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Remote Sensing and Geographic Information System for Optimizing Land Use Base on Fertility Capability Classification

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Author's contribution

The sole author designed, analyzed and interpreted and prepared the manuscript.

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ABSTRACT

Soil is one of the most precious national resources and the knowledge of soil resources of an area is vital for optimizing land use and any developmental activities. Remote sensing and GIS have emerged as extremely valuable tools to study the soil resources, their potential for various use and problems. Hence an attempt has been made to study the soils of some soils of the Eastern Desert Part of Sohag Governorate and map them based on the fertility capability classification (FCC) using remote sensing and GIS. False color composite (FCC) of Landsat ETM imageries were visually interpreted incorporated with Digital Elevation Model (DEM) which generated from the Shuttle Radar Topographic Mission (SRTM). Different imaging interpretation units were identified and soil pedons were examined in each unit. Horizon wise soil samples were collected and analyzed for physiochemical properties by adopting standard procedures. Based on the results, the major landforms of the studied area were described as Wadi Bottom (WB), Bajada (B), Alluvial Fans (AF), Tableland (T), Gently Undulating Sand Sheet (GUS) and Undulating Sand Sheet (US). The type, substrata type and condition modifiers were also identified for each landform. The main condition modifiers of the study area were texture (S), low CEC (e), K deficiency (k), calcareous (b), salinity (s), dry condition (d), gravels (r) and low organic matter (m). Relevant FCC units were assigned to various landforms based on the type, substrata type and condition modifiers. A utility map was prepared using GIS with the FCC units, their limitations and extent distribution. Generally, the

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fertility of these soils was poor on account of low organic matter, total nitrogen, available phosphorus, potassium and micronutrients. Also, the water retentively was not satisfactory by the virtue of poor organic matter and higher percentage of coarser fraction. Based on the fertility constrains various soil management practices have been suggested to optimize the land use.

Keywords: Remote sensing; GIS; land used; fertility capability classification; landforms.

ABBREVIATIONS

GIS	*: Geographic Information System*
FCC	*: False Color Composite*
DEM	*: Digital Elevation Model*
SRTM	*: Shuttle Radar Topographic Mission*
WB	*: Wadi Bottom*
AF	*: Alluvial Fans*
GUS	*: Gently Undulating Sand*
US	*: Undulating Sand*
FCC units	*: Fertility Capability Classification units*
USDA	*: United States Department of Agriculture*

1. INTRODUCTION

Soils are one of the most precious natural resources and the basic soil resource information is a prerequisite for planning sustainable agriculture and for optimizing land use and developmental activities. Natural soil classification systems such as Soil Taxonomy place more emphasis on subsurface than on topsoil properties, because of their permanent nature, whereas most soil managements practices are largely limited to the plowed layer. To bridge the gap between soil classification and soil fertility, fertility capability classification (FCC) system has been used. The need for Fertility Capability Classification (FCC) therefore arose out of identified technical problems of soil fertility maintenance in our fragile soils and the need for appropriate technology to improve fertility management of soils. FCC is a technological tool for agricultural land management that shows graphically the different fertility limitation sites in an area and the kinds of fertility management problems faced by users of the land. The FCC focuses attention on surface soil properties most directly related to management of field crops and is best used as an interpretative classification in conjunction with a more inclusive natural soil classification. The FCC, or some modification thereof, can serve as the basic for grouping soils for specific soil management evaluations and land use planning. Remote sensing and GIS have emerged as an extremely valuable tool to study the soil resources, their potential for various land use and problems. [1] classified some soils of Akwa Ibom State in South Eastern Nigeria and they found that gleying (g), low potassium reserve (k) and acidic reaction (h) were the general constraints of these soils. Also, some other inland depression soils had sandy (S) top soils while Bku had loamy top (L) soils but the three sub soils were loamy (L). All the floodplain soils had sandy (S) soils at both top and subsoils. For effective management of these soils, application of organic manure (including cattle manure) would supply the basic cations including K, as well as reduce soil acidity. In other study conducted in Sokoto-Rima flood plains at Sokoto Nigeria [2] identified three fertility capability classes dominate in the soils, namely Lgm (Loamy soils low in organic matter with gleying limitations) ; Lghm (Loamy soils, low in organic matter and with gleying and pH limitation) and Sgm (Sandy soils low in organic matter and with gleying limitations). The three classes were then resolved to form the three mapping units shown in the FCC map. Soil class Lghm has higher fertility/yield potential followed by the class Lgm then Sgm class. Periodic monitoring of soil quality, adding organic manure and applying ameliorative measures such as liming can improve and sustain productive capacity of the soils. [3] classified the lowland soils of Cameroon as Lagk, Cagk, Laegk, Cbgm, Caeg, Lbg, Lgk, Cgv, LCg and Cgv. In addition, they concluded that the main soil fertility limitations were Fe- and Al-toxicities (a), low nutrient capital reserves (k), high leaching potential (e), and micronutrient deficiencies. Hence, an attempt has been made to study the soils of the Eastern Desert Part of Sohag Governorate and map them based on fertility capability classification using remote sensing and GIS. This will be the key for applying the efficient soil management practices for sustainable agriculture production especially in newly reclaimed area.

