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Land evaluation and suitability of Hala'ib and Shalateen region, Egypt, by integrated use of GIS and remote sensing techniques.

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Abstract

Land suitability and capability evaluation was done by integrating remote sensing and GIS techniques for Hala'ib and Shalateen region which are located south east of the eastern desert of Egypt. The regions are of high priority for development. Ten soil profiles were taken to represent the main geomorphic units in the study area. Topographic maps, field work observations and digital elevation model (DEM) were used to generate the geomorphologic map.Eight main geomorphologic units were identified i.e wadis, 2- alluvial fans and deltas, 3- alluvial plains, 4- sand sheets, 5- sand dunes, 6- alkali flats (sabkhas), 7- plains with rock outcrops and 8- high rocky lands. Land capability evaluation was performed using Micro-LEIS-Cervatana capability model. Percentages of land capability were as follows 8.50% "good of use" , 24.72% "moderate use", 9.14% "marginal or non-productive"; 57.7% "rocky and erosion-risk". The main capability limitations are soil erosion risks and rockiness. The Micro-LEIS-Almagra model was used to produce the optimum cropping pattern and limitations of soil units. Land suitability using the Micro-LEIS-Almagra program showed suitability for wheat, potato, maize and sugar beet (as annuals); alfalfa (as semi-annuals), peach, citrus fruits and olive (as perennials). Main limitations include salinity, sodicity, shallowness, rockness and inadequate drainage and low fertility.

Keyword: Land capability, Land suitability, Remote sensing, GIS, Hala'ib and Shalateen region.

Introduction

Land evaluation is the assessment of land performance for its use specific purpose **(FAO, 1985 and Sys et al., 1991)**. It interprets the principal inventories of soil properties, vegetation cover, climate, environmental conditions, and other aspects **(Dent and Young, 1981; FAO, 1983; Sys, 1993; Rossiter, 1996 and Sayed, 2006)**. It explains and predicts land potential use **(Van Lanen, 1991)**. Evaluation involves the technical coefficients necessary for optimal allocation **(Rossiter, 1996)**.Two major aspects are involved, i.e. physical resources and socio-economic resources **(FAO, 1985; Sys, 1985; and Várallyay, 2011).**Physical resources concern aspects such as soil, topography and climate, which have relatively stable properties. Socio-economic resources concerns aspects such as farm size, management level, availability of manpower, market position and human activities. They are affected by the social, economic, and political decisions. The main objective for land evaluation is appraisal of land's potential for alternative uses by a systematic comparison of its requirements with its resources **(Dent and Young, 1981)**. Land evaluation procedures show what is wrong with the land in its current use, what and where the conflicts are **(De la Rosa et al., 2004)**.Computer programs are used in evaluation of land use. Computerized models can integrate socioeconomic and biophysical factors to fulfill the appraisal within a specific timeframe, and distribute insights for future appraisals. However, such models may be expensive, time-consuming and eliminate needed resources from other planning activities. Computerized systems vary on their basis of purpose, their use, andthe required data. There are many of these systems, such as APT(Agricultural Planning Tool-kit),CRIES(Comprehensive Resource Inventory and Evaluation System), LECS (Land Evaluation Computer System), ALES(Automated Land Evaluation System) and MicroLEIS(Microcomputer Land Evaluation Information System) **(Kalogirou, 2002 ,Elaalem, 2010 and Rossiter, 1990).** The ALES system is a framework for evaluators to build their own expert system, with many applications. The MicroLEIS system aims at establishing an interactive friendly procedure for optimal allocation of land use and define production levels for arable crops and forests under Mediterranean conditions **(De la Rosa and Moreira, 1987)**. This system includes several biophysical evaluation methods which give appropriate agricultural and forestry land uses in Mediterranean regions. **De la Rosa et al., (2004)** used scale-appropriate models ranging from purely qualitative (reconnaissance) scales through semi-quantitative (semi-detailed) scales to quantitative (detailed) scales.

