CORPORATION OF REMOTE SENSING AND GIS IN WATER MANAGEMENT AND LAND USE PLANNING IN EL-HAMMAM AREA, NORTHERN COAST OF EGYPT

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ABSTRACT :

The present work aims to use of GIS, remote sensing and soil data, as a mean for decision making in natural resources management and planning the sustainable land use in El-Hammam area, North-Western Coast of Egypt. The selected region represents one of the high priority regions for future development in the country. It lies between longitudes 29° 15` and 29° 30`E and latitudes 30° 45` and 31° N, with a total area of about 94752 acres. The sustainable land use was established based on: land capability and suitability, water resources availability, economic return from water and financial return from land and water.

Remote Sensing (RS) and Geographic Information System (GIS) are incorporated to execute the soil base map. Field survey is carried out to represent the SMUs by soil profiles. Laboratory analysis for the collected samples is done and stored as attributes in a geographical soil database linked with the soil map units. The soils are classified mainly as Typic Haplocalcids; Calcic Petrocalcids; Calcic Aquisalids; Calcic Haplosalids; Typic Aquisalids; Typic Torripsamments; and Lithic Torriorthents.

Land capability assessment is done to define maps of the suitable areas for agricultural production using a capability model built in ALES software and the results are exported to GIS. Results indicate that the area currently lacks high capability and moderate capability classes. By improving the soil properties, the soil can approach potential capability; and about 55629.52 acres (80.27 % of the evaluated soils) will become marginally capable. Then the assessment of soil physical suitability for different land use (wheat, sorghum, barley, clover, maize, olive, fig, guava and citrus) are done for the capable areas.

The crop water requirements and the irrigation requirements are calculated for the defined LUTs with the help of CropWat software. Irrigation scheduling is determined in order to define the timing and quantities of the needed supplementary irrigation. The results indicated the needs for supplementary irrigation requirements ranged between 152.97mm for clover (for one cut) and 981.07mm for guava.

The net return from each LUT, net return per month and the net return per cubic meter of irrigation water are calculated. Two different scenarios were applied to assess the sustainable land use depending on the soil physical suitability, irrigation requirements, and the net return per cubic meter of irrigation water and net return per acre . The environmental impact of changing to the recommended sustainable land use is tested through the prediction of soil loss due to the rainfall-runoff and the results are represented with maps. The results indicate that, the study area is susceptible for potential soil loss at different severity levels.

It is concluded that GIS, combined with modeling are powerful tools for decision making in the area.

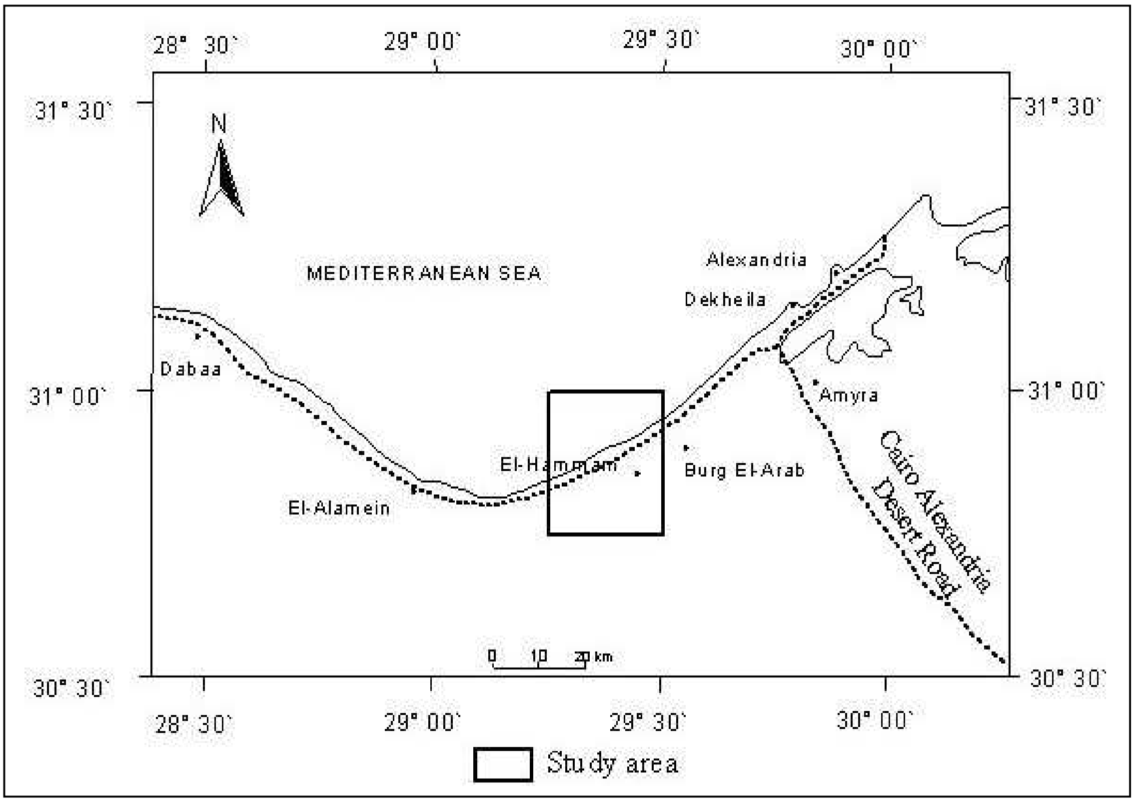
1. INTRODUTION

Nowadays, a great attention is directed in Egypt towards its Northern coast for future development. Therefore, studies on management of natural resources in such region are considered of vital importance. Remote Sensing (RS) and Geographic Information System (GIS) techniques create great possibilities for fast inventory, monitoring and updating the natural resources status. The combination of GIS and RS proved to be effective in management and planning studies.

The study area is located in the northwestern coast of Egypt. It lies between longitudes 29° 15` and 29° 30`E and latitudes 30° 45` and 31° N, with a total area of about 94752 acres, Map 1. As a part of the Mediterranean coast of Egypt, the long dry summer and the short rainy winter characterize the study area. The annual rainfall varies considerably from month to month with mean of 14.91 mm/month. The average of the available metrological data is indicated in Table 1 . The northwestern coast of Egypt geomorphology is distinguished by a northern coastal plain with succession of ridges which are separated from the other by a depression and a southern tableland, Balba (1987). These ridges are composed of oolitic limestone that considered as the product of the consolidation of ancient littoral dunes formed along the shoreline. The areas between the depressions are formed from materials washed from the neighboring ridges and hills and considered the main potentially agricultural land, Balba (1990).

The study was conducted in 2002 and mainly aimed to;

1. Build up a geographic soil database for the area, that can be used for different development and management models needed for decision makers.
2. To assess soil capability and suitability for different crops to plan the most sustainable land use .
3. To determine the suitable water requirements needed for the development of the study area.
4. To study erosion status and estimating its condition after applying the proposed sustainable land use.



Map 1. Location map of the study area

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Table 1. Climatological data of El-Dekhila station (average of 30 years).

Climatic month	Temperature (°C)			Mean monthly relative humidity %	Mean daily evaporation (mm/day)	Rainfall (mm/ month)	Wind speed (m/sec)	ETo (mm/day)
	Max.	Min	Mean					
January	17.80	9.60	13.70	68	5.5	54.60	8.8	3.39
February	18.70	10.40	14.55	66	6.2	23.30	9	3.76
March	20.70	12.10	16.40	63	7.1	12.80	9.7	4.12
April	23.20	14.40	18.80	65	7.4	2.90	9.4	4.39
May	25.20	17.00	21.10	69	6.7	1.00	9.1	4.08
June	27.80	20.80	23.40	71	9.6	0.10	8.7	5.99
July	28.70	22.80	25.75	72	7.4	0.00	9.1	4.54
August	29.60	23.50	26.55	70	7.7	0.00	8.9	4.74
September	28.80	22.10	25.45	65	7.8	1.20	8.1	4.91
October	26.50	18.80	22.65	67	7.1	11.00	7.3	4.66
November	23.50	15.50	19.50	68	6.5	23.90	7.5	4.24
December	19.80	11.30	15.55	67	6.1	48.10	8.2	3.85
Mean	**24.19**	**16.53**	**20.28**	**67.5**	**6.9**	**14.91**	**8.65**	**4.39**

source: Climatological normals of Egypt, 1990.

2. MATERIAL AND METHODS

The present study had been conducted in the following stages:

1- Processing of satellite data, GIS data preparation and soil map generation.
2- Field work, laboratory analysis and re-interpretation of satellite data.
3- Coding soil database attributes and testing the geographic soil database.
4- Land capability assessment and land suitability assessment for different crops.
5- Crop water requirements and planning the sustainable land use.
6- Soil erosion assessment.

The methodological approach is summarized in Figure 1.

