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Integration of Terrain, Thematic Mapper and Soil Quality Data for Surface Hydrology, Water Erosion and Land Suitability Modeling: NW Coast, Egypt

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AT A REPRESENTATIVE area at Omyed, NWC, the present study aims to integrate GIS and RS technologies with soil qualities data in assessing and modeling the rain- runoff relationship, the water erosion hazards and the land suitability for specific uses. The GIS-modeling capability was used to integrate the analysis outputs of thematic mapper image, of digital terrain, and of soil qualities to model the following :

1. Rainfall–Runoff: The rainfall–runoff relationship was estimated by using the curve number method The study indicated that a total number of 46 cisterns are required for collecting and reserve 4121 m^3 in November and 19202 m^3 in January of runoff water for eleven natural undisturbed watersheds.

2. Water Erosion Hazards : The revised universal soil loss equation was used .The analysis showed that, about 506.23 km^2 are subject to erosion rate of less than 20 ton/ha/year and about 153.31 km^2 are subject to erosion rate of more than 20 ton/ha/year for the maximum erosion hazard scenario. For the current erosion hazard scenario 567.26 km^2 are subject to erosion rate of less than 20 ton/ha/year and about 92.28 km^2 are subject to erosion rate of more than 20 ton/ha/year.

3. Land suitability for specific uses : MicroLEIS land evaluation model linked with GIS was used. The capability evaluation indicated that, about S2 : 178.49 km^2 , S3 : 188.09 km^2, and N : 296.77 km^2. The irrigated agriculture suitability for 12 specific land gave for olive about 9.67 km^2 as S2 and 7.86 km^2 as S3 for olive, for peach and citrus about 11.05 km^2 as S3 and 6.39 km^2 as S4 and for Wheat, Corn, Alfalfa, Sunflower, Cotton, soybean, Sugar Beat, Potato and Melon about 17.44 km^2 are S4. The rainfed agriculture suitability evaluation indicated that, about 366.58 km^2 are class II, 292.35 km^2 are class III and 4.42 km^2 are class IV for rainfed agriculture.

Keywords: RS-classification, Terrain analysis, GIS-modeling, Rainfall – Runoff modeling, Water erosion hazards, Land suitability, NWC, Egypt.

The North Western Coastal Region (NWCR) of Egypt is one of the most promising areas for agricultural development. It extends from Alexandria in the east to Sallum in the west with about 500 km width and about 40 km depth. The area occupies about 30 million feddan and is considered as one of the most promising areas for agricultural expansions in Egypt.

Many studies proved that the limiting factors for sustainable agricultural production in NWC are the annual rainfall, the soil characteristics, the land suitability for trees, crops, and range as will as salinity, overgrazing, and water and wind degradation risks. Therefore, land degradation and suitability assessment at spatial and temporal scales could play a vital role in addressing the sustainable land management and conservation issues in the North Western Coast.

The present study aims to integrate GIS and RS technologies in assessing and modeling land degradation and land suitability of land resources in NWC in order to help the planners and the decision makers to realize the crucial environmental data, and understanding their spatial association.

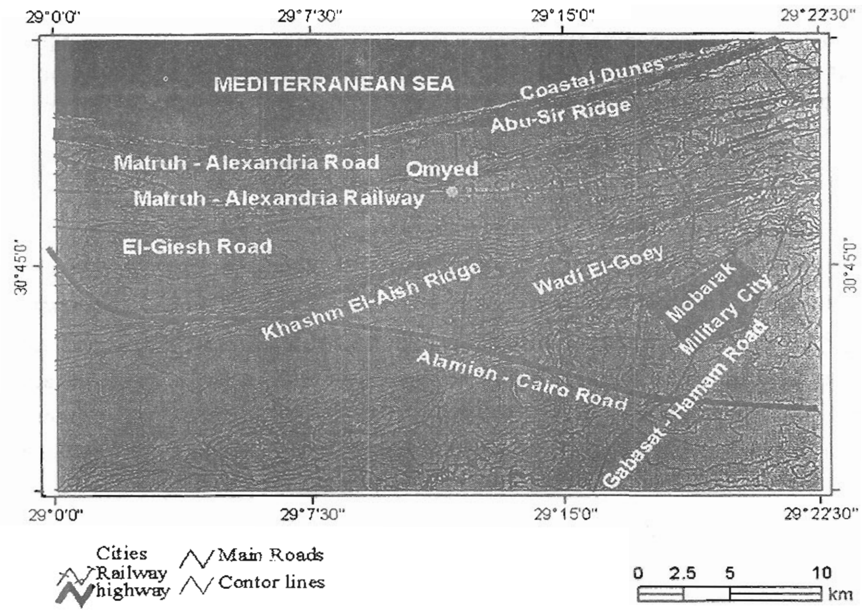
At a representative area at Omyed, NWC, the specific objectives of the present study are to:

1. Analysis of TM Satellite image to assess the optimum spectral classes.
2. Assess the terrain surface characteristics.
3. Define the soil mapping units qualities and their spatial characteristics.
4. Model rainfall-runoff, soil water erosion hazard, and land suitability for specific uses in GIS environment.

Area Studied

The study area lies in the northern part of the Western Desert of Egypt, situated about 68 km to the west of Alexandria City. It is bounded to the north by the Mediterranean Sea and extends about 25 km to the south direction and bounded by longitudes 29° 00′ 00" & 29° 22′ 30" E and Latitudes 30° 37′ 30" & 30° 52′ 30" N, with a total area of about 863.6 Km^2 (Map 1).

The study area characterized by the short rainy season begins during the latter part of October with 75% of the annual rainfall occurring in November through March and the long hot summer that characterize the North Western Coast which has a Mediterranean climate. The geological formation of the North Western Coast shows that it is essentially covered by sedimentary rocks belonging to the Tertiary and Quaternary periods. The most of the soils are young and characterized by the absence of diagnostic horizons and the only prominent features of development are calcic, gypsic and salic horizons. The main source of surface water in the study area is precipitation. The surface runoff occurs during and immediately after the rainy periods and depending on some factors such as slope of the ground surface and areal extend of the catchment area. The ground water occurs under both free water table and perched conditions.



Map 1. Location map of the study area.

Most of the study area is unused land, the land uses in the study area are cultivated areas, Urban areas, and Quarries. Cultivated areas are irrigated by Bahig canal extension or as scattered small areas depending on rainfall and wells. Urban areas presented as village (Roysat village), tourism area comprises of resorts located at the north along the Mediterranean sea shore line, protectorate (Omyed protectorate) and military city (Mobarak military city). Quarries are located mostly at south and as few small scattered quarries at north and these quarries are for Gypsum, Limestone extraction, and also for cutting of the ridges which are of limestone.

Material and Methods

1. Processing of satellite TM image

The study area (El-Hamam– El-Alamien) is represented by a window (1507* 1195 pixels) of TM-Scene dated of 21-6-1998, Path/Row 178/39. ERDAS IMAGINE Software version 8.4 (ERDAS, 1999) was used to elaborate preprocessing, processing and classification accuracy of the satellite image (Saleh , 2003 and Abd El-Hady, 2004).

2. Processing of topographic maps

Six topographic maps covers the study area with scale (1:25000) were prepared and scanned by the scanner device. Screen digitizing of topographic maps is done by using the software "AutoCAD R14" (AutoDesk, 1997). The digitized features exported to DXF format that transformed by ArcInfo Workstation 8.1 (Environmental Systems Research Institute, ESRI 2001) to ARC format. The LAT-LONG coordinate system was converted to a real-world projection (Universal Transverse Mercatore, UTM). The parameters for geo-referencing are:

Projection: UTM Zone: 35 Spheroid: WGS84

3. Terrain analysis

Digital Terrain Model (DTM) was generated from the contour lines (5 m interval) and spot heights of the topographic maps by using the deterministic thin-plate spline interpolation technique (Wahba, 1990) in the Geostatistical analyst, ArcMap 8.1.A validation process was performed on the Digital Terrain Model (DTM) to assess its accuracy. In this process, the predicted values were compared to the actual values. The mean of the predicted error and the Predicted Root Mean Square Error (PRMSE) were calculated. This procedures were performed using the geostatistical analyst in ArcMap 8.1 Sinks in DTM were identified and filled by using an iterative routine proposed by Hickey *et al.* (1994). Land Forms……

The slope and aspect of the study area were calculated using the Slope function in the 3D analyst of ArcMap 8.1. Flow direction and Flow accumulation were calculated from DTM by using the flowdirection and flowaccumulation functions in ArcInfo Workstation 8.1.

