of the studied area

Landscape	Relief	Lithology/origin	Landform	Area, km^2	Area, %	Main soil	Kind of mapping unit
Plateau	Almost flat	Limestone	Summit	33.13	5.97	Rocky area	----
	Rolling		Escarpment	13.32	2.40		
Pediplain	Flat to almost flat	Limestone, siltstone, sandstone	Pediplain	15.91	2.87	Typic Torriorthents	Consociation
Depression	Gently undulating	Shale, clay stone, limestone, siltstone, sandstone	Depression edge	130.21	23.45	Typic Torriorthents Typic Haplocalcids Typic Haplosalids	Complex
	Almost flat		Depression floor	207.41	37.35	Typic Torriorthents Vertic Torriorthents	Association
Aeolian plain	Gently undulating	Sandstone, limestone	Low sand sheet Moderate sand sheet	119.28 36.01	21.48 6.49	Typic Torripsamments	Consociation

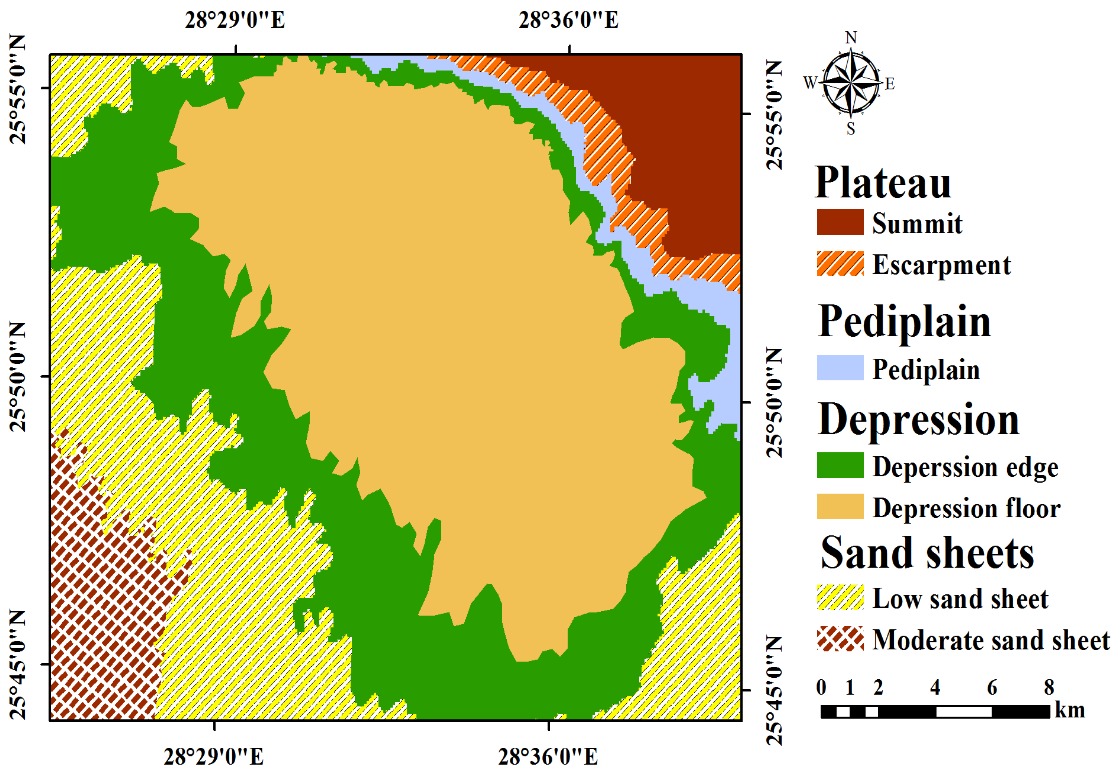

Fig. 6. Landforms of the studied area

Table 3. Main soil properties of the studied area

Soil properties	Pediplain	Depression	Sand sheet
Slope, %	2.72 - 2.76	0.31 - 1.89	1.21 - 8.56
Gravel, %	15.11 – 44.89	0.13 – 3.96	0.56 – 11.45
Soil depth, cm	70 - 110	95 - 150	90 - 130
Soil texture	GSL - VGSL	SL - C	S - SGLS
pH	7.61 - 7.88	7.18 - 7.82	7.46 - 8.03
EC, dS m^{-1}	7.22 - 23.90	5.11 - 40.52	5.67 - 23.53
OM, g kg^{-1}	0.92 - 1.25	0.59 - 10.75	0.74 - 4.92
$CaCO_3$, g kg^{-1}	154.10 - 548.20	56.10 - 449.29	106.10 - 604.20
Gypsum, g kg^{-1}	52.32 - 61.46	8.15 - 81.22	21.33 - 36.52
CEC, cmolc kg^{-1}	7.80 - 11.60	12.30 - 54.10	7.60 - 29.20
ESP	2.21 - 8.92	2.51 - 32.33	4.10 - 30.41

VG, very gravelly; G, gravelly; SG; slightly gravelly; SL, sandy loam; C, clay; S, sand; LS, loamy sand

3.2.2 Soils of the depression

The soils are flat to very gently sloping and moderately deep to very deep. Slope values ranged from 0.31 to 1.89% with a soil depth of 95 to 150 cm. Soil texture varied from sandy loam to clay. Soil pH varied from 7.18 to 7.82, indicating that the soils are neutral to slightly alkaline. Soil salinity varied from slightly saline to strongly saline with EC of 5.11 to 40.52 dS m^{-1}. As a result of the absence of natural vegetation and aridity, soil organic matter was low with values of 0.59 to 10.75 g kg^{-1}. Calcium carbonate and gypsum contents varied from 56.10 to 1.12 g kg^{-1} and from 8.15 to 81.22 g kg^{-1}, respectively. Cation exchange capacity (CEC) varied from 12.30 to 54.10 cmolc kg^{-1} soil, while exchangeable sodium percentage (ESP) varied from 2.51 to 32.33. The main soil subgroups are Typic Torriorthents, Vertic Torriorthents, Typic Haplosalids and Typic Haplocalcids.

3.2.3 Soil of the sand sheet

The slope ranged from 1.21 to 8.56%, which means that the soils are very gently sloping to sloping. The soils are moderately deep to very deep since soil depth ranged from 90 to 190 cm. The soils are sandy to slightly gravelly loamy sand. Values of pH and EC ranged from 7.46 to 8.03 and from 5.67 to 23.53 dS m^{-1}, respectively. Thus, the soils are slightly to moderately alkaline and slightly to strongly saline with organic matter of 0.74 to 4.92 g kg^{-1}. Calcium carbonate and gypsum ranged from106.10 to 604.20g kg^{-1} for the former and from 21.33 to 36.52 g kg^{-1} for the latter. CEC varied from 7.60 to 29.20 cmolc kg^{-1} soil and ESP varied from 4.10 to 30.41. The main soil subgroup is Typic Torripsamments.

3.3 Water Quality for Irrigation

The chemical composition of irrigation water is shown in Table 4. Results show that pH values ranged from 6.85 to 7.82, indicating a normal range for irrigation (6.5 – 8.4).Salinity shows low values in all wells with EC ranging from 0.21 to 0.31 dS m^{-1}. Values of SAR varied from 0.58 to 1.12, with negative RSC values. The results indicate that water quality is good for irrigating. Such high water quality enables crop cultivation under salinity and sodicity stress.

3.4. Crop Water Requirements

The crop water requirements for the selected crops are presented in Table 5. Values of the ETo from January to December were 3.1, 3.9, 5.3, 6.8, 8.4, 8.7, 8.8, 8.3, 7.3, 5.7, 3.8 and 2.9 mm day^{-1}. The calculated ETc values for the selected crops were as follows: maize = 816.33 mm, sunflower = 795.98 mm, soy bean = 1003.83 mm, wheat = 550.78 mm, sugar beet = 865.13 mm, cotton = 1150.83 mm, watermelon = 797.87 mm, alfalfa = 2113.47 mm, potato = 397.37 mm, peach = 1577.86, citrus = 1503.92 mm and olive = 1163.96 mm.