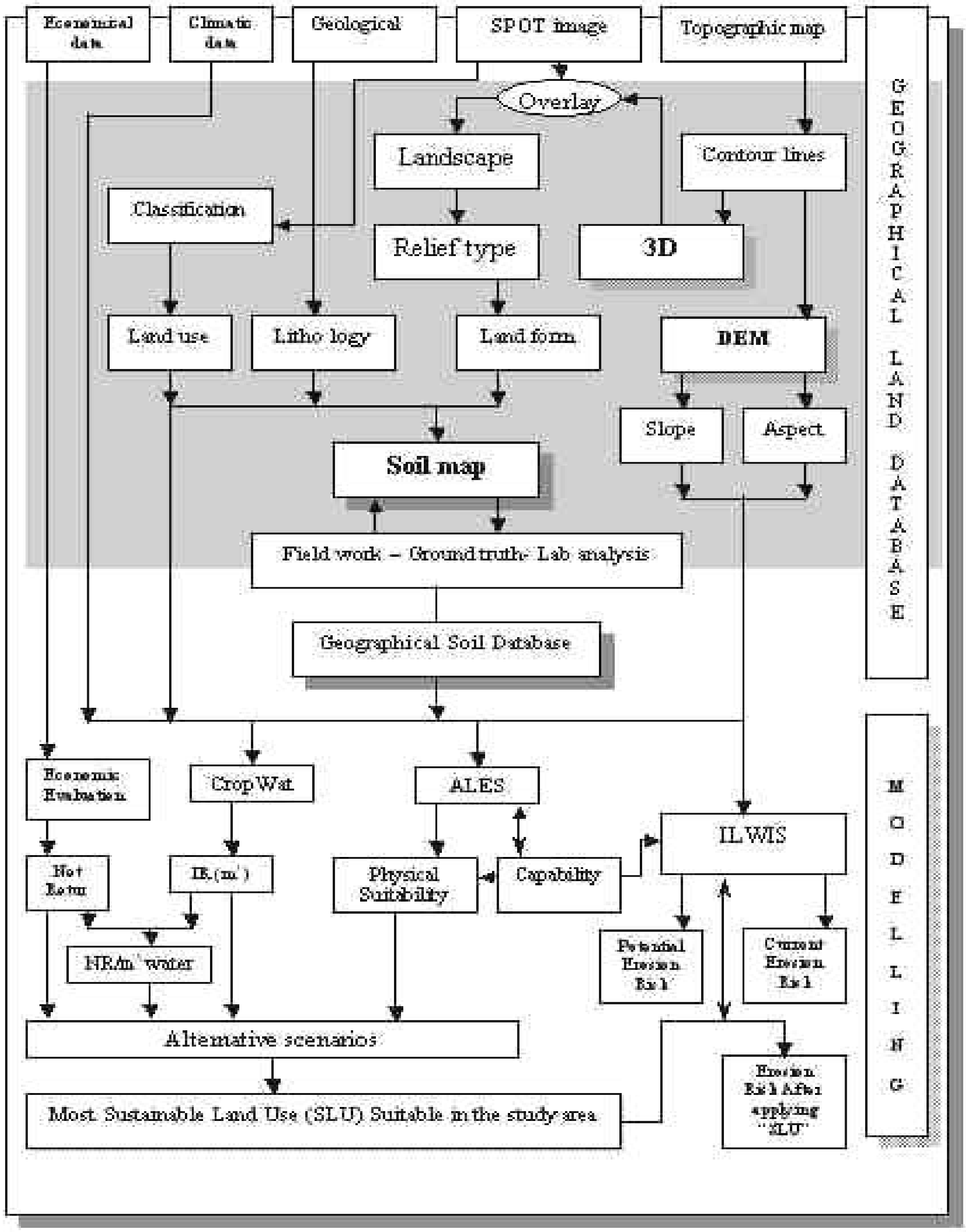


Figure 1. Methodological approach.

2.1- Enhanced false color composite of Spot multispectral image dated (July 1997) was used for the present study. Scanned topographic maps scale 1:50.000 were used first for the image geo-referencing using image-to-image geometric correction module in ERDAS IMAGINE 8.4. Stretching radiometric enhancement and convolution and adaptive filtering were applied. The resulted enhanced false colour composite was used for visual interpretation of land use units, whereas, the Normalized Difference Vegetation Index (NDVI) is used to distinguish the different land covers in the area.

The contour lines and all spot heights (from 1:50,000 topographic map) are digitised, then, interpolation is made using ARCVIEW GIS to create digital elevation model (DEM) with pixel size of 5m. An enhanced false color composite of SPOT image is made and overlayed on the 3D model, created using ARCVIEW 3.2, Figure 2. The same is made also using the lithological map instead of the SPOT image.

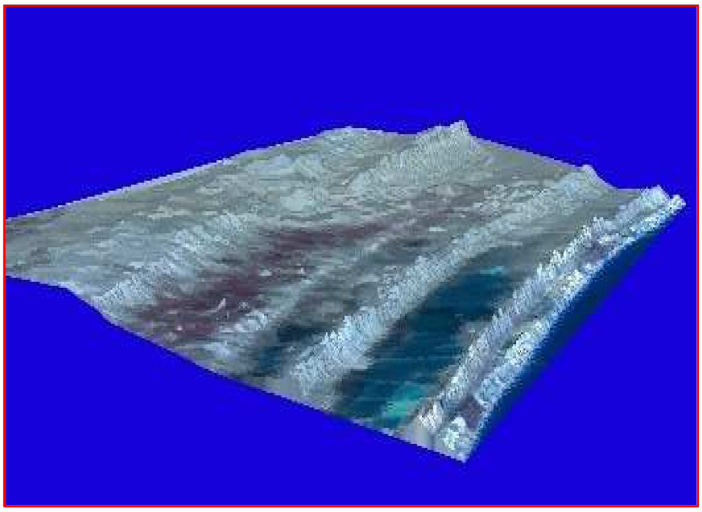
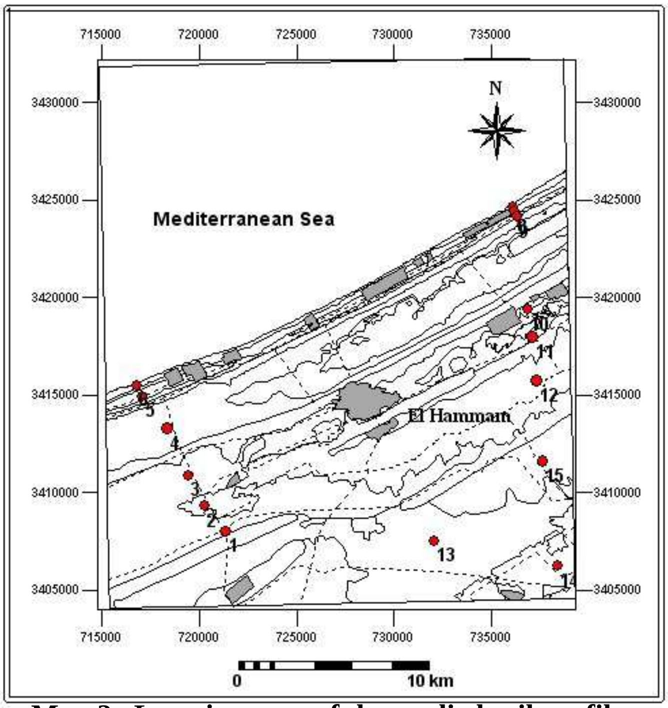


Figure 2. SPOT image overlayed on the 3D model of the study area.

The geopedological approach (Zinck, 1989) of the physiographic aerial photo interpretation is adapted to be applied on the SPOT image interpretation. The enhanced colour composite SPOT image is overlayed on the 3D model, then visual interpretation is made to apply the geopedological approach and produce the soil map.

.2.2- A general reconnaissance survey is carried out first throughout the area using intensive testing auger samples, then transect sampling method is applied to cross the different mapping units in the area where fifteen soil profiles were tested and sampled, Map 2. Detailed morphological description is made for each soil profile, on the bases outlined by FAO (1977) and tentatively classified according to Soil Survey Staff (2003). The collected disturbed soil samples are air dried; ground gently; and sieved through 2 mm sieve where the main physical and chemical properties are determined. After carrying out the ground truth view during the field work, re-interpretation is made for the SPOT image to produce the final soil map, Map 3 and Table 2.



Map 2. Location map of the studied soil profiles

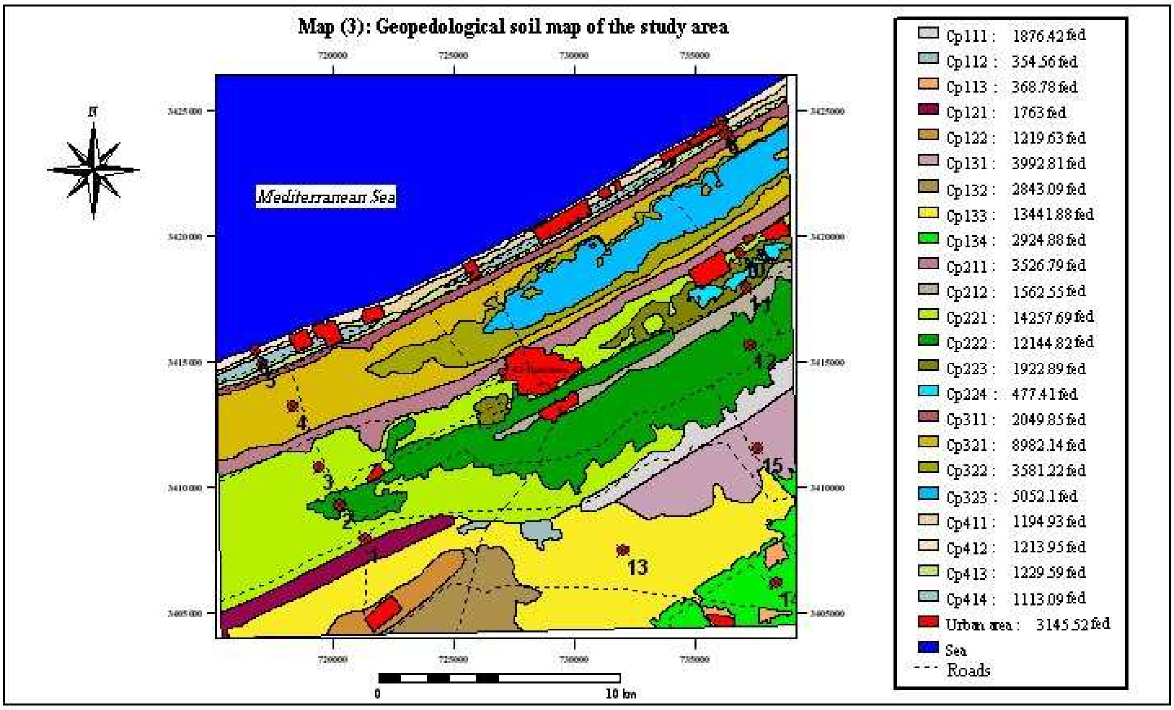


Table 2. Legend of the geopedological soil map units.