2. MATERIALS AND METHODS

2.1 Study Area

The study area is a part of the Eastern Desert of Sohag, Egypt and located between geocoordinates 26° 25` to 26° 45`latitudes (N) and 32° 40`, 33° 00` longitudes (E) covering about121,316 feddan. It is situated between the Nile Valley in the West and the Red Sea mountains in the East. The location map of the studied area is shown in Fig. 1.

The area under study is characterized by hot dry sub-humid to semi-arid transition with intense hot summer, cold winter and general dryness throughout the year except during July and September. The maximum temperature goes up to 45℃ in the month of June. The lowest temperature goes down to 6.5° during January and February. The relative humidity (RH) ranges between 30% and 56% and the average about 43% in summer and 48% in winter. Prevailing winds are dominantly from the northwest to the southeast with an average maximum speed of 10 knots/h. The area receives mean annual rainfall ranging between 2.75 and 50 mm at the extreme Southeastern zone, while heavy showers are recorded occasionally during winter causing flash floods [4,5].

2.2 Methodology

2.2.1 Remote Sensing data and processing

In the present study the Landsat ETM+ satellite data of 2010 was used. The study area is covered by one image (172Path /42 Row). The false color composite of the study area is presented in Fig. 2. The digital data of geo-coded cloud free of three images was downloaded from http://glcf.umd.edu/data/landsat/[6]. Table 1 presents the principle specifications of the sensor used in the investigation. The Shuttle Radar Topographic Mission (SRTM) images of 30 pixel size resolution have been used to generate the DEM for the study area and its surrounding were consulted to represent the area landscape. The study area was extracted from the whole image (Fig. 2) of through on screen digitization of the area of interest (AOI) and masking out using subset module of ENVI software ver.4.8 (Research Systems Inc., Boulder, CO, USA).

Table 1. Satellite and sensor specifications

Bands		Spatial resolution (m)	Spectral resolution (µm)
1	Blue	30	0.414 – 0.514
2	Green	30	0.519 - 0.601
3	Red	30	0.631 – 0.692
4	NIR	30	0.772 – 0.898
5	SWIR-1	30	1.547 – 1.749
6	TIR	60	10.31 – 12.36
7	SWIR-2	30	2.064 – 2.345
8	Pan	15	0.515 – 0.896

2.2.2 Delineation of different landforms

The delineation of the landform units from the satellite data needs a high spatial resolution images; therefore the spatial resolution of the used Landsat ETM+ was enhanced through the data merge process. This process is commonly used to enhance the spatial resolution of multi-spectral datasets using higher spatial resolution panchromatic data or single band (band 8). In this study merged data were performed using multi-spectral bands (30 m) as a low spatial resolution with panchromatic band 8 of ETM+ satellite image as a high spatial resolution (15 m) resulting in multi-spectral data with high spatial resolution (15 m). The landforms map has been generated from the SRTM (30 m) and enhanced Landsat ETM+ images using the ENVI 4.8 software [7].

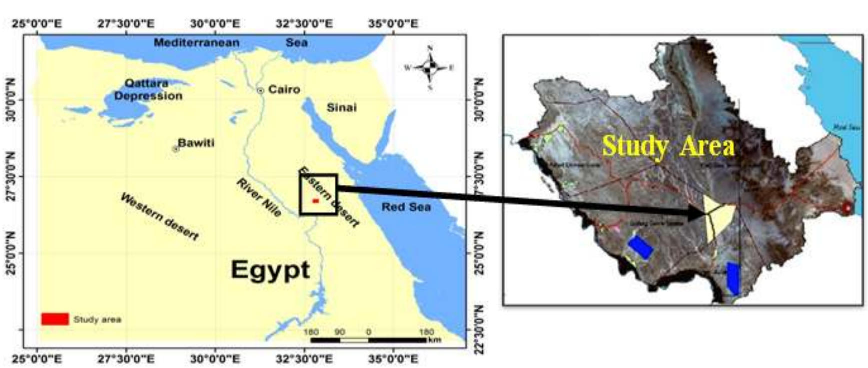

Fig. 1. Location map of the studied area

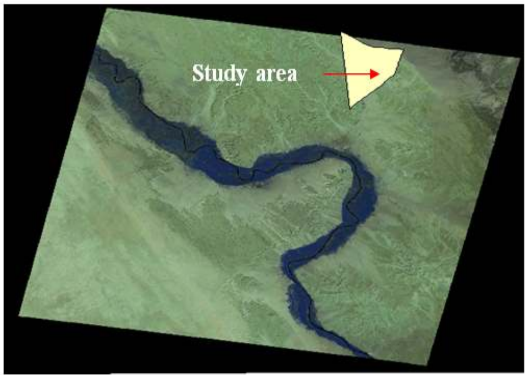

Fig. 2. False color composite of Landsat image of the studied area

By using the image elements such as texture, parcelling, pattern, shape, size, color, site and situation, many information about the terrain have been extracted from enhanced ETM+ image. Moreover, The SRTM data has been used in conjunction with enhanced ETM+ to provide a better visualization of the topographic features, namely surface elevation, slope, aspect, shaded relief and convexity. The topographic features have extracted using ENVI 4.8 software. Afterwards, the landform units were defined and classified and the map legend was established. DEM of the study area has been generated from the SRTM image using ArcGIS 9.3 software. The extracted data generates a preliminary geomorphologic map which was checked and completed through field observation.