3.5 Land Suitability for Selected Crops

The agricultural suitability performed by applying MicroLEIS-Almagra model for different mapping units is presented in Fig. 7 and Table 6. Calculations were done using modal profile representing the dominant main soil in each mapping unit. Soils of depression and sand sheets are high suitable (S2), moderately suitable (S3) and marginally suitable (S4) for all selected crops, except watermelon, peach, citrus, and olive, as the soils are moderately suitable (S3), marginally suitable (S4) and not suitable (S5), respectively. On the other hand, soils of the pediplain have severe limitations, and thus they are not suitable (S5) for all the selected crops. The most recommended crop in the area is sugar beet, as 66.35% of the soils are suitable (S2).

Table 4. Chemical composition of irrigation water samples

Sample	pH	EC, dS m^{-1}	TDS, mg L^{-1}	SAR	RSC
1	7.61	0.21	122.00	0.58	-0.66
2	7.82	0.30	177.00	0.97	-0.74
3	6.95	0.29	179.00	0.95	-0.81
4	6.91	0.26	153.00	0.86	-0.62
5	6.93	0.25	147.00	1.12	-0.58
6	6.85	0.24	142.00	0.75	-0.64
7	7.73	0.21	124.00	0.66	-0.51
8	7.61	0.29	175.00	1.12	-0.76
9	7.31	0.25	150.00	0.95	-0.62
10	7.52	0.26	155.00	0.96	-0.95
11	7.11	0.31	188.00	1.03	-0.75

EC, electrical conductivity; TDS, total dissolved solids; SAR, sodium adsorption ratio; RSC, residual sodium carbonate

Table 5. Crop water requirements (mm season^{-1}) for the proposed crops in the studied area

Month	ETo, mm day^{-1}	Maize		Sunflower		Soya bean		Wheat	
		Kc	ETc, mm month^{-1}	Kc	ETc, mm month^{-1}	Kc	ETc, mm month^{-1}	Kc	ETc, mm month^{-1}
Jan	3.10							0.93	89.37
Feb	3.90							1.15	125.58
March	5.30							1.15	188.95
April	6.80					0.50	102.00	0.72	146.88
May	8.40	0.30	78.12	0.35	91.14	0.86	223.94		
June	8.70	0.89	232.29	0.91	237.51	1.00	261.00		
July	8.80	1.10	300.08	1.10	300.08	1.00	272.80		
August	8.30	0.80	205.84	0.65	167.25	0.56	144.09		
September	7.30								
October	5.70								
November	3.80								
December	2.90								
Total ETc, mm season^{-1}			**816.33**		**795.98**		**1003.83**		**550.78**
Month	**ETo, mm day^{-1}**	**Sugar beet**		**Cotton**		**Watermelon**		**Alfalfa**	
		Kc	**ETc, mm month^{-1}**	**Kc**	**ETc, mm month^{-1}**	**Kc**	**ETc, mm month^{-1}**	**Kc**	**ETc, mm month^{-1}**
Jan	3.10	1.05	100.91					0.95	91.30
Feb	3.90	1.20	131.04					0.95	103.74
March	5.30	1.20	197.16	0.35	57.51			0.95	156.09
April	6.80	1.18	240.72	0.40	81.60	0.55	112.20	0.95	193.80
May	8.40	0.75	195.30	0.83	216.13	0.78	203.11	0.95	247.38
June	8.70			1.10	287.10	0.95	247.95	0.95	247.95
July	8.80			1.10	300.08	0.86	234.61	0.95	259.16
August	8.30			0.81	208.41			0.95	244.44
September	7.30							0.95	208.05
October	5.70							0.95	167.87
November	3.80							0.95	108.30
December	2.90							0.95	85.41
Total ETc, mm season^{-1}			**865.13**		**1150.83**		**797.87**		**2113.47**