Landscape	Relief type	Lithology	Landform	Map unit symbol	Area (acres)	Main Soil
Coastal Plain	High Terraces	Limestone	Tidal riser ridge	Cp111	1970.37	Rock
			Isolated hillock	Cp112	372.35	Rock
			Rock out crop	Cp113	387.21	Rock
		Limestone + Marl	Tidal riser ridge	Cp121	1851.29	Rock
			Rocky ridge	Cp122	1280.64	Rock
		Limestone + sand	Rocky tread	Cp131	4192.57	Lithic Torriorthents
			Tread with slope faced complex with out crop	Cp132	2985.31	Rock
			Tread with sand sheet	Cp133	14113.71	Typic Haplocalcids
			Cultivated depression 1	Cp134c	3071.18	Calcic Petrocalcids
	Moderately high Terraces	Limestone	Tidal riser ridge	Cp211	3703.08	Rock
			Rocky ridge	Cp212	1640.77	Rock
		Limestone + sand	Tread	Cp221	14970.46	Typic Haplocalcids
			Cultivated depression 2	Cp222c	12751.88	Typic Haplocalcids
			Seasonal marches	Cp223	2003.87	Calcic Aquisalids
			Permanent marshes	Cp224	479.33	-
	Mod. Low Terraces	Limestone	Riser ridge	Cp311	2152.28	Rock
		Limestone + sand	Tread 2	Cp321	9431.29	Calcic Haplosalids
			Sabkha with seasonal marshes	Cp322	3760.31	Calcic Aquisalids
			Permanent marshes	Cp323	5304.86	-
	Low Terraces	Limestone	Sand dunes	Cp411	1254.78	Typic Torripsamments Typic Haplocalcids
			Sea beach	Cp412	1274.43	Typic Torripsamments
			Tread 3	Cp413	1291	Calcic Petrocalcids
			Sabkha with seasonal marches	Cp414	1168.83	Typic Aquisalids

2.3- Soil attributes of the different mapping units are added from the analysis results of the modal soil profiles representing the dominant main soil, Tables 3,4 and 5.

Table 3. Main soil characteristics of the different soil mapping units

Mapping unit	Main soil	Profile depth (cm)	Drainage	Salinity (dS/m)	CEC ($Cmol_c/kg$)	$CaCO_3$ %	ESP	Texture class	Available water %	Area (acres)
Cp131	Lithic Torriorthents	<25	Poor drained	Non saline	5-10	30-40	<5	Sand	5-10	4192.57
Cp133	Typic Haplocalcids	120-150	Moderately well drained	Very slightly saline	5-10	30-40	<5	Sandy loam	10-15	14113.71
Cp134	Calcic Petrocalcids	60-90	Moderately well drained	Very slightly saline	25-30	30-40	5-10	Sandy clay loam	15-20	3071.18
Cp221	Typic Haplocalcids	120-150	Well drained	Moderately saline	15-20	30-40	5-10	Sandy loam	10-15	14970.46
Cp222	Typic Haplocalcids	120-150	Well drained	Non saline	15-20	20-30	5-10	Sandy clay loam	15-20	12751.88
Cp223	Calcic Aquisalids	25-60	Moderately poor drained	Strongly saline	5-10	20-30	35-40	Sand	5-10	2003.87
Cp321	Calcic Haplosalids	60-90	Moderately drained	Strongly saline	30-35	30-40	15-20	Sandy clay loam	15-20	9431.29
Cp322	Calcic Aquisalids	25-60	Moderately poor drained	Strongly saline	5-10	20-30	35-40	Sand	5-10	3760.31
Cp412	Typic Torripsamments	60-90	Moderately well drained	Slightly saline	5-10	>50	<5	Sand	5-10	1274.43
Cp413	Calcic Petrocalcids	60-90	well drained	Very slightly saline	20-25	30-40	<5	Sandy loam	10-15	1291
Cp414	Typic Aquisalids	25-60	Moderately drained	Strongly saline	5-10	5-10	<5	Sand	5-10	1168.83

2.4- A land capability model is built using ALES software and the resulted table is imported to ILWIS GIS to produce the capability map, Map 4, and the potential capability map is also predicted, Map5. The soil characteristics rates used in the capability model are given in Table 6. The assessment of physical land suitability for 10 different crops has been conducted for the capable soil units using Automated Land Evaluation System, ALES, (Rossiter and Van Wambek, 1997) by implementing the FAO framework (FAO, 1976). The suitability maps were produced using ILWIS GIS.

2.5- The CropWat software is used to estimate the crop water requirements of the selected crops to define the periods and quantities of the supplementary irrigation. The most sustainable land use in the study area is suggested by applying the methodology introduced in Figure 1.

2.6- The USLE equation is used to predict the annual soil loss in the study area. ILWIS 3.3 GIS software environment is used for presenting the six equation parameters. The generated USLE layers, are used to calculate the annual soil loss before and after applying the recommended sustainable land use, Maps 6 &7.

Table 4. Particle size distribution, CaCO3, organic matter, available moisture and hydraulic conductivity in the studied soils

Profile No.	Depth (Cm)	Sand %		Silt %	Clay %	Texture class [1]	$CaCO_3$ %	Organic matter %	Available moisture %	Hydraulic conductivity (cm/h)
		Coarse %	Fine %							
1	0-60	34.42	53.04	4.01	8.53	S.	39.60	0.18	9.81	6.74
	60-150	34.43	51.10	5.99	8.48	L S.	90.80	-	9.93	6.32
2	0-25	51.23	42.35	1.97	4.44	S.	41.33	0.17	8.74	3.71
	25-100	45.73	47.89	1.96	4.42	S.	40.15	-	8.61	5.01
	100-150	54.51	40.98	2.00	2.51	S.	41.79	-	8.32	11.84
3	0-40	23.31	60.37	5.94	10.39	L.S.	37.99	0.10	10.03	7.41
	40-140	13.52	58.05	11.97	16.46	S.L.	40.13	-	13.48	2.46
4	0-3	6.30	67.78	10.58	15.34	S. L.	29.04	0.95	13.65	2.10
	3-20	9.27	57.98	18.14	14.61	S.L.	30.27	0.75	14.52	3.71
	20-50	4.15	40.70	25.21	29.94	C.L.	34.85	-	20.24	1.57
	50-80	5.54	30.39	24.60	39.47	C.L.	33.64	-	21.85	0.25
5	0-10	24.30	60.24	9.89	5.57	L.S.	23.52	0.50	8.47	1.10
	10-15	77.75	13.35	2.74	6.16	S.	2.24	0.15	8.93	0.96
	15-60	72.27	16.67	7.81	3.26	S.	2.90	-	7.89	3.32
6	0-80	89.38	6.21	1.96	2.45	S.	94.22	0.24	6.65	22.87
7	0–85	83.70	12.00	1.80	2.50	S.	75.30	0.22	6.68	21.33
8	0-30	88.60	10.00	0.50	0.90	S.	86.40	0.26	6.21	7.13
	30-50	91.80	7.20	0.40	0.60	S.	90.80	0.14	6.15	7.02
	50-110	93.70	5.60	0.30	0.40	S.	92.60	-	6.01	6.87
9	0-40	16.68	48.87	19.26	15.19	S.L.	34.27	0.17	14.32	2.84
	40-90	25.03	58.81	6.32	9.84	L.S.	37.09	0.12	10.21	3.26
10	0-20	4.80	52.60	19.60	23.00	S.C.L.	32.60	2.02	17.86	1.32
	20-90	2.00	30.80	28.40	38.80	C.L.	40.00	1.39	21.57	0.57
	90-110	5.20	37.00	21.00	36.80	C.L.	39.60	-	20.21	0.63
	110-130	5.00	36.20	23.80	35.00	C.L.	39.70	-	19.74	0.68
11	0-15	27.21	57.16	10.02	5.61	L.S.	26.90	0.62	9.78	1.48
	15-30	72.59	18.92	2.52	5.97	S.	22.10	0.23	7.43	1.32
12	0-25	22.50	45.90	16.40	15.20	S.L.	24.20	1.28	11.49	0.57
	25-45	20.80	40.60	16.80	21.80	S.C.L.	20.60	0.76	17.14	0.43
	45-150	15.40	42.50	18.50	23.60	S.C.L.	26.80	0.28	18.67	0.37
13	0-30	26.28	56.43	10.47	6.82	L.S.	38.23	0.14	9.68	1.86
	30-110	23.12	49.64	17.31	9.93	S.L.	33.47	0.11	10.74	1.47
14	0-50	11.0	35.80	22.40	30.80	S.C.L.	35.40	1.64	19.89	0.43
	50-70	6.20	40.00	21.00	32.80	S.C.L.	34.60	1.64	20.13	0.37
15	0-12	52.31	39.20	2.64	5.85	S.	37.61	0.11	6.27	5.74

* S: sand S.L.: Sandy LoamL. S.: Loamy Sand C.L.: Clay Loam S.C.L.: Sandy Clay Loam.