2.2.3 Field work and samples collection

A rapid reconnaissance survey of the area under study was conducted in order to achieve more detailed information of the soil patterns, land forms and characteristic of the landscapeand landforms occurring in the study area.

Twelve soil profiles were selected representing various types of landforms occurring in the study area. The morphological examination of soil profiles was carried out in the field as per procedures laid out in the Soil Survey Manual [8]. Horizon wise disturbed soil samples (1 Kg) as well as core samples (diameter 2.5 cm and length 6 cm) were collected from each profile and kept separately in polyethylene bags for further analysis. Location coordinates were recorded with hand held GPS under WGS 84 (Lat-Lon) coordinate system (Fig. 3).

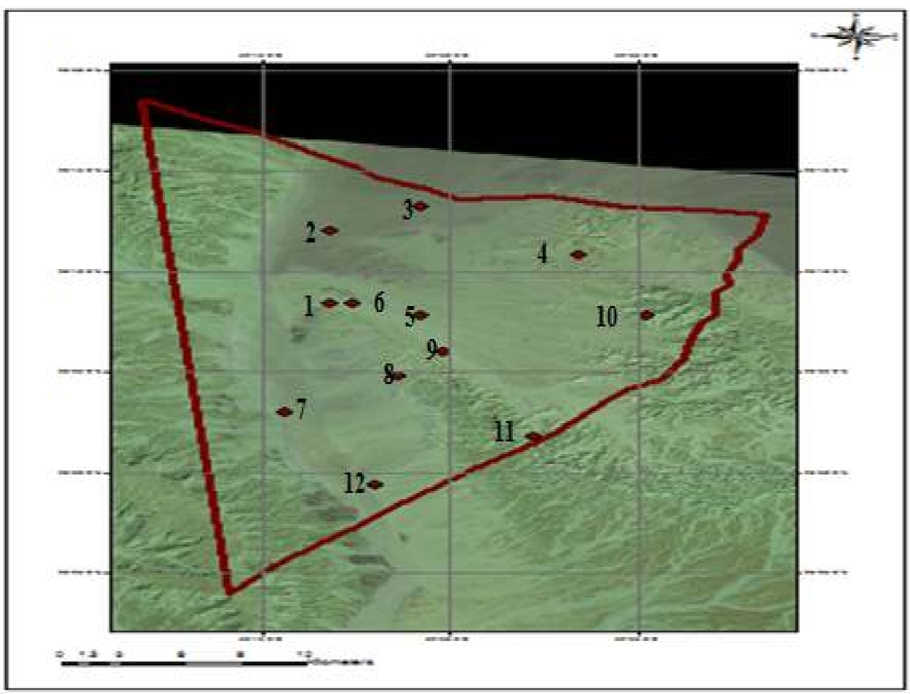

Fig. 3. Location of the representative soil profiles laid on studied area

2.2.4 Laboratory analysis and soil classification

The collected soil samples were subjected for the following analyses: Particle size distribution [9], calcium carbonate, electric conductivity (ECe) in the soil paste extract, soluble cations and anions, soil pH, organic matter content [10]; cation exchange capacity and exchangeable sodium [11].

The American Soil taxonomy [12] was followed to classify the different soils of the studied area up to the family level. Then the correlation between the physiographic and taxonomic units, were identified [13].

2.2.5 Fertility capability classification

Each landform were further classified under FCC system proposed by [14] and later modified by [15]. The FCC system consists of three categories viz., Type (topsoil texture or upper 20 cm depth), substrata type (subsoil texture between 20 and 50 cm depth) and condition modifiers (physical or chemical properties which influence the interaction between soil and fertilizer materials).

2.2.6 Generation of thematic maps

Inverse Distance Weighted (IDW) interpolation determines cell values using a linearly weighted combination of a set of sample points. The weight is a function of inverse distance. IDW lets the user control the significance of known points on the interpolated values, based on their distance from the output point. Thematic maps were generated using IDW interpolation provided in Arc GIS 9.3 software [16].

3. RESULTS AND DISCUSSION

3.1 Characterization of Map Units

The visual interpretation of the Landsat data and DEM integrated with Soil Taxonomy and soil field data using GIS have been used to generate the slope map and physiographic soil map (Fig. 5 and 6). The studied soils are classified according to USDA (2010) as TypicHaplocalcids, TypicTorripsamment and TypicTorriorthents (Table 2). The main soil characteristics of the mapping units are shown in Table 3.