Month	**ETo, mm day^{-1}**	**Potato**		**Peach**		**Citrus**		**Olive**	
		Kc	**ETc, mm month^{-1}**	**Kc**	**ETc, mm month^{-1}**	**Kc**	**ETc, mm month^{-1}**	**Kc**	**ETc, mm month^{-1}**
Jan	3.10	0.97	93.22			0.75	72.08	0.50	48.05
Feb	3.90					0.75	81.90	0.50	54.60
March	5.30			0.55	90.37	0.73	119.94	0.65	106.80
April	6.80			0.68	138.72	0.70	142.80	0.61	124.44
May	8.40			0.83	216.13	0.67	174.47	0.55	143.22
June	8.70			0.90	234.90	0.65	169.65	0.48	125.28
July	8.80			0.90	245.52	0.65	177.32	0.45	122.76
August	8.30			0.90	231.57	0.65	167.25	0.45	115.79
September	7.30			0.90	197.10	0.65	142.35	0.49	107.31
October	5.70	0.60	106.02	0.82	144.89	0.66	116.62	0.56	98.95
November	3.80	0.91	103.74	0.69	78.66	0.68	77.52	0.63	71.82
December	2.90	1.05	94.40			0.69	62.03	0.50	44.95
Total ETc, mm season^{-1}			**397.37**		**1577.86**		**1503.92**		**1163.96**

ETo, referenced crop evapotranspiration; ETc, water requirements

The limiting factors are salinity, followed by lime content, sodium saturation, and soil depth. Salinity and alkalinity are difficult to be reclaimed due to salt enriched parent material such as shale/limestone [35,36]. Also, high evaporation rate results in salt accumulation at the soil surface [37]. Finally, the impermeable layers under the shallow soil profiles prevent water