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Table 5. Chemical characteristics of the studied soils

Profile No.	Depth (Cm)	pH (paste)	ECe (dS/m)	Cations (meq / 100g soil)				Anions (meq / 100g soil)			SAR	ESP	CEC (cmolc/kg)
				Ca^{++}	Mg^{++}	Na^{+}	K^{+}	SO_4^{--}	HCO^{-}	Cl^{-}			
1	0-60	8.25	4.60	0.056	0.046	0.287	0.007	0.35	0.02	0.02	2.09	4.27	13.73
	60-150	7.72	13.09	0.270	0.132	0.808	0.014	1.14	0.02	0.07	3.14	5.70	15.09
2	0-25	7.82	0.68	0.016	0.006	0.025	0.002	0.02	0.03	0.001	1.24	3.07	9.25
	25-100	7.46	0.47	0.017	0.004	0.014	0.001	0.01	0.02	0.001	1.41	3.32	8.08
	100-150	7.52	0.56	0.015	0.006	0.020	0.002	0.001	0.04	0.001	1.41	3.31	8.04
3	0-40	8.65	0.69	0.006	0.002	0.043	0.002	0.02	0.03	0.001	1.66	3.67	12.26
	40-140	8.15	25.24	0.311	0.370	2.550	0.025	3.05	0.02	0.18	7.68	11.43	20.40
4	0-3	7.08	131.119	2.592	3.305	9.257	0.316	14.04	0.03	1.40	4.66	26.27	24.31
	3-20	7.78	37.492	0.779	0.913	2.755	0.120	4.24	0.02	0.31	6.97	11.97	26.20
	20-50	7.97	35.432	0.879	1.066	4.413	0.165	6.09	0.03	0.40	11.49	15.74	33.87
	50-80	8.2	28.222	0.895	1.055	4.630	0.172	6.32	0.04	0.40	12.55	16.87	35.81
5	0-10	8.25	144.82	1.727	3.583	14.663	0.399	19.02	0.03	1.32	3.80	6.582	18.15
	10-15	8.39	31.11	1.286	1.189	4.695	0.127	6.83	0.04	0.43	2.40	4.702	8.98
	15-60	8.07	55.62	2.568	0.673	8.552	0.188	11.12	0.07	0.79	0.80	2.447	7.71
6	0-80	8.4	4.13	0.018	0.036	0.184	0.011	0.22	0.02	0.01	1.45	3.37	9.11
7	0–85	8.5	25.7	0.20	0.80	4.03	0.10	0.58	0.05	4.50	41.46	39.03	9.14
8	0-30	7.82	0.92	0.06	0.03	0.13	0.01	0.04	0.04	0.14	3.96	6.80	9.62
	30-50	7.46	0.75	0.05	0.02	0.10	0.01	0.04	0.03	0.10	3.51	6.19	7.76
	50-110	7.52	0.45	0.03	0.02	0.05	0.01	0.03	0.02	0.06	2.11	4.29	4.89
9	0-40	8.21	3.23	0.51	0.038	0.21	0.005	0.42	0.073	0.27	2.420	4.72	29.34
	40-90	8.36	3.45	0.53	0.041	0.23	0.006	0.44	0.087	0.28	2.547	4.89	17.63
10	0-20	7.97	8.82	1.17	0.85	1.45	0.04	1.74	0.12	1.65	7.39	11.09	23.15
	20-90	8.09	3.18	0.44	0.26	0.77	0.04	0.68	0.12	0.71	6.02	9.42	28.84
	90-110	8.10	10.57	1.23	1.30	2.12	0.03	1.46	0.07	3.15	8.97	12.94	25.78
	110-150	7.92	8.37	0.99	1.27	2.60	0.04	0.95	0.08	3.33	8.75	12.69	24.35
11	0-15	8.43	191.21	2.18	4.21	27.90	0.45	13.52	0.05	20.47	43.958	40.41	8.62
	15-30	8.52	152.43	1.85	3.41	9.37	0.33	5.31	0.5	9.15	35.941	35.76	8.81
12	0-25	7.92	1.05	0.12	0.07	0.24	0.03	0.22	0.04	0.20	3.76	6.54	12.35
	25-45	7.96	1.20	0.18	0.10	0.27	0.03	0.31	0.04	0.23	3.29	5.90	18.27
	45-150	8.10	2.06	0.48	0.18	0.35	0.03	0.67	0.03	0.34	2.72	5.13	20.72
13	0-30	8.13	2.84	0.38	0.28	0.73	0.03	0.86	0.09	0.47	1.35	3.23	6.13
	30-110	8.29	2.23	0.32	0.25	0.63	0.02	0.76	0.05	0.41	1.31	3.17	7.46
14	0-50	8.13	3.57	0.36	0.31	0.88	0.02	0.96	0.10	0.51	7.81	11.59	28.34
	50-70	8.29	2.94	0.37	0.40	0.89	0.03	0.82	0.06	0.81	1.18	2.99	28.73
15	0-12	8.23	0.68	0.016	0.006	0.025	0.002	0.02	0.03	0.001	1.25	3.08	7.31

3. RESULTS AND DISCUSSION

3.1- Soil Map generation: The interpretation of the resulted geopedological map, Map 3, indicated that the area is characterized by coastal plain landscape, subdivided into four relief types , i.e., High Terraces, Moderately High Terraces, Moderately Low Terraces and Low Terraces.. Finally, the area are differentiated into different lithology and subdivided into twenty three landforms as indicated in the physiographic map legend Table 2.

The High Terraces relief unit "Cp1" contains nine land forms that are representing the oldest sea beach and the inland area when the Mediterranean Sea level was high enough to flood all the northern area. The total area of these land forms are 30224.63 acres. The main recorded soils are; Typic Haplocalcids, Calcic Petrocalcids and Lithic Torriorthents, whereas 29.27% of these units are hard limestone rock.

The Moderately High Terraces unit "Cp2" comprises six different land forms that cover an area about 34919.39 acres. These land forms represents mainly the tidal rocky ridges, terrace tread, depression and marshes. The rocky ridges are considered the second marine coastal beach ridges formed through the Pleistocene times They are composed mainly of limestone intercalated with gravels, elongated in shape, extend from north east to south west, and runs parallel to the current sea shoreline with a distance of about 2-4 km from the shoreline. The main soils recorded in the tread and depression land forms are Typic Haplocalcids. They constitute about 79.9% of the total relief unit area, whereas the seasonal marshes possess Calcic Aquisalids soils.

The Moderately Low Terraces "Cp3" relief unit covers an area about 20621.19 acres and consists of four land forms; ridge riser, tread, sabkha with seasonal marshes and permanent marshes. The soils are mainly Calcic Haplosalids and Calcic Aquisalids.

The Low Terraces relief unit "Cp4" is consists of four land forms; sand dunes, sea beach, tread and Sabkha with total area about 6139.18 acres, Table 2. These landforms are considered the youngest landforms in the area that extend parallel to the present sea shoreline at a distance of a maximum 1200 m. The main recorded soils in these units are; Typic Torripsamments, Typic Haplocalcids, Calcic Petrocalcids and Typic Aquisalids. The main physical and chemical characteristics of the studied soils are given in Tables 3,4 and 5. It is noticed that the majority of the upper area have Calcic horizon in their representative profiles. With getting close to the sea in the lower area, Salic horizon appeared and intercalated with Calcic horizon , Figure 3, Annex IV.

3.2- Coding of soil attributes: The average of the different soil attributes were calculated for the representative modal profiles only. The attributes were coded and stored as map unit attributes where different thematic maps were able to be created, Figure 3.