The physiography of the studied area was identified based on the Landsat ETM+ images, the Digital Elevation Model (DEM) and slope map (Figs. 4 and 5). The obtained results revealed that, therewere six physiographic units in the area under studied (Fig. 6) viz. theWadi Bottom (WB), Bajada (B), Alluvial Fans (AF), Table land (T), Gently Undulating Sand Sheet (GUS) and Undulating Sand Sheet (US). The detailed characteristics of these physiographic units were discussed by [17].

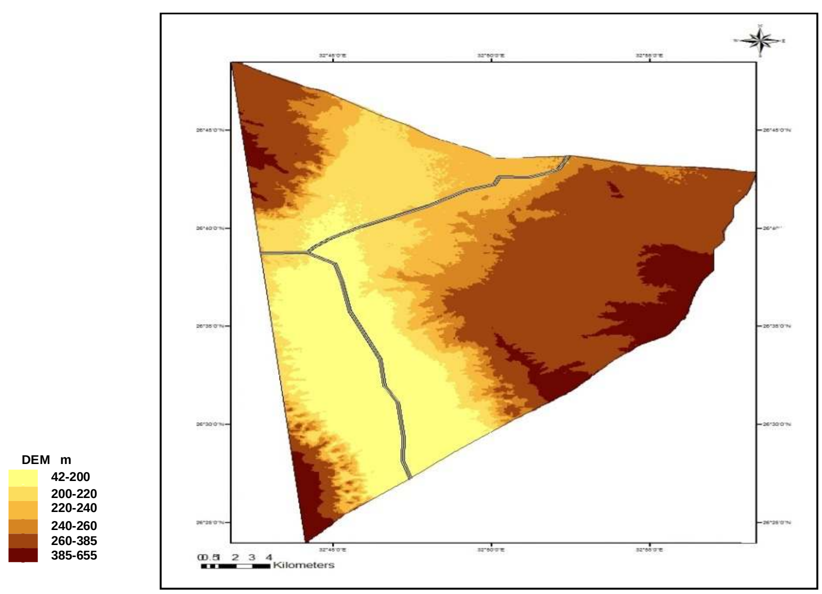

Fig. 4. DEM of the studied area

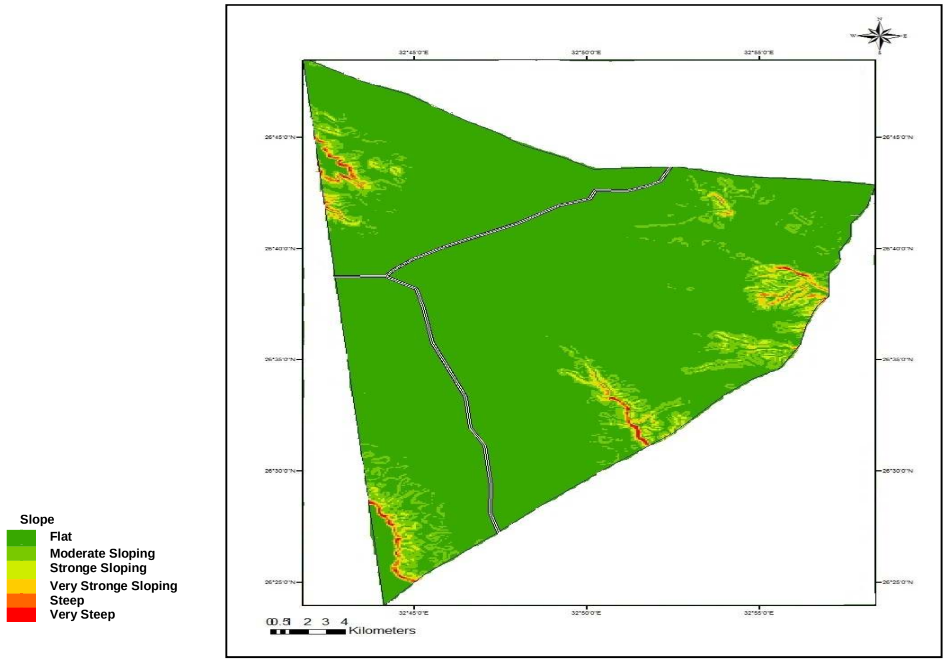

Fig. 5. Slope map of the studied area

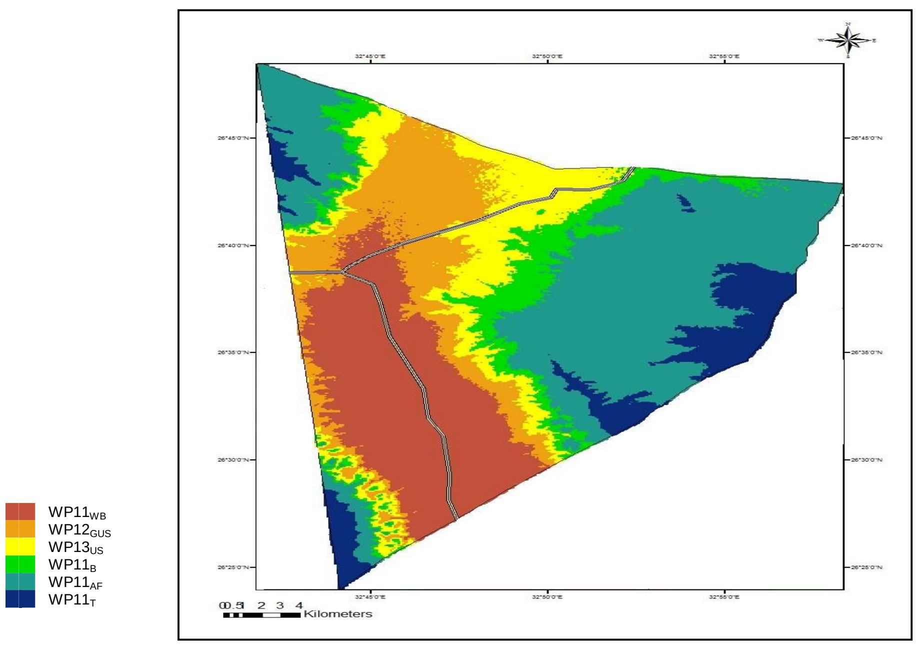

Fig. 6. Physiographic units map of the studied area

3.2 Fertility Capability Classification

Based on analytical results (Table 3), the FCC units were established. The type, substrata type and condition modifiers were also identified. The main condition modifiers of the study areawere texture (S), low CEC (e), K deficiency (k), calcareous (b), salinity (s), dry condition (d), gravels (r) and low organic matter (m). Relevant FCC units were assigned to various map units (Tables 4 & 5) and Fig. 7.

Table 2. Legend of the physiographic map of the studied area

Landscape	Lithology	Relief	Landform	Land use	Map unit symbol	Sub group	Area	
							Feddan (1000)	**%**
Wadi Plain (WP)	Eocene Deposits (1)	Almost Flat (1)	Wadi Bottom (WB)	Barren	$WP11_{WB}$	TypicHaplocalcids	26.426	21.78
			Alluvial Fans (AF)	Barren	$WP11_{AF}$	TypicTorriorthents	33.457	27.58
			Bajada (B)	Barren	$WP11_{B}$	TypicHaplocalcids	15.785	13.02
			Tableland (T)	Barren	$WP11_{T}$	TypicTorriorthents	16.648	13.72
		Gently Undulating (2)	Gently Undulating sand sheet (GUS)	Barren	$WP12_{GUS}$	TypicTorripsamments	16.500	13.60
		Undulating (3)	Undulating sand sheet (US)	Barren	$WP13_{US}$	TypicTorripsamments	12,500	10.30
Total							121.316	100

The results of FCC units of WP11WB, WP11AF, WP11B and some parts of WP12GUS and WP13US were classified as Sekbsdrm (1-2%) only an area of 3125 feddan of WP11B was classified as Sekbsdrm (2-4%). This implies that these map units have sandy (S) soils at both top and subsoils. The soils also have constraints of high leaching potential (e), low nutrients reserve (k), basic reaction (b) and salinity (s). As the soil exhibit ustic or xeric soil moisture regime, the Soil moisture stress constraint (d) has been recognized. The other modifiers are because of gravels content (r) and low organic matter (m). The soils of WP11T were classified as SekbsdrSRm (8-10%) and SekbsdrSRm (10-12%) which having the same condition modifiers but different slope grade. These soils are characterized by a high risk of soil erosion (SR) that erosion can negatively affect plant productivity and ecosystem functions. The FCC unit Sekbdrm (1-2%) has been found in some areas belongs to WP12GUS and WP13US.

3.3 Suggestive Plausible Soil Managements

Now, there is a raised question i.e. at what time scales are FCC attributes refer todays, months, years, decades or centuries? And hence the scientific management technologies can be applied for mitigating these constrains. Experience in using FCC indicates that some of the condition modifiers can be changed with management at different time scales. In the current study, the possibility of overriding constrains is presented in Table 6.

From the previous table, some of the soil constrains cannot be changed in less than century (inherent) such as type/substrata type, high leaching potential, low nutrient reverses, gravels and high erosion risk. Whereas, condition modifiers can change at the decadal scale (10–100 years) include calcareous reaction by sustained irrigation and subsequent leaching, salinity and sodicity by applying effective leaching and low level of organic matter which can be maintained under certain levels by supplying soil with different rates and sources of organic inputs. The soil water stress can be managed by applying the water through irrigation using the effective method of application such as trickle irrigation [18]. Some soil management considerations are mentioned hereunder:

3.3.1 Low organic matter (m) and low nutrient reserves (k)

Low organic matter content which is prevailing in all soil profiles can be improved through application of organic manure, green manuring, mulching, crop rotation and so on. Also base saturation can be improved by applying fertilizers and amendments. Use of nitrogen and phosphorus fertilizers to mitigate major nutrient deficiencies is a must.