Stream Networks were derived from the Digital terrain model (DTM) by applying an area threshold value to the output from the flowaccumulation function using a GRID algebraic expression. A unique value was assigned for each of the links in the raster linear stream network by using the streamlink function. The raster linear network was converted to an arc coverage using streamline function in Arc Info Workstation 8.1. Watersheds were derived from the Digital Terrain Model (DTM) by first identifying the pour points (outlets), cells above which the watershed will be determined, through selectpoint and snappour functions and then using the identified outlets and the flow direction grids in the watershed function in Arc Info Workstation 8.1 .

4. Field work and Laboratory analysis

Based on the pre-field interpretation and the information gained during a reconnaissance survey, four sample areas were chosen. These sample areas were selected so that they passing through the different landforms. 21 soil profiles were described (67 disturbed soil samples) according to FAO (1990). Physical and chemical soil sample analysis were carried out according to Richards (1954) and Jackson (1967).

5. Modeling in GIS environment

Rainfall-Runoff Modeling

An estimation of runoff quantity from rainfall was generated using the Soil Conservation Service (SCS) curve number method (USDA-SCS, 1985).

Soil water erosion modeling

An estimation of soil loss due to water erosion was generated used the Revised Universal Soil Loss Equation (RUSLE) Renard *et al.* (1997). The rainfall erosivity factor (R) was calculated from the available agro-climatological data for Burg El-Arab climatic station. The soil erodability factor (K) was calculated from the data obtained from grain size analysis, structure, permeability and organic matter content) Wischmeier & Smith (1978). The combined slope length factor (Ls) was calculated by using the "Iterative Slope Length Processing" proposed by Hickey (2000) and Van Remortel *et al.* (2001) . The cropping management factor (C) was obtained from land use prevailed in the study area and applied to the different land units. The erosion control practice factor (P) is set to one (1) . Each of these factors was converted into a GRID file in ArcMap 8.1, by assigning the specific value of each factor to its corresponding land unit, then the multiplicative approach is then applied to get the soil loss rate grid which then overlapped with the watersheds grid to get the soil erosion risk for each watershed.

Land Evaluation

Twelve land uses were tested for their suitability in the study area, namely, Wheat, Corn, Melon, Potato, Soya Bean, Cotton, Sunflower, Sugar beat, Alfalfa, Peach, Citrus, Olive. The requirements of each kind of land use are obtained from Sys *et al.* (1993). The land use requirements are matched to the land characteristics of each mapping units to determine its suitability for this land use.

A land evaluation procedure for irrigated agriculture was carried out using the MicroLEIS (De La Rosa *et al.,* 1992) evaluation software. Matching tables were used to define four capability classes: Class S1 (Excellent); Class S2 (Good); Class S3 (Moderate); and Class N (Marginal). Four subclasses were defined according to site (t), soil (l), erosion risks (r) and bioclimatic deficiency (b) limitations. The suitability class revealed the kinds of limitations for specific use. The soils limitations for this study are useful depth (p), texture (t), drainage (d), carbonate) (r), salinity (s) and sodium saturation (a).

A land suitability evaluation procedure, for rainfed agriculture, was performed. The applied method takes into consideration three compound land uses, namely, trees, cereals, and grazing. The land use requirements were obtained from Sys *et al.* (1993). Six land characteristics/land qualities were used in the land evaluation procedure, which were grouped into four land classes (Abdel-Kader *et al.*, 1998). The first two land characteristics (slope and flow accumulation) were combined together through the overlay process to make water collection capability (FAC) land quality. Other land characteristics/land qualities are: soil depth, soil texture, soil salinity, and soil sodicity. The matching of land characteristics/land qualities with the land use requirements was carried out using the overlay capabilities of the GIS software.