Land suitability classification is appraising assessment of land for its use for specific crops or otherwise. Qualitative suitability classification in an empirical assessment based on assumed relationships several land characteristics that influence, a specific land use **(FAO, 1976)**. Land suitability classification is useful for precision land utilization. It cloud be expressed not only in terms of types of crop production, but also in terms how they are done**(Sys et al., 1991)**. Land suitability takes into consideration environmental variables such as topography, soil type, vegetation and landforms. Integration of various variables for a single assessment utilizes the GIS “Geographic Information System”**(Pereira and Duckstein 1993; Steiner et al., 2000 and Zhang et al., 2011)**.Land capability was applied to determine potentiality for agriculture in Wadi Hodein, Eastern Desert, Egypt limiting factors and showed that the limiting factors are: water resources, climate and texture **(El-Taweel, 2006)**. **Abdel-Kawy et al. (2010)** stated that the use of ALES arid-model in arid and semi-arid regions facilitates finding of the most suitable agriculture system to be adopted.

Remote sensing imagery is a powerful tool for studying the surface of Earth **(Rozenstein et al., 2016)**,and covers large areas with multiple spectra information and constant observations**(Mulder et al.,2011 and Taghizadeh-Mehrjardi et al., 2014)**. It is an important technique for soil survey, mapping and environmental investigations**(Sadeghi et al., 2015)**.The Geographic Information System (GIS) incorporates database systems for spatial data **(Ekanayaki and Dayawansa, 2003)**.It can incorporates remote sensing data with soil survey information GIS to assess crop suitability. Integration of various variables for a single assessment cannot result in accurate and efficient results unless the GIS is used.**(Steiner *et al*., 2000; Zhang *et al*., 2011 and Abdel Rahman et al., 2016)**.

The main objective of the current work was to identify and evaluate land resources of Hala’ib and Shalateen, regions in the South Eastern Desert, Egypt and formulate suitability maps for crops using the MicroLEIS and the GIS systems.

Materials and Methods

The study area.

The study area is located in the south east desert of Egypt between latitudes 22 ˚ 10 `50`` and 23 ˚ 31 ` 41.5`` N, and longitudes 34 ˚ 45 ` 4.4`` to 36 ˚ 19 ` 4.6`` E, (Figure 1) with a total area of about 1718100 ha. According to **EMA (2010)**, the area is nearly totally arid with less than 0.5mm annual rainfall and with an annual temperature of 24°C, having a wide difference between summer and winter. The average temperature ranges between 18.92 °C to 30.38 °C. The highest monthly average temperature is 37.5°C in July and August, while the lowest is 7.5 °C in January. Average annual relative humidity is 39.10 % and average monthly relative humidity ranges between 26.00% in July and 55.00% in January and February. Figure 2 shows the climate diagram of Hala’ib and Shalateen.