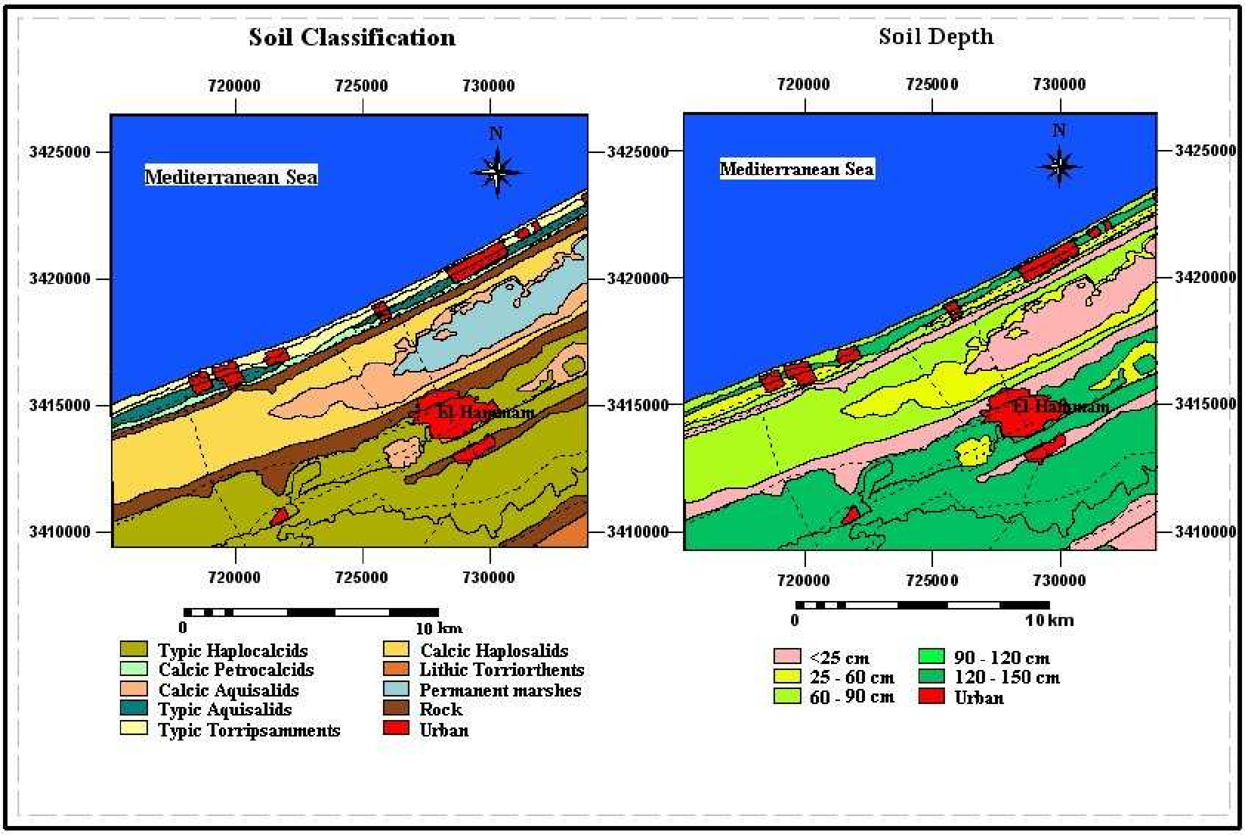


Figure 3. Soil classification and soil depth of the study area.

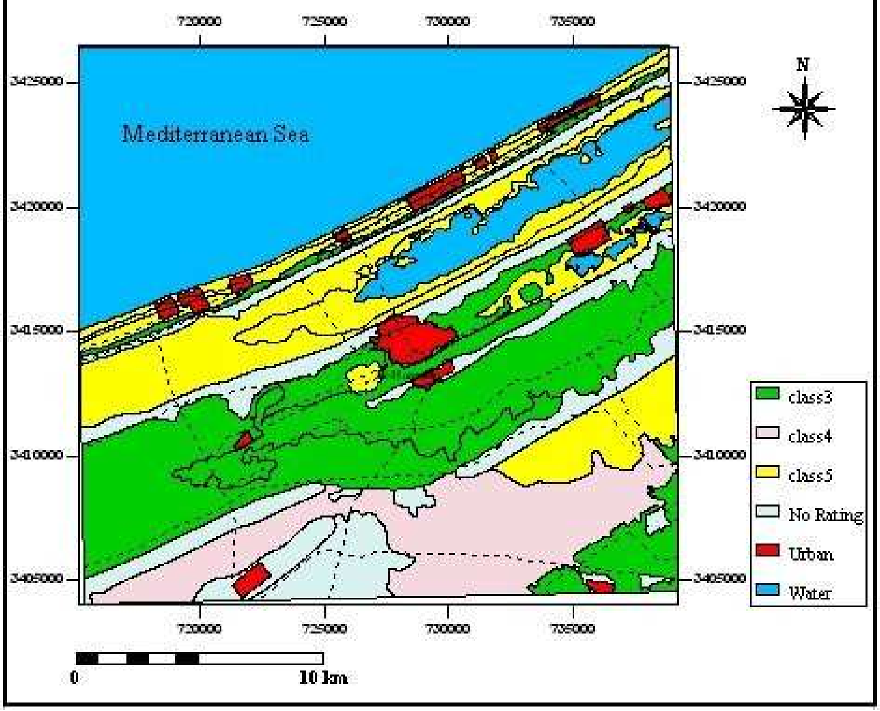
3.3- Land capability :

A land capability model is built in ALES for defining the capability of the represented map units in the study area. Table 6, shows the used soil characteristics and their limiting values for each capability class, as used in the capability model. By matching the land characteristics of the modal profiles of each map units with the land capability model, the land capability map is obtained. Potential capability map is also produced after eliminating the correctable limitations, Map 4,5.

As indicated in Tables 7, the soil depth in the Cp413 mapping unit is exceptionally considered a correctable limiting factor as the soils possess shallow thin Petrocalcic horizons which can be corrected by deep subsoil ploughing. While calcium carbonate content and shallow soil depth are mostly the main uncorrectable limiting factors in the area. The results indicated that 80.27 % of the area are potentially suitable for agriculture. The recommended soil management practices to improve the current capability include;

a- Deep ploughing to improve soil permeability and moisture availability.
b- Organic fertilization to improve permeability, CEC and nutrient availability.
c- Drainage improvement in low parts to improve salinity and oxygen availability.
d- Applying modern irrigation systems to supply the needed uniform water and to avoid soil crust formation.

Map (4): Current land capability



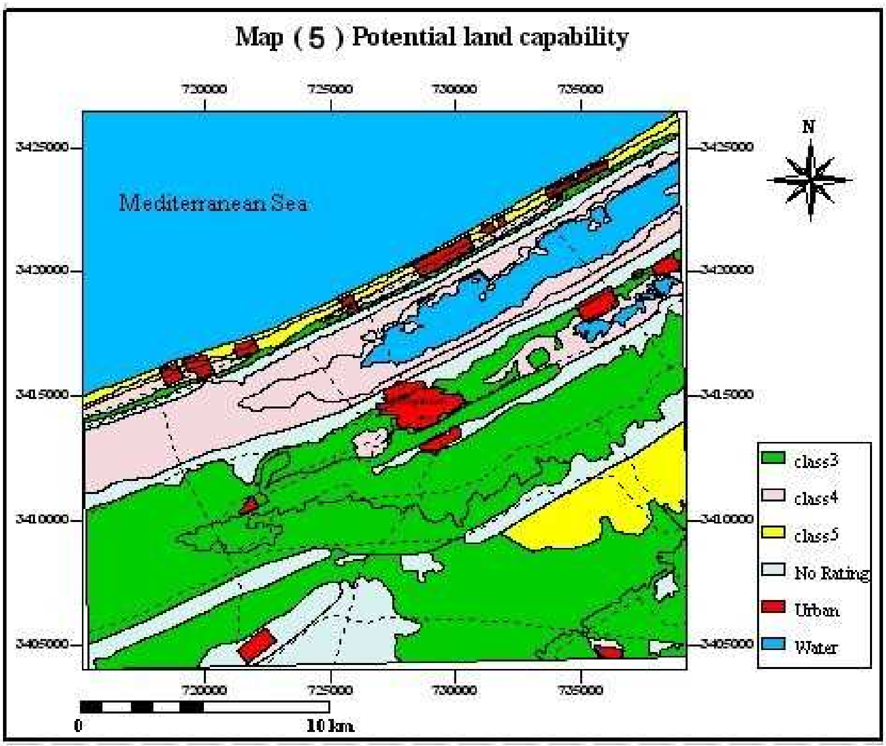


Table 6. Soil Characteristics of the soil map units, which used in the capability model

Soil Characteristics	Class 1 High Capability	Class 2 Moderate Capability	Class 3 Marginal Capability	Class 4 Limited Capability	Class 5 Not Suitable
Slope %	<2	2-5	5-8	8-16	>16
Effective depth (cm)	≥ 120	90-120	60-90	25-60	<25
Drainage (1)	Class 4	Class 3,5	Class 2,6	Class 1	Class 0
Texture class(2)	L, SL, SCL, CL, SC	SiL, SiCL, SiC, Si, light C	F. S, C	S, G.S	Extremely G. sand
Clay %	<35	35-50	50-60	60-80	>80
Permeability (cm/hr)	2-6.25	0.5-2 6.25-12.5	0.25-0.50 12.5-25	0.12-0.25 25-40	>40 <0.12
A. Water(3) **(mm)**	≥120	80-120	80-60	60-30	<30
CEC ($cmol_c$/kg)	≥30	15-30	10-15	5-10	<5
EC (dS/m)	<4	4-8	8-16	16-32	>32
ESP	<15	15-20	20-30	30-40	>40
$CaCO_3$ %	<10	10-20	20-40	40-50	>50

(1) According to FAO, 1977.
(2) Texture classes: L: Loamy SL: Sandy loam SCL: Sandy clay loam
CL: Clay loam SC: Sandy clay SiL: Silty loam SiCL: Silty clay loam
SiC: Silty clay Si: Silty F.S.: Fine sand C: Clay
S: SandyG.S.: Gravely sand
(3) Available water capacity depth till the effective depth up to 80 cm.

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Table 7. Current land capability

Mapping Unit	Capability Class	Limiting Factor(s)		Area (acres)
		Correctable	Not Correctable	
Cp131	Class 5	AW	Sd	4192.57
Cp133	Class 4	AW/ CEC		14113.71
Cp134	Class 3	Prm	$CaCO_3$/ Sd	3071.18
Cp221	Class 3	Dr/ECe	$CaCO_3$	14970.46
Cp222	Class 3	Prm	$CaCO_3$	12751.88
Cp223	Class 5	AW/ ECe		2018.89
Cp321	Class 5	ECe		9431.29
Cp322	Class 5	AW/ECe		3760.31
Cp411	Class 5		$CaCO_3$	1254.78
Cp412	Class 5		$CaCO_3$	1274.43
Cp413	Class 3	Sd	$CaCO_3$	1291.00
Cp414	Class 5	ECe		1168.83

Limiting factors: AW: available water Dr: drainage Prm: permeability
Sd: soil depth CEC: cation exchange capacity ECe: electric conductivity

Table 8. Current capability verses potential capability

Capability class	Current area (acres)	%	Potential area (acres)	%
Class 3	32084.52	46.30	55629.52	80.27
Class 4	14113.71	20.37	6948.03	10.03
Class 5	23101.10	33.34	6721.78	9.70
Total area	69299.33	100.00	69299.33	100.00

3.4- Land suitability for different crops:

Physical land suitability for ten different LUTs were tested in the capable soils using ALES software. The results were imported to ILWIS GIS to display maps, Tables 9 & 10 and Fig 4. It is starkly observed that the study area suffers from a lack of highly suitable soils for the different land use types presented in the area due to the different soil limiting factors presented in Table 9.