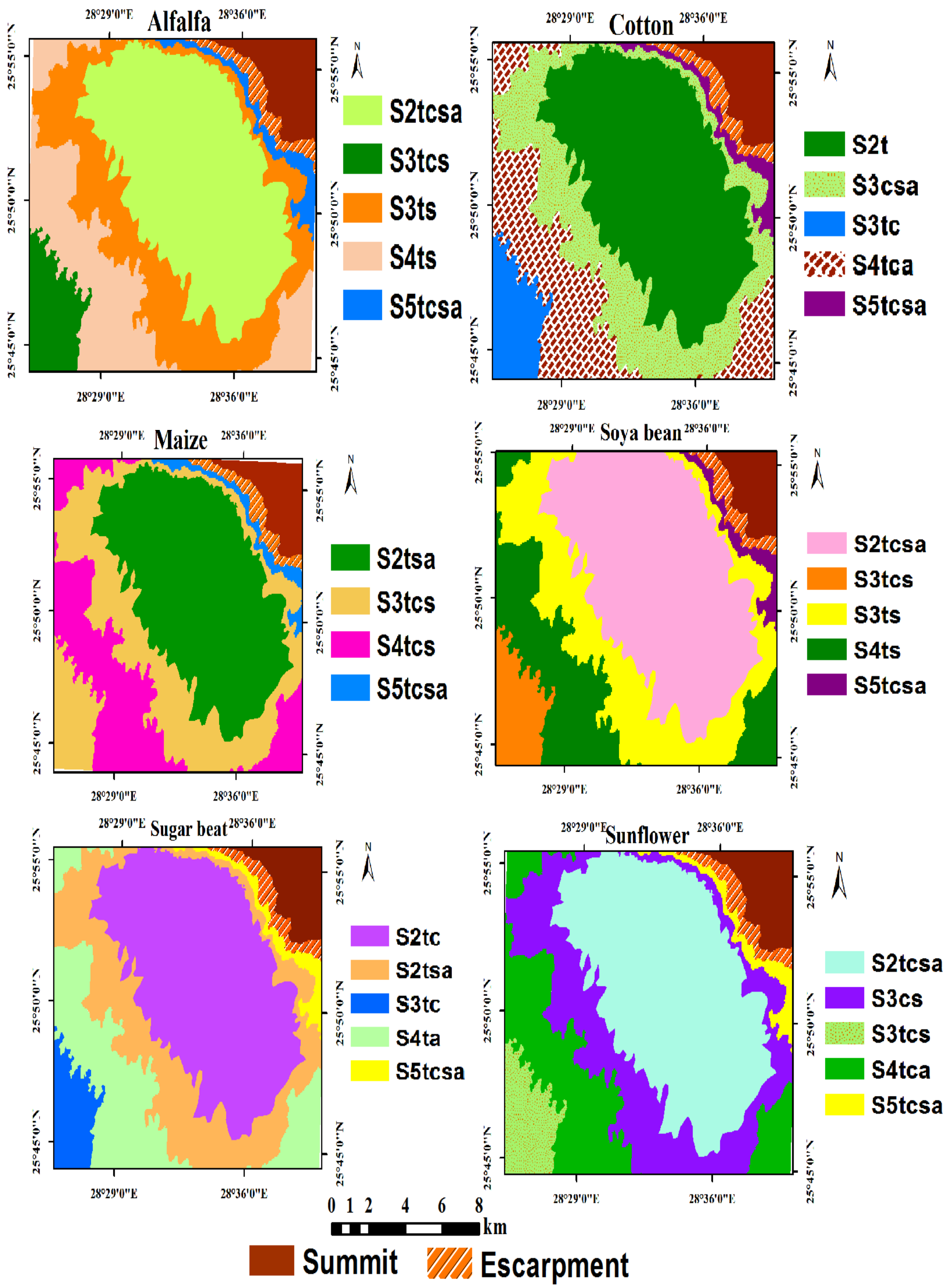

Fig. 7. Land suitability for the selected crops in the study area

(S2, high suitable; S3, moderate suitable; S4, marginal suitable; S5, unsuitable; Letters follow the Arabic number are the limiting factors; depth (p), texture (t), carbonate (c), salinity (s) and sodium saturation (a)