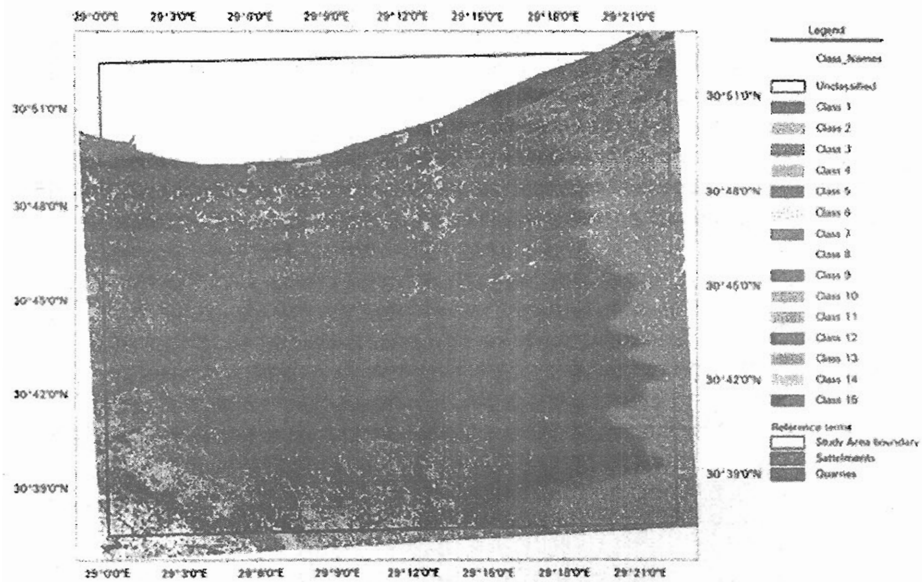
Result and Discussion

1.Spectral surface units

The soil adjusted vegetation index (SAVI) gave five vegetation categories, and the informative bands combination is TM1, TM2, and TM7. The spectral class's centers are 15 clusters defined by selected test zones (Table 1& Map 2). The biased principal component classification produced the highest overall accuracy, for mapping the soil surface units, which is 97.93 %, the hybrid classification produced an overall accuracy of 88.78 %, the principal components classification produced an overall accuracy of 80.87 %, and the unsupervised classification produced the lowest overall accuracy which is 73.97% (Saleh, 2003 and Abd El-Hady, 2004).

TABLE 1. Spectral soil units .

CLASS	Description
1	Cultivated, and few shells on the surface
2	Aeolian sandy deposits with few shells and ripples
3	Aeolian and Alluvial deposits with small gullies, ripples, shells and gypsum crystals
4	Sand with moderate shells and ripples
5	Sand with abundant shells, rills, and ripples
6	Aeolian deposits over limestone
7	Sandy hummocks and ripples
8	Sandy surface with small ripples
9	Alluvial deposits with Small gullies
10	slopes with narrow gullies and Some scattered boulders
11	Former lagoon bed with natural vegetation
12	Former lagoon bed
13	Beach sand
14	Ridge summit
15	sand dunes



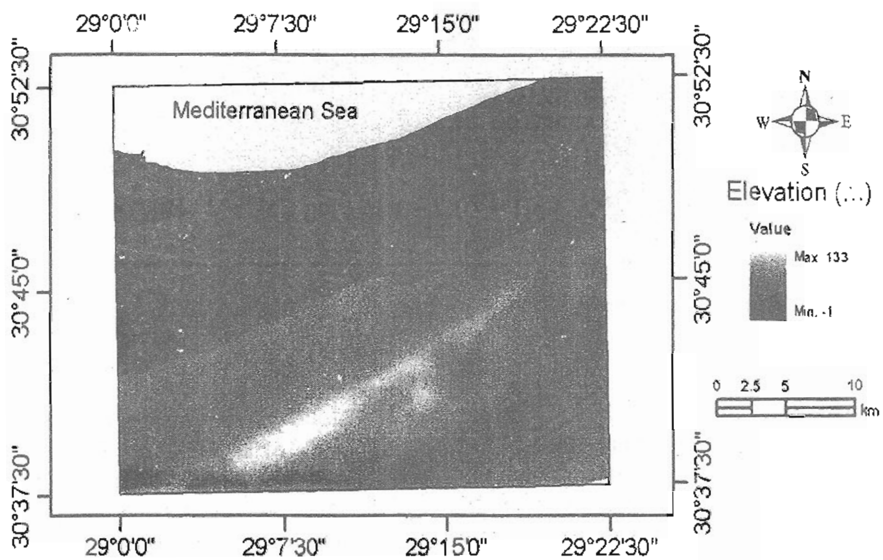
Map 2. Classification of biased principal components data .