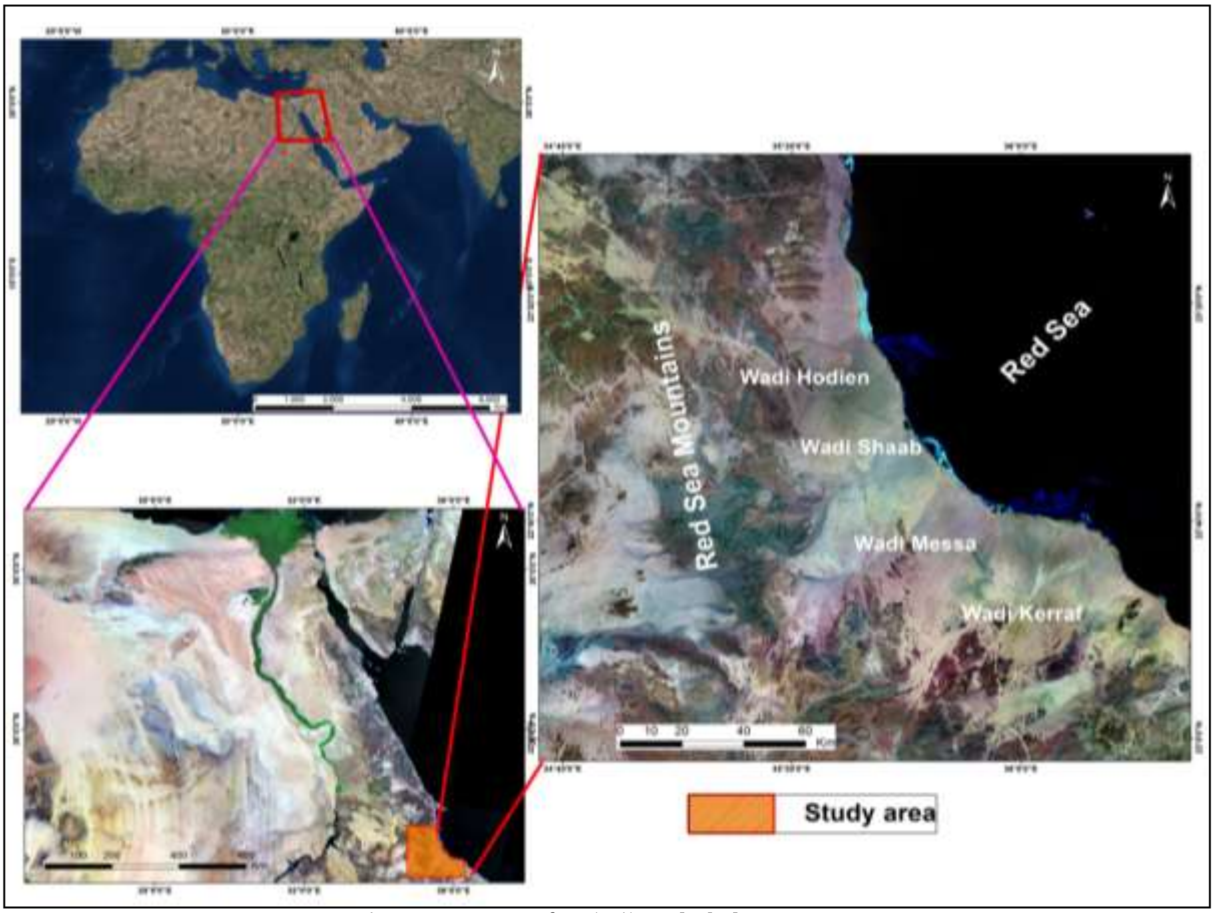

Fig. 1: Location of Hala’ib and Shalateen area.