Table 9. Physical Land Suitability Sub-classes

LUTs LMUs	Wheat	Barley	Clover	Maize	Sorghum	Groundnut	Olive	Fig	Citrus	Guava
Cp133	3m/nr	3m/na/nr	3m/na/nr	4na	3m/nr	4na	3na/nr	3m/na/nr/r	4na	4na
Cp134	2m/na/r	2m/na/r	3na	4na	2na	3na	4r	4r	4na/r	3sk/na
Cp221	3sk/m/na	3m/na	4sk	4sk/na	3sk/m/na	4sk/na	3na	3m/na/r	4sk/na	4sk/na
Cp222	2m/r	2m/na/r	3na	2m/na	2m	3na	2m/na	2m/na/r	3na	3na
Cp413	2e/m/na/r	3na	3na	4na	2e/m/na/r	4na	3na	3m/na/r	4na	4na

2 = moderately suitable. 3 = marginally suitable. 4= not suitable.
m = moisture availability o = oxygen availability r = rooting Condition na= nutrient availability
nr = nutrient retention capacity e = topography sk = salinity and alkalinity

Table 10. Suitability classes' areas (acre) for the LUTs

LUTs / Capability class	Wheat	Barley	Clover	Maize	Sorghum	Groundnut	Olive	Fig	Citrus	Guava
S1	0	0	0	0	0	0	0	0	0	0
S2	17114.06	15823.06	0	12751.88	17114.06	0	12751.88	12751.88	0	0
S3	29084.17	30375.17	31227.77	0	29084.17	15823.06	30375.17	30375.17	12751.88	15823.06
N	0	0	14970.46	33446.35	0	30375.17	3071.18	3071.18	33446.35	30375.17
Area (acres)	46198.23	46198.23	46198.23	46198.23	46198.23	46198.23	46198.23	46198.23	46198.23	46198.23

S1 = highly suitable. S2 = moderately suitable. S3 = marginally suitable. N= not suitable.

3.5- Crop Water Requirements, Irrigation Requirements, Net return and Irrigation scheduling:

The crop water requirements (CWR) and irrigation water requirements (IR) are calculated for each LUT taking into consideration the amount of rainfall during the growth season, Table 11. The CWRs are found to range between 210.35 mm for clover (for one cut) and 1123.95mm for guava. While the irrigation requirements range between 152.97 mm for clover (for one cut) and 981.07 mm for guava, Table 11.

The net return for each land use type is obtained from the Agricultural Statistics (2000 & 2001), then the net return per month (NR/acre. month) is calculated . Net return per cubic meter of water is also calculated as L.E. /m^3 of irrigation water for each LUT. It is clear from Table (12) that the highest net return per month is obtained from clover (412.2 L.E. /acre. month), and the lowest one is obtained from barley (69.8 L.E. /acre. month). On the other hand, the highest net return per cubic meter of irrigation water is obtained from clover (1.68 L.E. /m^3), while the lowest NR/m^3 is obtained from guava (0.23 L.E. /m^3).

Since the study area suffers from shortage of water resources, the irrigation scheduling is thus a limiting factor. The objective is thus to maximize return from the existing water resources (rains and surface water). Three LUTs (wheat as a winter crop, maize as a summer one and fig as orchard) are used as examples for calculating irrigation scheduling if they will be planted in "Cp222" mapping unit (Tables 13, 14 and 15). As seen from Table 13, there is a need only is for supplementary irrigation in the periods that the amount of rains is not sufficient for the crop. In case of wheat, it can obtain the required moisture for (84 days) from the rains; and it needs supplementary irrigation for three times with total amount of 364.3 mm. On the other hand, in case of maize as a summer crop, Table 14, the contribution of rain is zero as there is no rain all over the growing season of the maize. In such cases the need for scheduling the irrigation application is of importance to manage the plant-water relationship and to get the most benefits from existing water resources. In case of fig trees plantation, Table 15, the amount of rainfall is sufficient in the first (47 days) growing period, but it needs supplementary irrigation after that for five months with total amount of 749.6 mm of irrigation water. The application of such schedules leads to ensure saving water resources and produce healthy plants.

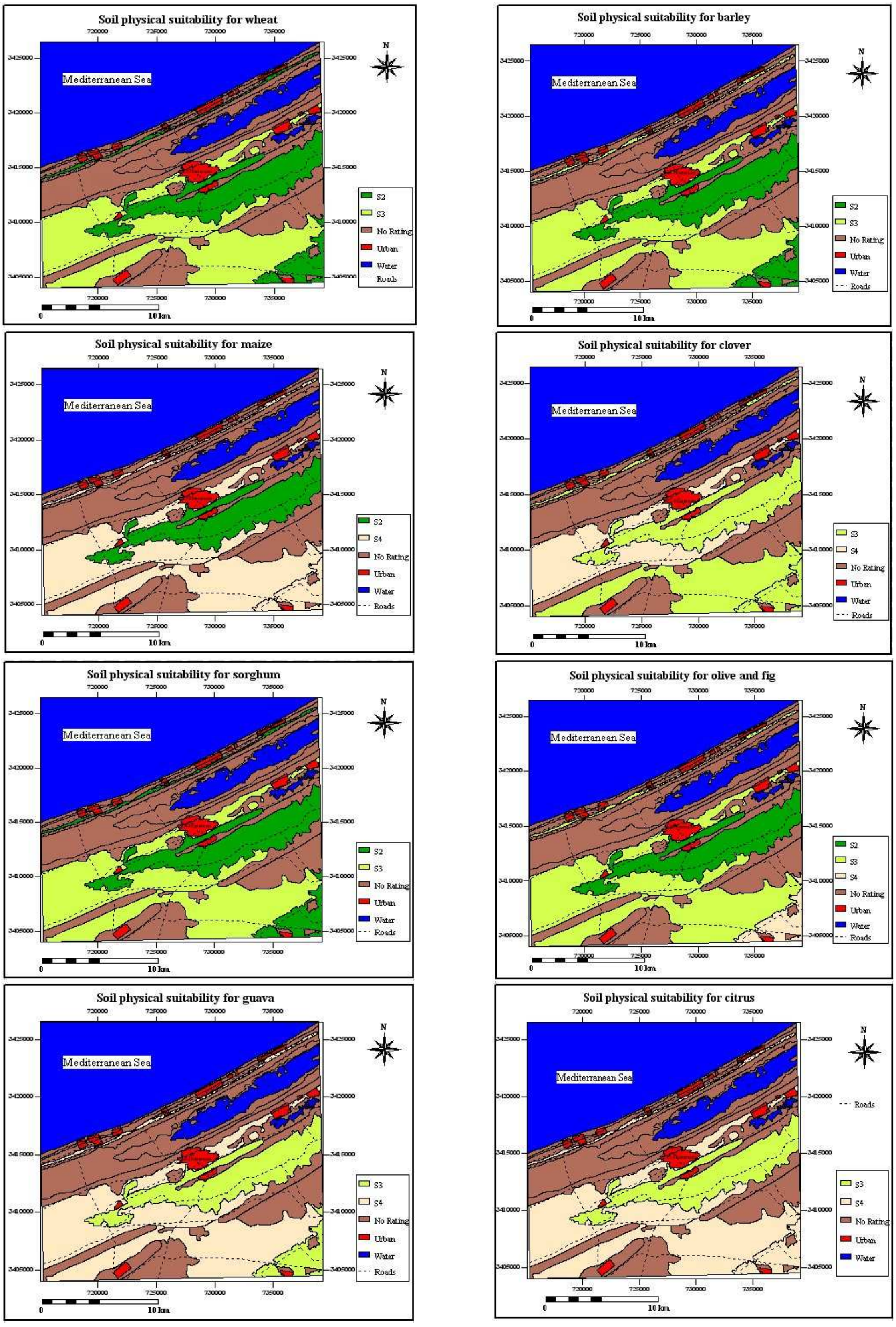

Figure 4. Physical land suitability for different utilization types.

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Table 11. Crop water requirements (CWR) and irrigation requirements (IR) for each LUT.

LUT	Total ETo* (mm)	Total CWR (ETm) mm	Total Effective Rain (mm)	Total IR (mm)	IR Rating
Wheat	624.69	529.04	132.5	396.54	W*3
Barley	456.76	355.03	132.5	222.54	W2
Clover	288.84	210.35	57.38	152.97	W1
Maize	588.86	477.47	0	477.47	S*2
Sorghum	579.26	412.21	0	412.21	S1
Groundnut	638.24	531.23	0	531.23	S3
Olive	1604.88	995.76	142.88	852.88	O*2
Fig	947.99	762.99	0	762.99	O1
Citrus	1604.88	1064.74	142.88	921.86	O3
Guava	1604.88	1123.95	142.88	981.07	O4

Total quantities over the growth period for each LUT
* ETo: Potential evapotranspiration.
Irrigation Efficiency = 70%
*** W** = winter crops. * **S** = summer crops. * **O** = orchards.