2. Terrain units

The thin –plate spline exact interpolation technique proved to be statistically unbiased and valid for DTM (Map 2) analysis. The DEM analysis revealed that, 85.07 % of the area are flat to nearly level (0–1%), 14.7 % of the area are very gently slope to sloping (1–10 %), 0.23 of the area are strongly sloping to moderately steep (10 15 %), and 0.01 of the area are steep (>30 %). The slopes of area are flat (5.2%), north (22.95%), northeast (8.21%), east (7.2%), southeast (12.7%), south (13.36%), southwest (6.2%), west (6.24%), and northwest (17.95%). The Digital Terrain Model (DTM) analysis with the aid the satellite image analysis, existing body of knowledge in geo-morphology, and field observations outlined 14 landform units according to Zinck (1997) .The main land forms are: Sand beach (0.50%), Coastal dunes (0.31%), Ridge (13.10%), Terraced footslopes (5.28%), Overflow basin (10.45%), Decantation basin (5.28%), Former lagoon bed (0.51%), High valley floor (2.08%), Moderately high valley floor (1.44%), Moderately low valley floor (2.64%), Low valley floor (1.22%), Deep sand over rock (13.29%), Hummocky sand over rock (0.78%), and complex of shallow sand and rock (33.78%). The DTM (Map 2) analysis indicated that 85 % of the area are flat to nearly level, 15 % are very gently slope to sloping, 0.2% are strongly sloping to moderately steep, and 0.01% are steep. The DTM analysis for stream networks and watersheds identified 49 sub basins in the study area .

3. Soil mapping unites

Six soil mapping units (Map 3) were identified and grouped based on the landform units. The soil units are group of soils having soil horizons/layers similar in differentiating characteristics and arrangement in the soil profiles, except for the texture of the surface horizon, and developed from a particular type of parent material. They are equivalent to the soil series of the American soil taxonomy (Soil Survey Staff, 1999). The soils within the soil units are essentially homogeneous in all soil characteristics that they qualify to specific scientific subgroup names of the soil taxonomy. The data revealed that :



Map 3. Digital terrain (DTM) of the study area.

Soil mapping unit 1

Is deep, sandy to sandy loam, non saline, with some scattered boulders and few shells on the surface. The unit is typic haplocalcids and comprises 15.73% of the study area. This unit is prevailing in the terraced foot slopes and the overflow basins of the study area.

Soil mapping unit 2

Is deep, sandy to sandy loam, moderately saline, with ripples, rills, few shells, and shell fragments on the surface. The unit is typic Haplogypsids and occupies 5.27% of the study area. The unit presents at the decantation basins of the study area.

Soil mapping unit 3

Is moderately deep to deep, gravely sandy loam, very saline, with shell fragments and natural vegetation on the surface. This unit is sodic haplocalcids and comprises 0.51% of the study area. This unit is prevailing in the former lagoon bed in the study area.

Soil mapping unit 4

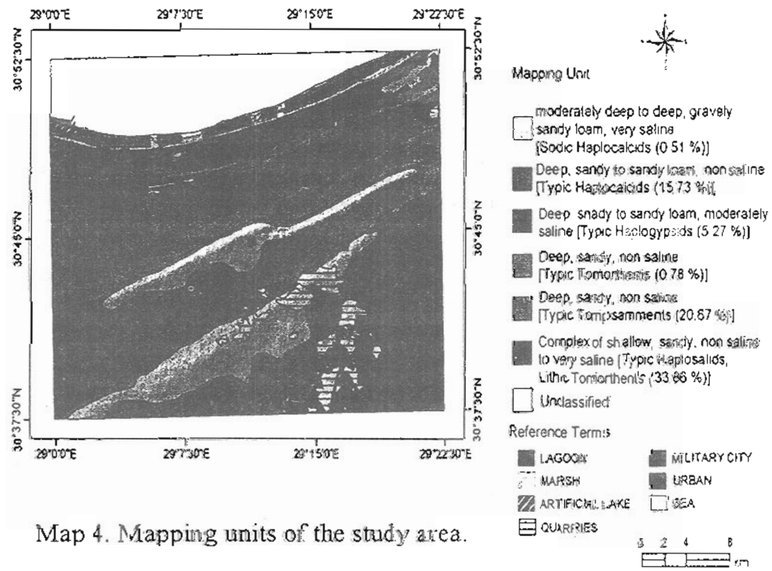
Is deep, sandy, non saline, with some natural vegetation and few shells and shell fragments on the surface. This unit is typic torripsamments and comprises 20.67% of the study area. This unit is prevailing in the high valley floor, moderately high valley floor, moderately low valley floor, low valley floor, and the deep sand over rock of the study area.