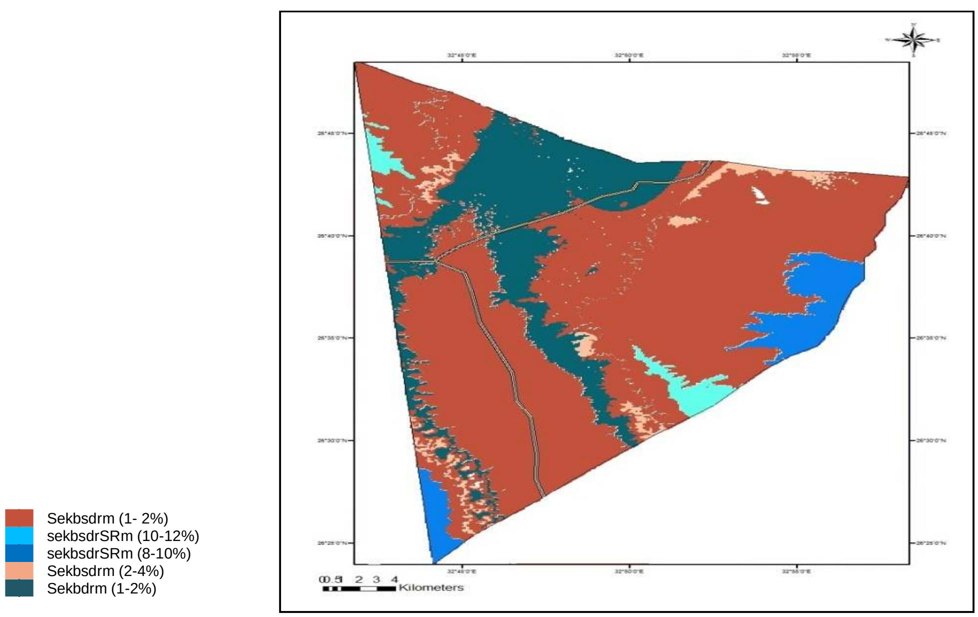

Fig. 7. Fertility capability classification (FCC) units of the studied area

Table 3. The main soil characteristics of the mapping units

	Unit	**$WP11_{WB}$**		**$WP11_{AF}$**		**$WP11_{T}$**		**$WP11_{B}$**		**$WP12_{GUS}$**		**$WP13_{US}$**	
Profile No.		**7**	**12**	**9**	**4**	**10**	**11**	**5**	**8**	**2**	**1**	**6**	**3**
1-Climate (c)													
Annual rainfall	mm	0	0	0	0	0	0	0	0	0	0	0	0
Mean temperature	^{0}C	32.0	32.0	32.0	32.0	32.0	32.0	32.0	32.0	32.0	32.0	32.0	32.0
Relative humidity	%	54	54	54	54	54	54	54	54	54	54	54	54
Actual sunshine	hrs	11.2	11.2	11.2	11.2	11.2	11.2	11.2	11.2	11.2	11.2	11.2	11.2
2-Soil physical charateristics													
Depth	cm	75	80	100	95	100	100	90	100	85	90	95	90
Gravels	%	4.65	5.36	11.65	12.86	28.37	34.64	5.79	5.59	5.48	6.37	6.06	7.24
Coarse sand	%	75.10	75.71	82.73	83.41	86.11	84.26	75.73	76.74	91.51	91.21	91.47	93.20
Fine sand	%	6.70	6.21	5.35	5.37	5.43	6.88	9.25	8.91	1.44	1.83	1.90	2.00
Silt	%	12.00	11.03	7.24	7.91	5.03	4.99	10.61	10.31	5.14	4.86	4.61	3.10
Clay	%	6.20	7.05	4.68	3.31	3.44	3.88	4.42	4.04	1.91	2.10	2.02	1.70
Texture		ls	ls	ls	s	GS	GS	ls	ls	s	s	s	s
3-Topography													
Slope	%	1-2	1-2	1-2	1-2	8-10	10-12	1-2	2-4	1-2	1-2	1-2	1-2
4-Wetness													
Drainage		well	well	well	well	well	well	well	well	well	well	well	well
Flood duration	Months	F0	F0	F0	F0	F0	F0	F0	F0	F0	F0	F0	F0
5-Fertility													
pH		8.09	7.83	8.16	8.28	8.39	8.36	8.09	8.41	8.45	8.37	8.24	7.95
Total Nitrogen	%	0.01	0.02	0.05	0.07	0.02	0.01	0.04	0.03	0.02	0.02	0.03	0.02
Organic carbon	%	0.16	0.15	0.08	0.10	0.08	0.08	0.11	0.11	0.11	0.08	0.13	0.07
Available P	mg/kg	6.0	5.4	5.6	7.1	6.5	4.4	4.6	5.0	3.4	5.0	4.6	4.3
Exchangable Na	Cmol+/kg	0.41	0.37	0.24	0.24	0.27	0.24	0.27	0.31	0.21	0.20	0.29	0.30
Exchangable K	Cmol+/kg	0.19	0.14	0.19	0.18	0.12	0.16	0.19	0.17	0.12	0.13	0.16	0.15
Exchangable Ca	Cmol+/kg	2.06	2.67	1.93	2.52	1.53	2.26	2.87	1.62	1.73	1.52	1.91	1.84
Exchangable Mg	Cmol+/kg	1.45	1.46	0.87	0.70	0.68	0.69	0.76	1.02	1.65	0.90	0.75	0.81
CEC	Cmol+/kg	4.26	4.76	3.38	3.75	2.68	3.46	4.19	3.20	3.82	2.81	3.19	3.18
Base saturation	%	96.71	97.54	95.57	96.76	97.61	96.58	97.49	97.05	97.12	97.62	97.21	97.48
ESP	%	9.67	7.76	7.33	6.43	10.35	6.76	6.69	9.84	4.85	7.94	9.18	9.51