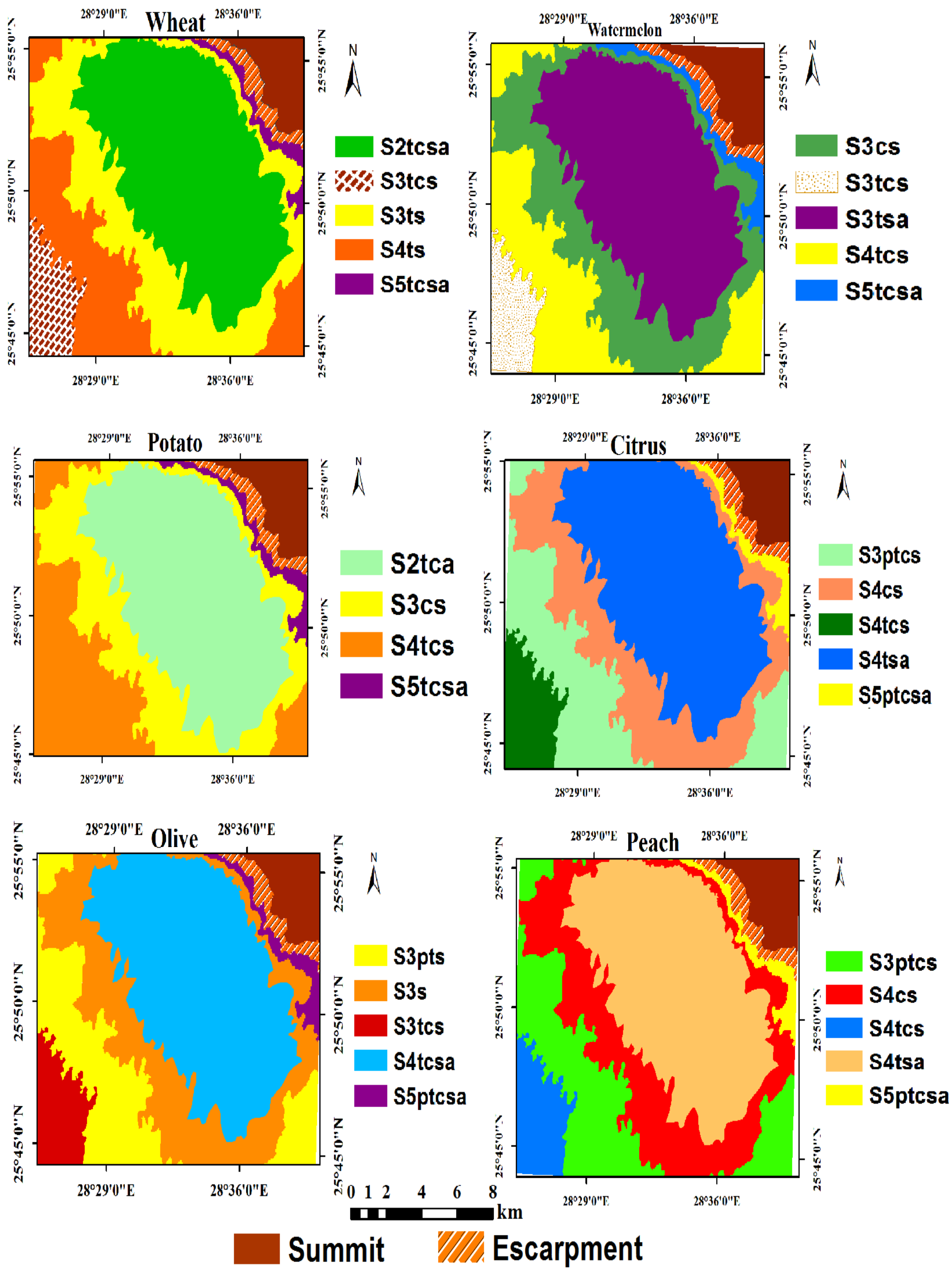
Wheat
S2tcsa
S3tcs
S3ts
S4ts
S5tcsa
Watermelon
S3cs
S3tcs
S3tsa
S4tcs
S5tcsa
Potato
S2tca
S3cs
S4tcs
S5tcsa
Citrus
S3ptcs
S4cs
S4tcs
S4tsa
S5ptcsa
Olive
S3pts
S3s
S3tcs
S4tcsa
S5ptcsa
Peach
S3ptcs
S4cs
S4tcs
S4tsa
S5ptcsa
28°29'0"E
28°36'0"E
25°55'0"N
25°50'0"N
25°45'0"N
N
0 1 2 4 6 8
km
Summit
Escarpment