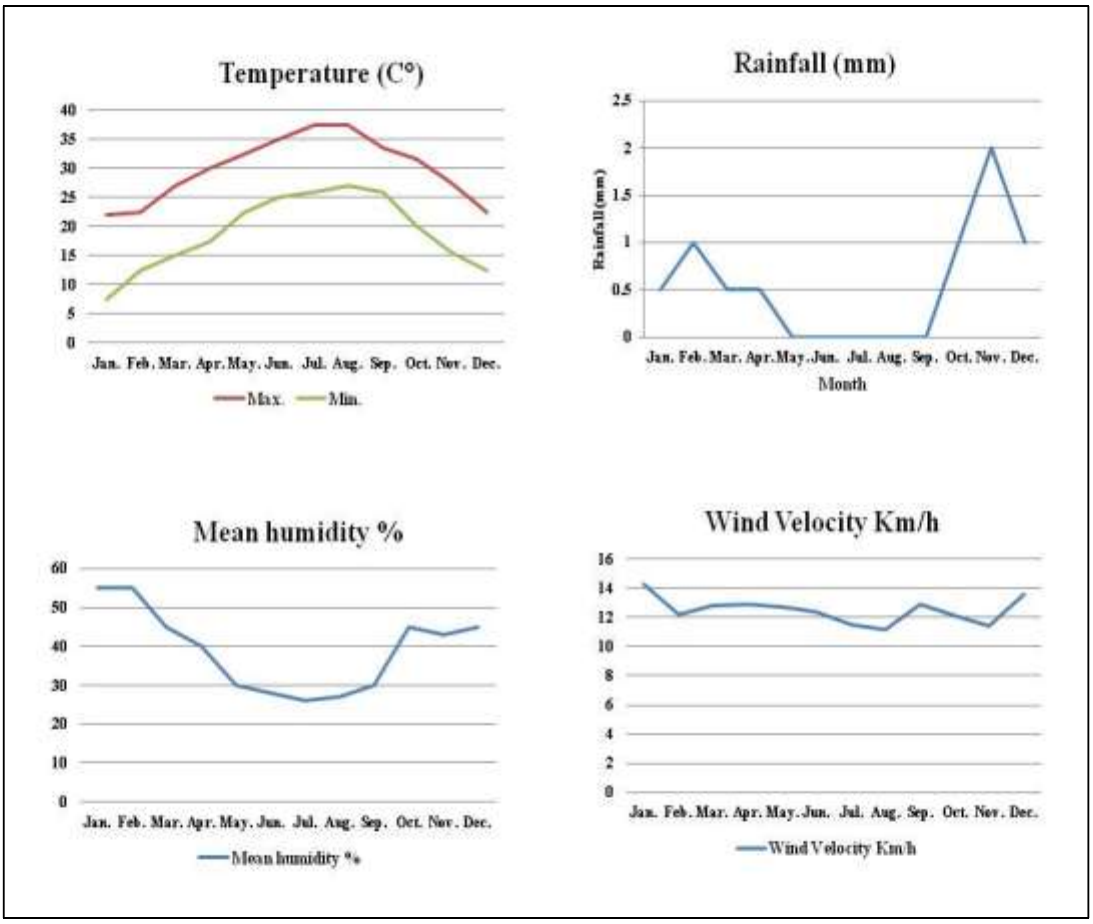

Fig. 2: climatologically diagram of Hala'ib Shalateen.

Geology.

According to **Said (1990), El-Rakaiby et al., (1996), El-Alfi, (1997) and EGPA(1987)** the regoins are occupied by fourteen rock formations belonging to Precambrian, Cretaceous, Miocene, and Quaternary ages**.** The formations (Figure 3) are: (1) Basement Rocks, (2) Tertiary Volcanic, (3) Sand Dunes, (4) Sand Sheets, (5) Sabkha deposits, (6) Wadi deposits, (7) Undifferentiated Quaternary Deposits, (8) Shagra formation "Fm"., (9) Umm Gheig Fm., (10) Umm Mahara Fm., (11) Undifferentiated Miocene Deposits, (12) Umm Barmil Fm., (13) Timsah Fm. and (14) Abu Aggag Fm.