	Unit	$WP11_{WB}$		$WP11_{AF}$		$WP11_{T}$		$WP11_{B}$		$WP12_{GUS}$		$WP13_{US}$	
Profile No.		**7**	**12**	**9**	**4**	**10**	**11**	**5**	**8**	**2**	**1**	**6**	**3**
DTPA extractable Fe	mg/kg	1.2	1.7	1.7	1.3	0.9	1.2	1.5	1.3	0.7	0.7	0.6	0.7
DTPA extractableMn	mg/kg	0.5	0.4	0.3	0.3	0.5	0.4	0.4	0.3	0.3	0.4	0.5	0.3
DTPA extractable Zn	mg/kg	0.3	0.4	0.4	0.5	0.3	0.4	0.5	0.5	0.2	0.2	0.2	0.2
DTPA extractable Cu	mg/kg	0.2	0.2	0.3	0.2	0.1	0.07	0.2	0.1	0.05	0.07	0.1	0.2
Salinity (ECe)	dS/m	5.69	5.41	10.67	7.38	5.38	5.85	5.02	6.45	5.58	3.83	4.28	3.99
ESP	%	9.67	7.76	7.33	6.43	10.35	6.76	6.69	9.84	4.85	7.94	9.18	9.51
$CaCO_3$	%	12.36	13.41	17.08	13.24	8.59	9.19	13.62	17.68	7.01	3.81	8.65	5.44

Table 4. Soil fertility limitations and fertility capability classification units

Map unit	Profile No.	Type	Substrata type	Condition modifiers										Area Feddan (1000)	FCC unit
				e	k	b	s	n-	d+	r+	SR	m	%		
WP11WB	7	S	S	+	+	+	+	-	+	+	-	+	0.8	26.426	Sekbsdrm (1-2%)
	12	S	S	+	+	+	+	-	+	+	-	+	0.7		Sekbsdrm(1-2%)
WP11AF	9	S	S	+	+	+	+	-	+	+	-	+	0.4	33.457	Sekbsdrm(1-2%)
	4	S	S	+	+	+	+	-	+	+	-	+	0.1		Sekbsdrm(1-2%)
WP11T	10	S	S	+	+	+	+	-	+	+	+	+	9.8	11.108	SekbsdrSRm (8-10%)
	11	S	S	+	+	+	+	-	+	+	+	+	10.5	5.54	SekbsdrSRm (10-12%)
WP11B	5	S	S	+	+	+	+	-	+	+	-	+	0.6	12.66	Sekbsdrm (1-2%)
	8	S	S	+	+	+	+	-	+	+	-	+	3	3.125	Sekbsdrm (2-4%)
WP12GUS	2	S	S	+	+	+	+	-	+	+	-	+	0.9	12.75	Sekbsdrm(1-2%)
	1	S	S	+	+	+	-	-	+	+	-	+	0.6	3.75	Sekbdrm(1-2%)
WP13US	6	S	S	+	+	+	+	-	+	+	-	+	1	7.85	Sekbsdrm(1-2%)
	3	S	S	+	+	+	-	-	+	+	-	+	0.7	4.65	Sekbdrm(1-2%)

S:sandy, e:low CEC, k:low nutrient reserves, b: calcareous, s: salinity, n^-: nitric, d^+: dry soil moisture condition, r^+: gravels, SR: erosion, m: low organic matter and %: slope

Table 5. Interpretation of soil fertility capability classification units

Map unit	FCC unit	Description
WP11WB , WP11AF	Sekbsdrm (1-2%)	Sandy surface and subsurface soils having low cation exchange capacity, low nutrients reserves, calcareous reaction, salinity. Soils with dry conditions, gravels and deficient in soil organic carbon.
WP11T	SekbsdrSRm (8-10%)	Sandy surface and subsurface soils having low cation exchange capacity, low nutrients reserves, calcareous reaction, salinity. Soils with dry conditions, gravels, erosion risk and deficient in soil organic carbon with steep slope.
	SekbsdrSRm (10-12%)	Sandy surface and subsurface soils having low cation exchange capacity, low nutrients reserves, calcareous reaction, salinity. Soils with dry conditions, gravels, erosion risk and deficient in soil organic carbon with steep slope.
WP11B	Sekbsdrm (1-2%)	Sandy surface and subsurface soils having low cation exchange capacity, low nutrients reserves, calcareous reaction, salinity. Soils with dry conditions, gravels and deficient in soil organic carbon.
	Sekbsdrm (2-4%)	Sandy surface and subsurface soils having low cation exchange capacity, low nutrients reserves, calcareous reaction, salinity. Soils with dry conditions, gravels and deficient in soil organic carbon.
WP12GUS	Sekbsdrm (1-2%)	Sandy surface and subsurface soils having low cation exchange capacity, low nutrients reserves, calcareous reaction, salinity. Soils with dry conditions, gravels and deficient in soil organic carbon.
	Sekbdrm (1-2%)	Sandy surface and subsurface soils having low cation exchange capacity, low nutrients reserves, calcareous reaction. Soils with dry conditions, gravels and deficient in soil organic carbon.
WP13US	Sekbsdrm (1-2%)	Sandy surface and subsurface soils having low cation exchange capacity, low nutrients reserves, calcareous reaction, salinity. Soils with dry conditions, gravels deficient in soil organic carbon.
	Sekbdrm (1-2%)	Sandy surface and subsurface soils having low cation exchange capacity, low nutrients reserves, calcareous reaction. Soils with dry conditions, gravels deficient in soil organic carbon.