Table 12. Net return (NR), net return/month, and net return/cubic meter of irrigation water (NR/ m3)

LUT	IR (m^3/acre)	NR* (L.E.)	Growth period (month)	NR/ month	NR/ month rating	NR/ m^3	NR/m^3 rating
Wheat	1586.16	863.9	5.5	157.1	W2	0.54	W2
Barley	890.16	279.3	4	69.8	W3	0.31	W3
Clover*	611.88	1030.4	2.5	412.2	W1	1.68	W1
Maize	1909.88	726.6	4	181.6	S2	0.38	S2
Sorghum	1648.84	472.1	4	118.0	S3	0.29	S3
Groundnut	2124.92	1139.4	4.5	253.2	S1	0.54	S1
Olive	3411.52	1066.7	12	88.9	O3	0.31	O3
Fig	3051.96	1961.9	12	163.5	O2	0.64	O1
Citrus	3687.44	2104.8	12	175.4	O1	0.57	O2
Guava	3924.28	900.0	12	75.0	O4	0.23	O4

* Source: Agricultural Statistics (2000&2001). "Net return calculated in Egyptian Pound"
* Clover: all calculations for the first cut.

Table 13. Irrigation scheduling for wheat

Date	Day No.	TAM (mm)	RAM (mm)	Rainfall (mm)	Efct. Rain (mm)	ETc (mm)	ETc/Etm (%)	SMD (mm)	Irr. nterv. (Days)	Net Irr. (mm)
15-11	1	49.7	29.8	4.3	0	1.2	100.00%	1.2		
20-11	6	63.2	37.9	5	5	1.2	100.00%	2.4		
25-11	11	76.8	46.1	5.7	5.7	1.2	100.00%	2.8		
30-11	16	90.3	54.2	6.4	6.4	1.2	100.00%	2.4		
05-12	21	103.9	62.3	7	7	1.3	100.00%	1.4		
10-12	26	117.4	70.5	7.5	7.4	1.7	100.00%	1.7		
15-12	31	131	78.6	7.9	7.9	2.2	100.00%	3.7		
20-12	36	144.5	86.7	8.2	8.2	2.6	100.00%	7.6		
25-12	41	158.1	94.8	8.5	8.5	3	100.00%	13.2		
30-12	46	171.6	103	3.4	3.4	3.4	100.00%	26		
01-1	48	177	106.2	8.7	8.7	3.6	100.00%	24.3		
06-1	53	190.6	114.4	8.9	8.9	4	100.00%	34.7		
11-1	58	198.7	119.2	8.9	8.9	4.2	100.00%	46.7		
16-1	63	198.7	119.2	8.7	8.7	4.2	100.00%	59		
21-1	68	198.7	119.2	8.3	8.3	4.2	100.00%	71.7		
26-1	73	198.7	119.2	7.7	7.7	4.2	100.00%	85.2		
31-1	78	198.7	119.2	6.9	6.9	4.2	100.00%	99.5		
05-2	83	198.7	119.2	5.9	5.9	4.3	100.00%	114.9		
07-2	85	198.7	119.2	0	0	4.3	100.00%	123.4	84	123.4
10-2	88	198.7	119.2	4.8	4.8	4.3	100.00%	8.1		
15-2	93	198.7	119.2	3.7	3.7	4.3	100.00%	25.9		
20-2	98	198.7	119.2	2.8	2.8	4.4	100.00%	44.9		
25-2	103	198.7	119.2	2.1	2.1	4.4	100.00%	64.7		
02-3	108	198.7	119.2	1.6	1.6	4.5	100.00%	85.3		
10-3	116	198.7	119.2	0	0	4.5	100.00%	121.4	31	121.4
11-4	148	198.7	119.2	0	0	2.7	100.00%	119.5	32	119.5
Total				142.9	138.5	529	100.00%			364.3

Table 14. Irrigation scheduling for maize

Date	Day No.	TAM (mm)	RAM mm)	Rainfall (mm)	Efct. Rain (mm)	ETc (mm)	ETc/Etm (%)	SMD (mm)	Irrigation Intervals (Days)	Net Irrigation (mm)
01-6	32	96.3	53	0	0	2.8	100.00%	53.8	31	53.8
18-6	49	121.9	67.1	0	0	5	100.00%	67.2	17	67.2
02-7	63	132.5	72.9	0	0	5.8	100.00%	78.3	14	78.3
15-7	76	132.5	72.9	0	0	5.8	100.00%	75.3	13	75.3
28-7	89	132.5	72.9	0	0	5.8	100.00%	75.6	13	75.6
11-8	103	132.5	75	0	0	4.5	100.00%	75.6	14	75.6
Total				0	0	477.5	100.00%			425.8

Table 15. Irrigation scheduling for fig

Date	Day No.	TAM (mm)	RAM (mm)	Rainfall (mm)	Efct. Rain (mm)	ETc (mm)	ETc/Etm (%)	SMD (mm)	Irrigation Intervals. (Days)	Net Irrigation (mm)
01-5	48	231.8	145.2	0	0	3.4	100.00%	146.4	47	146.4
10-6	88	231.8	150.3	0	0	4.1	100.00%	151.5	40	151.5
16-7	124	231.8	150.7	0	0	4.3	100.00%	152.5	36	152.5
21-8	160	231.8	150.7	0	0	4.3	100.00%	154.5	36	154.5
26-9	196	231.8	141.4	0	0	3.5	100.00%	144.7	36	144.7
Total				0	0	763	100.00%			749.6

TAM= Total Available Moisture = (FC% - WP %)* Root Depth [mm].
RAM= Readily Available Moisture= TAM * P [mm]. SMD= Soil Moisture Deficit [mm].
Etc= actual crop evapotranspiration. ETm= maximum crop evapotranspiration

3.6- Sustainable Land Use Assessment:

In order to define the most sustainable land use for each land mapping unit, the results of physical suitability, net return, net return per month, irrigation requirements and net return per cubic meter of irrigation water are rated, Table 16.

Table 16. physical suitability of LMUs, IR-rating, NR/month rating, and NR/m^3 rating

LMUs LUT	Cp133	Cp134	Cp221	Cp222	Cp413	IR Rating	NR/month Rating	NR/m^3 rating
Wheat	3	2	3	2	2	W3	W2	W2
Barley	3	2	3	2	3	W2	W3	W3
Clover	3	3	4	3	3	W1	W1	W1
Maize	4	4	4	2	4	S2	S2	S2
Sorghum	3	2	3	2	2	S1	S3	S3
Groundnut	4	3	4	3	4	S3	S1	S1
Olive	3	4	3	2	3	O2	O3	O3
Fig	3	4	3	2	3	O1	O2	O1
Citrus	4	4	4	3	4	O3	O1	O2
Guava	4	3	4	3	4	O4	O4	O4

IR= irrigation requirements (m^3/acre).
NR/month= net return per month (L.E. /acre. month).
NR/m^3 = net return per cubic meter of irrigation water (L.E. /m^3).

For planning the most sustainable land use, there are three LUT groups; winter crops, summer crops and orchards. Therefore, there are two choices; either planting field crops (winter and summer) or orchards. The criteria for decision, as used herein, depend on the physical land suitability. Once, the LUT has the highest suitability among its group; then it will be the most sustainable LUT. If the physical land suitability is the same for LUTs; then the next factor that comes into consideration will depend on its priority.
In the present study, two scenarios are proposed; one for the present situation, where there is a scarcity of irrigation water in the study area, and the priority is given for the LUT with lower irrigation requirement. The other scenario considers abundance of irrigation water, therefore, the net return per month and net return per cubic meter will have the priority after the physical land suitability, Table 17.
The results indicated that most sustainable crops under the limited irrigation conditions are clover , barely , wheat and sorghum. Fig and olive are the most sustainable orchards in area, whereas guava can be considered in the Cp134 mapping units.

Table 17. The most sustainable land use for the present and the coming up situations scenarios.

LMU	Scenario	Decision criteria	Most sustainable land use
Cp133	1	IR	Clover and Sorghum against Fig
	2	NR/m^3 &NR/month	Wheat and Sorghum against Fig
Cp134	1	IR	Barely and Sorghum against Guava
	2	NR/m^3 &NR/month	Wheat and Sorghum against Guava
Cp221	1	IR	Barely and Sorghum against Fig
	2	NR/m^3 &NR/month	Wheat and Sorghum against Fig
Cp222	1	IR	Barely and Sorghum against Fig
	2	NR/m^3 &NR/month	Wheat and Maize against Fig
Cp413	1	IR	Wheat and Sorghum against Fig
	2	NR/m^3 &NR/month	Wheat and Sorghum against Fig

IR= irrigation requirements (m^3/acre).
NR/m^3 = net return per cubic meter of irrigation water (L.E. /m^3).
NR/month= net return per month (L.E. /acre. month).