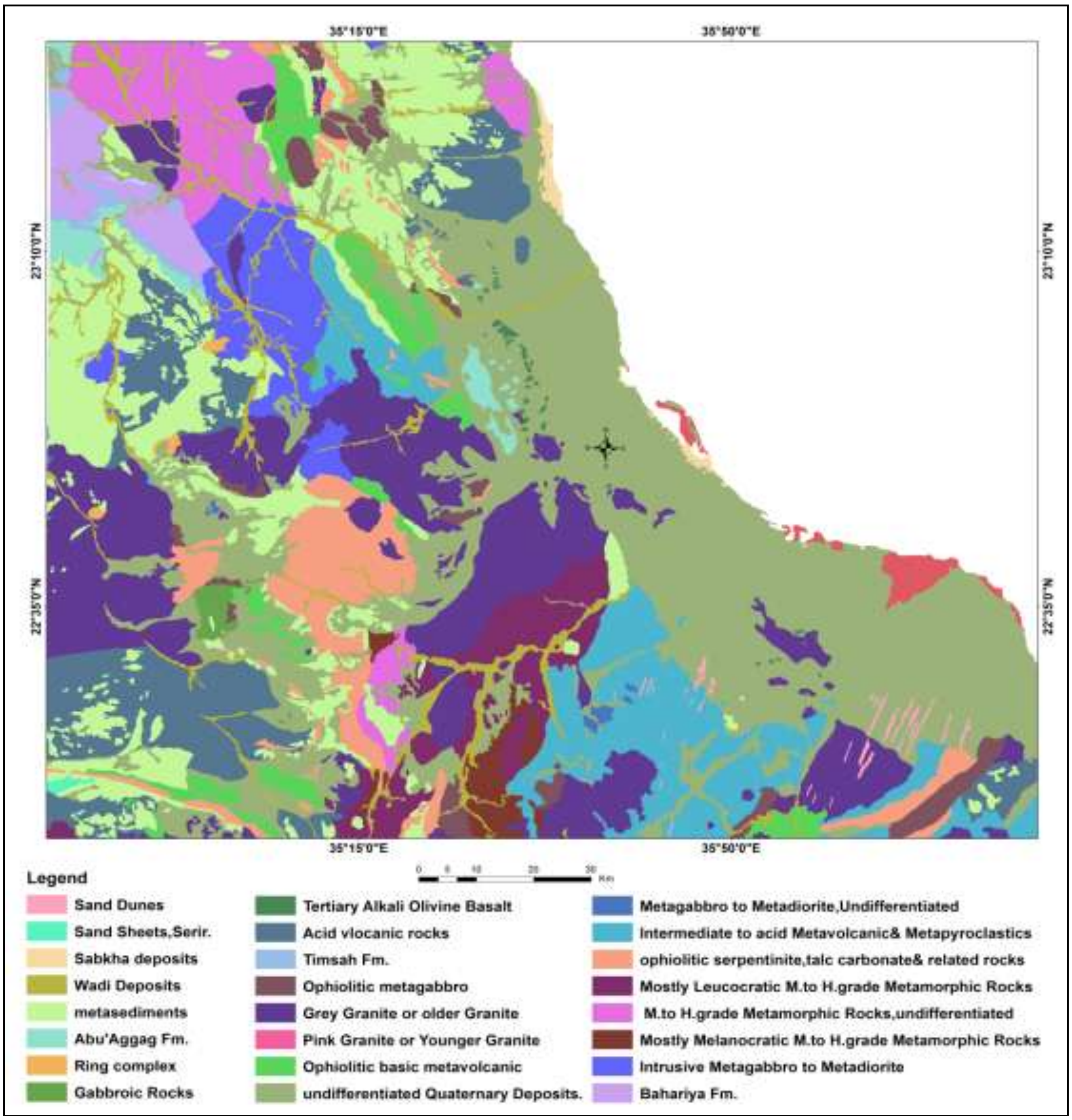

Fig. 3: Geological map of Hala'ib and Shalateen area (After EGPA, 1987).

Image processing.

Remote sensing analyses of the area used data from Landsat Data Continuity Mission (LDCM) sensor (Landsat 8) in 2016. All further digital image processing and analyses were executed using the standard approaches provided by the ENVI 5.1 and the Arc-GIS 10.1 software. Image processing included bad line manipulations by filling gaps module designed using IDL language and data calibration to radiance according to **Lillesand and Kiefer (2007).**

Soil classification

Based on to climatic data**(EMA, 2010)**, the soil temperature regime of the studied area was defined as ***thermic*** and the soil moisture regime was defined as ***torric*** on basis of classification of the USDASoil Taxonomy System (USDA 2014). Soils were classified under two soil orders, ***Aridisols*** and ***Entisols.***

Soil survey and field work

A semi detailed survey was carried out. One profile pit was dug representing each major soil type, since the soils have been identified as benchmark soils. Ten soil profiles were observed and the morphological features were outlined according to the FAO guidelines **(FAO,2006)**.

Laboratory analyses

Soil samples were air-dried ground and sieved through a 2-mm sieve and analyses were done including particle size distribution, salinity, pH, calcium carbonate (g/kg), gypsum (g/kg) and CEC (**USDA 2004 and Bandyopadhyay 2007)**

Land evaluation and suitability.

Land evaluation(in terms of land capability) was done using the MicroLEIS-CERVANTANA model while land suitability was done using the MicroLEIS-ALMAGRA model.

Land capability model (MicroLEIS-CERVANTANA model)

Prediction of general land use capability is a result of qualitative evaluations and overall interpretations of the following factors: relief, soil, erosion, bioclimatic deficit. Capability evaluation orders and classes are excellent (S1), good (S2), moderate (S3) and marginal or null (N).Subclasses depend on limitation factors: Slope (t), Soil texture (I), Erosion risks(r) and Bioclimatic deficit (b). Applying the capability CERVATANA model, concerning slope, erosion, bioclimatic deficit and soil properties, Tables 1 and 2 reveal that these soils belong to orders S1, S2, S3 and N.

Table 1. Agro-ecological evaluation method of land capability classes using the MicroLEIS-CERVANTANA model.