Soil mapping unit 5

Is deep, sandy, non saline, with small to medium hummocks and ripples on the surface. This unit is typic torriorthents and comprises 0.78 % of the study area. This unit prevails in the hummocky sand over rock landform unit of the study area.

Soil mapping unit 6

Is a complex of shallow, sandy, non saline to very saline, with some shells and shell fragments on the surface. This unit comprises typic haplosalids and typic torriorthents and 33.86% of the study area and dominates the complex of shallow sand and rocky landform unit.



Map 4. Mapping units of the study area.

4. GIS modeling

Rainfall – Runoff

The runoff of selected eleven undisturbed watersheds was estimated for the maximum two rainfall months November and January. Also, the required cisterns number to collect and reserve the runoff for these watersheds were calculated as the cistern is designed to store 500 m^3 of runoff (Table 2).

Water erosion

The soil loss rate was estimated, on a pixel wise basis, for two cases; the fist case for the maximum potential erosion risk whereas cropping management factor and erosion control practice factor are set to one (1) and the second case is the current erosion loss rate whereas the cropping management factor indicating the land use prevailed in the study area. These output maps were reclassified to get the soil loss erosion rate for each watershed, (Map & Table 3).

TABLE 2. The runoff volume of the selected undisturbed watersheds and number of required cisterns.

Watershed	Area (km^2)	Runoff (m^3)		No. of cisterns
		January	November	
7	24.16	3734.85	764.10	9
8	5.19	802.49	164.18	2
9	22.40	3463.26	708.54	8
10	13.65	2110.18	431.71	5
11	10.31	1593.62	326.03	4
12	79.62	1427.56	484.13	4
21	9.33	1442.62	295.14	3
22	8.14	1258.56	257.48	3
23	11.49	1775.53	363.25	4
24	2.72	420.67	86.06	1
25	7.59	1173.03	239.99	3

TABLE 3 . Maximum and current erosion rate.

Maximum erosion hazard		Current erosion hazard	
Loss rate (ton/ha/year)	area (km^2)	Loss rate (ton/ha/year)	area (km^2)
<10	87.43519	<10	123.3098
10-20	418.7942	10-20	443.9468
20-30	132.2033	20-30	79.0582
30-40	18.25538	30-40	11.3061
>40	2.850016	>40	1.917136

Land evaluation

A land evaluation procedure (land capability and irrigated agriculture suitability) was performed on the study area using the MicroLEIS evaluation software. The outputs from the land evaluation software were linked to the GIS software (ArcMap 8.1) across a database file and different queries were carried out to get the final outputted maps.

Land capability

The land capability classes are given in Table 4. The main limitations of lands S2 capability class are soil, erosion risks, and bioclimatic deficiency. These lands have moderate limitations that restrict the range of the crops. These lands can be managed with little difficulty. Under good management, they are moderately high to high in productivity for a fair range of crops. The lands of the capability class S3 have erosion risks and bioclimatic deficiency limitations. These lands have moderately sever limitations that restrict the range of crops or require special conservation practices. These lands are low to fair in productivity for a fair range of crop, and improvement practices can be feasible. The lands of the capability class N have soil and bioclimatic deficiency limitations. These lands have very sever limitations that restrict their use for arable culture. These lands are recommendable for producing forage crops.

TABLE 4. Land capability classes of the study area.

Land Capability Classes	Area (ha)	Area (km^2)	Area (%)
Class S2	17849	178.49	20.67
Class S3	18809	188.09	21.87
Class N	29677	296.77	34.37

Irrigated land suitability

The data indicates that the soils of mapping unit (1) are currently moderately suitable (S3) for Olive and marginally (S4) suitable for Wheat, Corn, Alfalfa, Sunflower, Cotton, soybean, Sugar Beat, Potato, Citrus, Peach, and Melon. The main limitations of the moderate and marginal suitability of these soils are texture (t) and carbonate (c). The soils of mapping unit (2) are currently of moderate suitability (S3) for the land uses Olive, Citrus, and Peach, and marginally suitable (S4) for the other selected land uses. The main limitations of these soils for the moderate and marginal suitability classes are texture (t), carbonate (c), and salinity (s). The soils of mapping unit (4) are currently highly suitable (S2) for olive, moderately suitable (S3) for peach and citrus, and marginally suitable (S4) the other land uses. The main limitation of these moderately and marginally suitable soils is texture (t).