Fig. 7. Cont.

Table 6. Relative extent of land suitability in the studied area

Crop	S2		S3		S4		S5	
	Area, km^2	Area, %	Area, km^2	Area, %	Area, km^2	Area, %	Area, km^2	Area, %
Wheat	207.41	40.76	166.22	32.67	119.28	23.44	15.91	3.13
Maize	207.41	40.76	166.22	32.67	119.28	23.44	15.91	3.13
Watermelon	--	--	373.63	73.43	119.28	23.44	15.91	3.13
Potato	207.41	40.76	130.21	25.59	155.29	30.52	15.91	3.13
Soya bean	207.41	40.76	166.22	32.67	119.28	23.44	15.91	3.13
Cotton	207.41	40.76	166.22	32.67	119.28	23.44	15.91	3.13
Sunflower	207.41	40.76	166.22	32.67	119.28	23.44	15.91	3.13
Sugar beet	337.62	66.35	36.01	7.08	119.28	23.44	15.91	3.13
Alfalfa	207.41	40.76	166.22	32.67	119.28	23.44	15.91	3.13
Peach	--	--	119.28	23.44	373.63	73.43	15.91	3.13
Citrus	--	--	119.28	23.44	373.63	73.43	15.91	3.13
Olive	--	--	285.50	56.11	207.41	40.76	15.91	3.13

S2, highly suitable; S3, moderately suitable; S4, marginally suitable; S5, not-suitable

percolation and lead to high water table levels [38]. Soil depth and lime content are permanent limiting factors which could not be improved. Soil depth is very apparent limiting factor in the pediplain unit. The importance of soil depth goes beyond the ease of root penetration and development [39]. Lime affects soil water relations and the availability of plant nutrients [40].

4. CONCLUSION

Assessment of land suitability for different crops helps in planning sustainable agriculture programs. An approach integrating remote sensing, GIS and the Micro LIES software (Almagra model) was undertaken in this study to assess the land performance of 555.27 km^2 (55527 ha) west of Dakhla oasis. About 97% of the studied soils are suitable for all the selected crops, while the remaining area (about 3%) is unsuitable. The most predominant limiting factors are salinity, lime content, sodicity and soil depth. The area is characterized by high water quality, giving it a priority in agricultural expansion projects.

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COMPETING INTERESTS

Authors have declared that no competing interests exist.

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