Land capability order and class		
Order	**Class**	
S	**S1**	Excellent
	S2	Good
	S3	Moderate
N	**N**	Marginal or Null

Table 2. Agro-ecological evaluation of land capability subclasses of the MicroLEIS-CERVANTANA model.

Land capability subclass		**Limitation factor**
Slope	**(t)**	Slope
Soil	**(i)**	Useful depth
		Texture class
		Stoniness and rockiness
		Drainage class
		Salinity
Erosion risks	**(r)**	Soil erodibility
		Slope gradient
		Vegetation density
Bioclimatic deficit	**(b)**	Aridity degree
		Frost risks

Land suitability model (MicroLEIS- ALMAGRA model).

Land suitability evaluation was applied using the MicroLEIS-ALMAGRA model **(De la Rosa et al., 1992 and De La Rosa et al., 2004)**,which indicates suitability without respect to economic conditions. Suitability classes for each crop(Table 3) are: optimum suitability (S1), high suitability (S2), moderate suitability (S3), marginal suitability (S4), and no suitability (S5).The main soil limitations are: useful depth (p), texture (t), drainage (d), carbonate content (c), salinity (s), sodicity (a) and degree of profile development (g). For each diagnostic criterion (or limiting factor), the evaluation results are presented in the form of a matrix, i.e. a two dimensional array with rows representing the soil characteristics and columns consisting of the soil units for which the evaluation was computed. The intersections of the two (i.e. the matrix cells) are considered as the results. The overall soil suitability of a soil component (unit) was assessed through the maximum limitation method where the suitability is decided upon the most limiting factor of soil properties.

Table 3. Land suitability classification index and ratings of the MicroLEIS program.

Class	Description	Rating (%)
S1	soils with optimum suitability	> 80
S2	soils with high suitability	< 80 > 60
S3	soils with moderate suitability	< 60 > 40
S4	soils with marginal suitability	< 40 > 20
S5	soils with no suitability	< 20 >10

Results and discussion

Geomorphologic features.

According to **Abdel Rahman,(1997)**, the landforms of Hala'ib and Shalateen are divided into three groups (Table 4 and Figure 4) of (1) Bahada Plains (alluvial fans and deltas, alluvial plains, wadis, sand sheets, sand dunes and plains with rock outcrops), (2) Faulted Mountains and Hills (mountains, mountain-foot slopes, hills and hill-foot slopes), and (3) Coastal Forms (alkali flats).

Table 4. Geomorphic and Mapping units and their area and percentages of the total area

Group	Geomorphologic unit	Mapping unit	Area (ha)	% of total area
Bahada Plains	Alluvial fans and Deltas	AFD	145400	8.46
	Alluvial plains	AP	157700	9.18
	Wadis	W	111300	6.48
	Sand sheets	SS	155700	9.06
	Sand dunes	SD	17400	1.01
	Plains with rock out-crops	PR	117000	6.81
Faulted Mountains and Hills	High rocky lands	HR	991000	57.68
Coastal Forms	Alkali Flats	AF	19900	1.16
	Beaches	B	2700	0.16
Total			1718100	100