Table 6. The temporal scale dimension of FCC attributes

FCC attribute	Can be changed by management with time (years)				Means of change
	<1	1-10	10-100	>100	
Type/substrata type - S				√	inherent, unless severely eroded
High leaching potential- e				√	inherent
Low nutrient reserves -k				√	inherent
Calcareous -b			√		by sustained leaching in slightlycalcareous ones
Saline - s		√			by effective leaching
Sodic - n		√			by effective leaching

FCC attribute	Can be changed by management with time (years)				Means of change
	<1	1-10	10-100	>100	
Soil moisture stress - d	√				temporarily by irrigation
Gravels- r				√	inherent, unless severely eroded
High erosion - SR				√	inherent; can be mitigated by soil conservation practices
Low organic matter - m		√			by organic input application rates that exceed decomposition rate

3.3.2 Salinity (s)

This can be removed by applying leaching and supplying the affected area with efficient drainage system in case of good quality water. Whereas, if the quality of irrigation water is poor due to either high salinity or high alkalinity or both, some suggestive management plans can be adopted such:

(1) In case of saline area and high salinity irrigation water, subsurface drainage system is a useful tool for desalinization.
(2) In case of saline area and high sodic irrigation water, subsurface drainage system along with application of gypsum could be used for improving the productivity. The gypsum amount to be added is determined by quality and quantity of water to be added per year by applying the simple equation [19]:

$$GR = ((RSC - 2.5) \times N \times 36)$$

Where:

GR: Gypsum requirement (tons/acre), RSC: Residual sodium carbonate, N: number of irrigations.

Thus, for soils irrigated with water having RSC 10.9, 10.4, 8.4 and 5.5 me/l and needing 5 irrigations, the GR will be 1512, 1422, 1062 and 540 kg/acre.

3.3.3 High ESP soils (n)

Application of gypsum to soils along with deep ploughing and subsurface drainage is recommended. GR can be calculated by using the following equation:

$$GR(tons/ha) = \frac{(ESP_I - ESP_F) \times CEC \times 25.8 \times P}{100}$$

Where

ESPI: Exchangeable Sodium Percentage initial (ESP) of soil, ESPF: ESP final, CEC: Cation exchange capacity of soil, P: purity factor of gypsum.

3.3.4 High erosion (SR)

Following measures are suggested to reclaim high erosion land:

- Leveling and construction of contour bunds.
- Pipe outlets or ramps with suitable grasses for draining excess run off.
- Perennial vegetation like fuel, fodder trees and grasses may help effectively to conserve the soil.

3.3.5 Rocky and quarried (r)

Following measures can be adopted

- Enclosures of the hilly area with barbed wire.
- Prohibition of grazing.
- Locally suited tree species may be grown to conserve soils.
- Rehabilitation of quarry lands- plantation of suitable tree species.

4. CONCLUSION

According to the results, the major landforms of the studied area were described as Wadi Bottom (WB), Bajada (B), Alluvial Fans (AF), Tableland (T), Gently Undulating Sand Sheet (GUS) and Undulating Sand Sheet (US). The results of FCC units of WP11WB, WP11AF, WP11B and some parts of WP12GUS and WP13US were classified as Sekbsdrm (1-2%) only an area of 3125 feddan of WP11B was classified as Sekbsdrm (2-4%).

This implies that these map units have sandy (S) soils at both top and subsoils. The soils also have constraints of high leaching potential (e), low nutrients reserve (k), basic reaction (b) and salinity (s). As the soil exhibit ustic or xeric soil moisture regime, the Soil moisture stress constraint (d) has been recognized. The other modifiers are because of gravels content (r) and low organic matter (m). The soils of WP11T were classified as SekbsdrSRm (8-10%) and SekbsdrSRm (10-12%) which having the same condition modifiers but different slope grade. These soils are characterized by a high risk of soil erosion (SR) that erosion can negatively affect plant productivity and ecosystem functions. The FCC unit Sekbdrm (1-2%) has been found in some areas belongs to WP12GUS and WP13US. By following the scientific technologies, the fertility constrains can be improved.

COMPETING INTERESTS

Author has declared that no competing interests exist.

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