Rainfed land suitability

The combination of the different land and topographic characteristics has resulted in three land suitability classes. The description of these classes is:

Class II: Moderately suitable lands for trees.

Class III: Marginally suitable lands for trees, but suitable for cereals.

Class IV: Unsuitable lands for trees and cereals, but suitable for grazing.

Table 5 representing the areas each class illustrates the distribution of these land classes for the study area. It is clear that classes II and III occupy most of the area 76.32 %, while class IV covers only 0.51 % of the total area.

TABLE 5. Land suitability classes for rainfed agriculture.

Land Evaluation Classes	Area (ha)	Area (km^2)	Area (%)
Class II	36658	366.58	42.46
Class III	29235	292.35	33.86
Class IV	442	4.42	0.51

Conclusions

1. RS images are vital sources in studying the spatial and temporal variability of land resources and assigned their spectral surface characteristics.
2. Terrain analysis save time and cost in identifying the major physiographic land units and their surface hydrological parameters.
3. The soil mapping units identify the morphological, physical, chemical and spatial variability of land qualities and land use limitations.
4. GIS Modeling is a powerful tool in integrating environmental databases at different spatial scales and in assigning the agro-ecosystem capacity concerning quality variability, degradation risk, and suitability for specific uses.
5. The GIS/RS provide a planning tool to help the planners and decision makers to organize land resources data, an understanding their spatial association. Well trained team is needed.
6. The integrated methodology of this study could be considered as a ready module for applying at different locations.
7. The study outputs represent significant GIS input layers for national/regional digital soil databases.

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تكامل بيانات نموذج التضاريس الرقمي والاستشــعار عــن بعـد وصفات الأرض لنمذجة الهيدرولوجى السطحى والتعرية المائيــة وصلاحيةالأراضى: الساحل الشمالى الغربي – مصر

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اعتمدت الدراسة على منهجية تكامل تقنيات الاستشعار عن بعد ونظم المعلومات الجغرافية في تقييم الأراضي ونمذجة الجريان السطحي للماء وتدهور وصلاحية الأراضي للاستخدام الزراعي بالمناطق الجافة وهدفت الدراسة بمنطقة العميد بالساحل الشمالي الغربي إلى تحليل الصورة الفضائية TM للوصول إلى القنوات الأكثر معلومية والوحدات الطيفية المثلى وتقييم الدقة لتقنيات التصنيف المختلفة ، الوصول إلى نموذج التضاريس الرقمي ، تحديد وتعريف وحدات التربة ، نمذجة للجريان السطحي ومخاطر التعرية المائية وصلاحية وحدات الأراضي لاستخدامات زراعية محددة.

وقد تم تحديد كثافة ومساحة الغطاء النباتي من خلال الدليل النباتي SAVI وتحديد نظم الاستخدام الزراعي المختلفة وقد تم الوصول إلى أن القنوات ١ ، ٢ ، ٧ هي القنوات الأكثر معلومية و أن تقسيم المكونات الأساسية المنحازة كان الأكثر دقة في تخريط الوحدات السطحية وتم تعيين درجات الميل و الاتجاه وتحديد الوحدات الجيومورفولوجية وتصنيف شبكة التصريف المائي ومجمعات المياه وتحديد ووصف كامل لوحدات الأراضي متضمنة الصفات المكانية وكذلك الصفات الطبيعية والكيميائية والتصنيفية لها ونمذجة الجريان السطحي والأمطار بتقنين كمي لكمية الجريان السطحي بمعلومية الأمطار الشهرية وتحديد عدد وموقع وسعة الخزانات الأرضية لحصاد وتخزين المياه السطحية بمجمعات المياه المحددة ونمذجة مخاطر التعرية المائية بتحديد مواقع وكميات النحر السنوي للهكتار المتوقع تحت الظروف المناخية والأرضية والطبوغرافية وكثافة الغطاء النباتي والإدارة المزرعية السائدة ونمذجة صلاحية أراضي المنطقة للاستخدام للزراعات المروية والمطرية متضمنة مساحات ودرجة صلاحية كل منها.