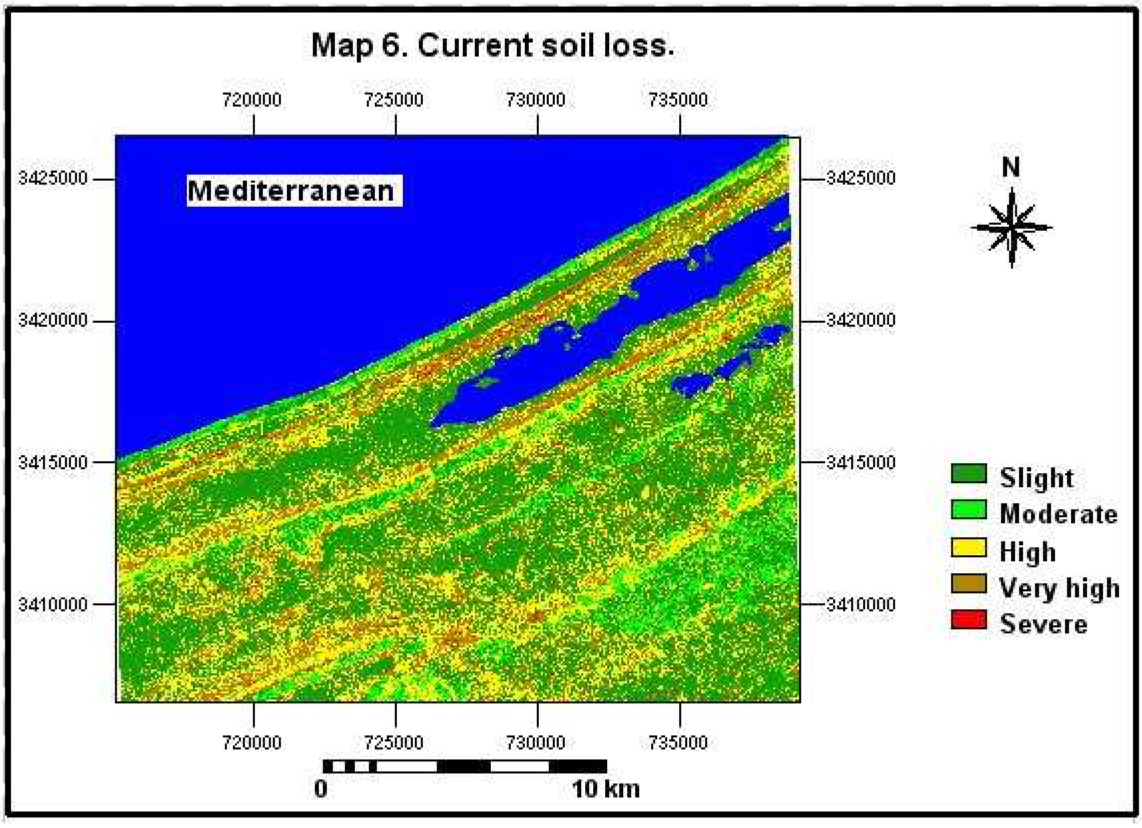
3.7- Soil erosion risk assessment and effect of sustainable Land use on erosion risk:

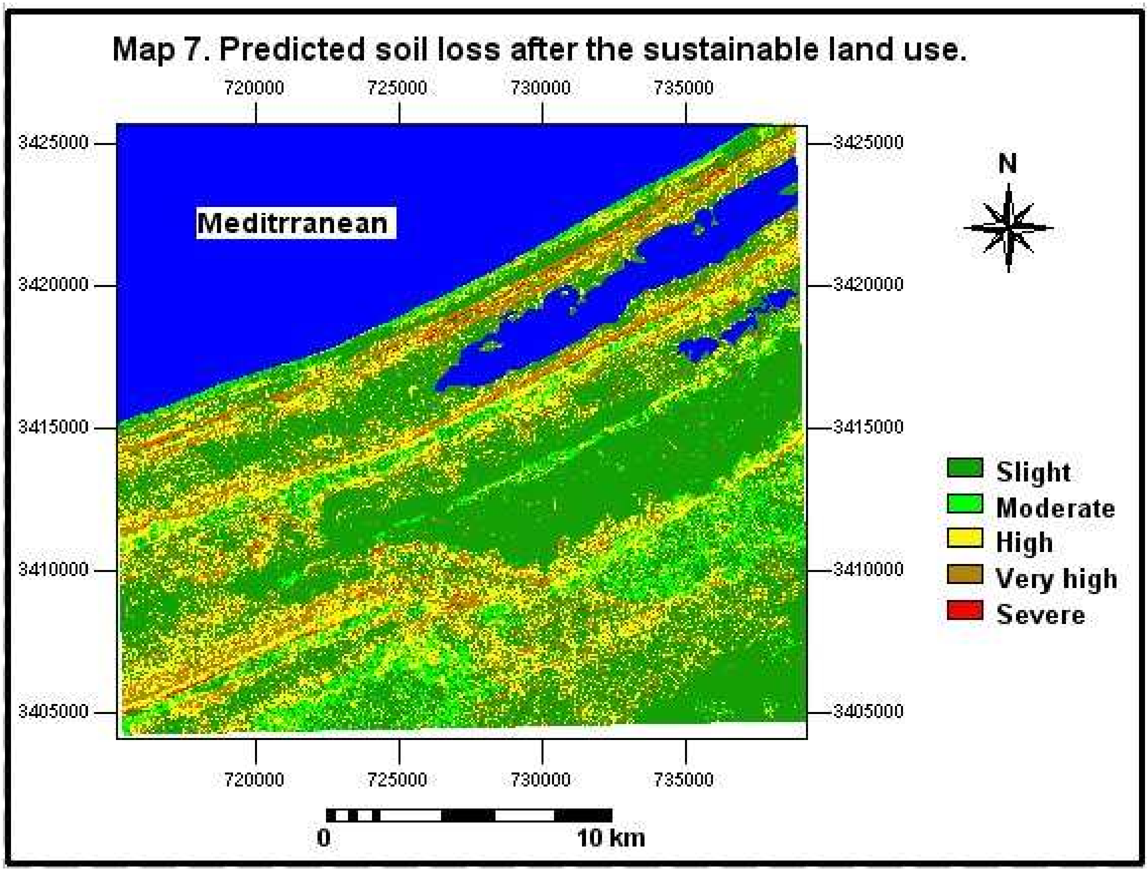
To investigate the environmental impact of the proposed sustainable land use, the soil erosion risk is estimated before and after applying the sustainable land use. The USLE (A=R.K.LS.C.P.) was used to estimate the soil loss due to water erosion. The "R" value is calculated as 370 J/ha , the soil erodability "K" values are obtained using the monograph, developed by Wischmeier et al. (1971), the slope length and the slope steepness factors are derived with the help of the GIS, the cropping management factor values are assigned 0.2 as an average for cultivated areas; and 1 for the areas with spares and scattered vegetation depending on the land use map created from the SPOT image of the area, and the management factor was assigned to 1 for all the study area, as there are no significant management practices in the area.

The potential soil loss and the predicted soil loss after applying sustainable land uses in the study area are presented in Table 18 and Maps 6&7. The obtained results indicated that the soil loss will be decreased significantly in the soils of Cp134, Cp212, Cp222 and Cp411 mapping units by applying the proposed sustainable land use and proper erosion control practices that enhance water percolation.

Table 18. Predicted annual soil loss for each mapping unit (excluding urban areas)

Map unit	K-factor	L-factor	S-factor	Potential soil loss average (mt/ha/y)	Soil loss after sustainable land use (mt/ha/y)	Area (acres)
Cp111	0.12	0.631	0.3383	9.06	9.06	1970.37
Cp122	0.12	0.645	0.2415	6.83	6.83	1280.64
Cp112	0.12	0.645	0.2219	6.25	6.25	372.35
Cp113	0.12	0.647	0.0923	2.72	2.72	387.21
Cp121	0.12	0.605	0.5497	13.67	13.67	1851.29
Cp131	0.14	0.648	0.1859	6.14	6.14	4192.57
Cp133	0.28	0.646	0.1717	11.30	11.30	14113.71
Cp132	0.12	0.645	0.1945	5.46	5.46	2985.31
Cp134	0.25	0.646	0.1143	**6.77**	**1.42**	3071.18
Cp211	0.12	0.617	0.4077	10.53	10.52	3703.08
Cp212	0.12	0.644	0.2388	**6.52**	**6.31**	1640.77
Cp221	0.33	0.643	0.2152	16.52	16.52	14970.46
Cp222	0.28	0.646	0.1731	**11.23**	**2.25**	12751.88
Cp223	0.12	0.646	0.1711	8.91	8.92	2003.87
Cp311	0.12	0.570	0.9222	22.02	22.02	2152.28
Cp321	0.26	0.637	0.2416	14.28	14.28	9431.29
Cp322	0.23	0.646	0.1116	6.04	6.04	3760.31
Cp411	0.12	0.611	0.5243	**13.07**	**11.15**	1254.78
Cp412	0.06	0.624	0.4169	5.50	5.22	1274.43
Cp413	0.25	0.608	0.5281	27.79	27.74	1291
Cp414	0.18	0.635	0.1917	7.44	7.41	1168.83


Map 6. Current soil loss.
720000
725000
730000
735000
3425000
3420000
3415000
3410000
Mediterranean
N
Slight
Moderate
High
Very high
Severe
0
10 km


Map 7. Predicted soil loss after the sustainable land use.
720000
725000
730000
735000
3425000
3420000
3415000
3410000
3405000
Meditrranean
N
Slight
Moderate
High
Very high
Severe
0
10 km

4. CONCLUSIONS

4.1 More than 55000 acres in the area are marginally capable for agriculture.
4.2 The present study proved that GIS, combined with modeling and soil data, are powerful tools for water management decision making in the area.
4.3 The most sustainable land use recommended under the present limited water resources are clover , barely , wheat and sorghum as field crops. Whereas, fig, olive and occasionally guava are the most sustainable orchards cultivations.
4.4 Considerable decrease in the erosion soil loss con be achieved by applying the recommended sustainable land use with proper erosion control practices.

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