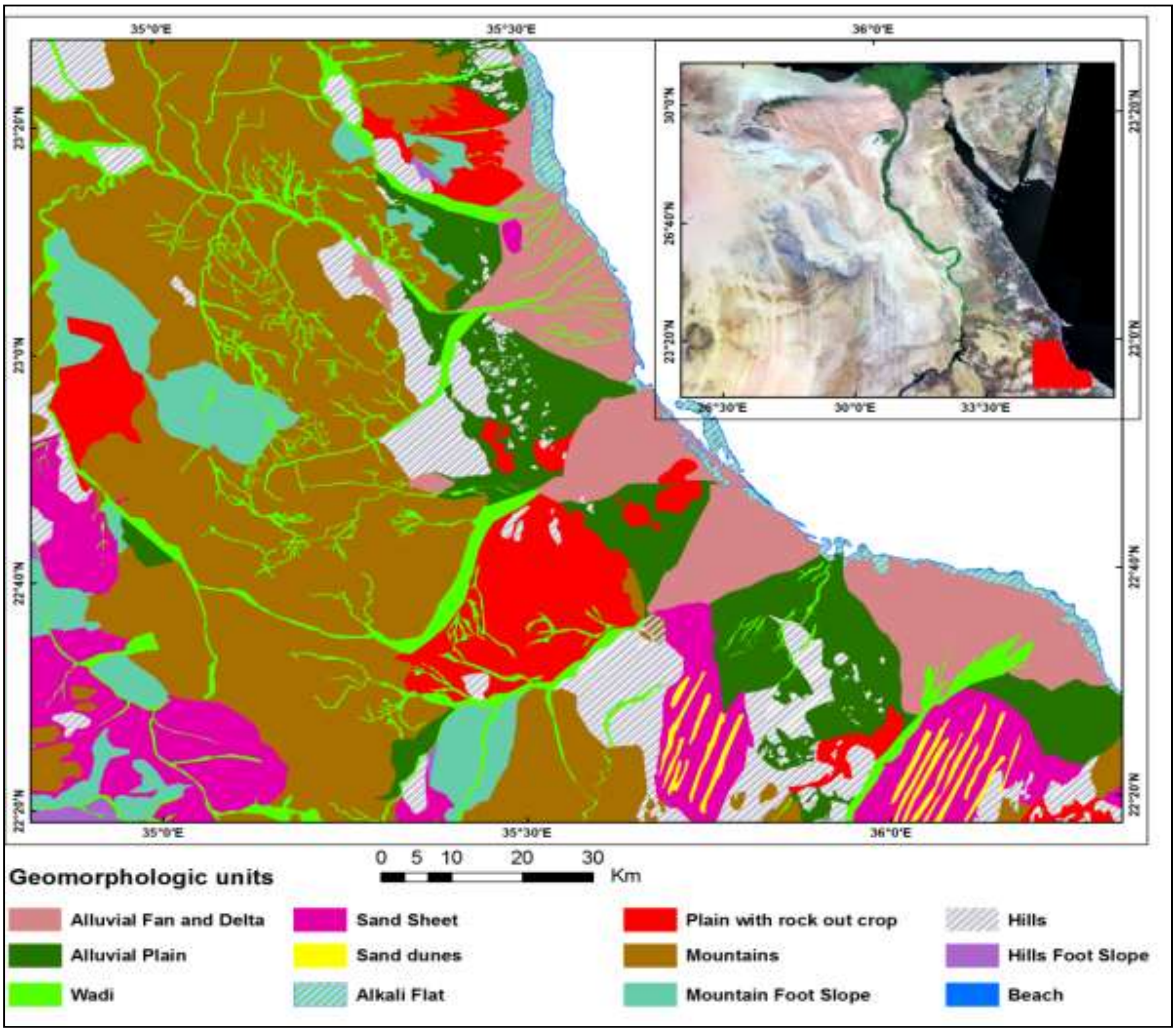

Fig. 4: Geomorphologic map of the Hala'ib and Shalateen area.

Land evaluation.

The fundamental principle of land evaluation is to estimate the potential of a land for different productive uses, taking in consideration the most suitable and appropriate way to achieve sustainability. The MicroLEIS system with an ALMAGRA model is an efficient decision support system for sustainable land use and management **(De La Rosa et al., 1992)**.

Land capability.

According to MicroLEIS CERVATANA model, lands of **Hala'ib and Shalateen** can be used for multiple purposes, mainly agriculture, pastures and forestry (Table 5). The outputs of the model were linked to the GIS modeling environment using database fields which have key attribute properties (Figure 5).

Table 5. Land capability classification for the Hala'ib and Shalateen, South East Egypt.

Land Capability Class	Land Capability Subclass	Landform	Degree	Area ha	Area %
S1		-	Excellent	0.00	0.00
S2	S2r	Alluvial fans and Deltas	Good	145400	8.50
S3	S3rb	Alluvial plain, Wadi and Sand sheet	Moderate	424700	24.72
N	Nltb	Plain with rock outcrop, Alkali flat, Sand dunes and Beach	Marginal or Null	157000	9.14
	Rocky land			991000	57.68
	Total area			**1718100**	**100.00**

Note: r= erosion risks, b=bioclimatic deficit.

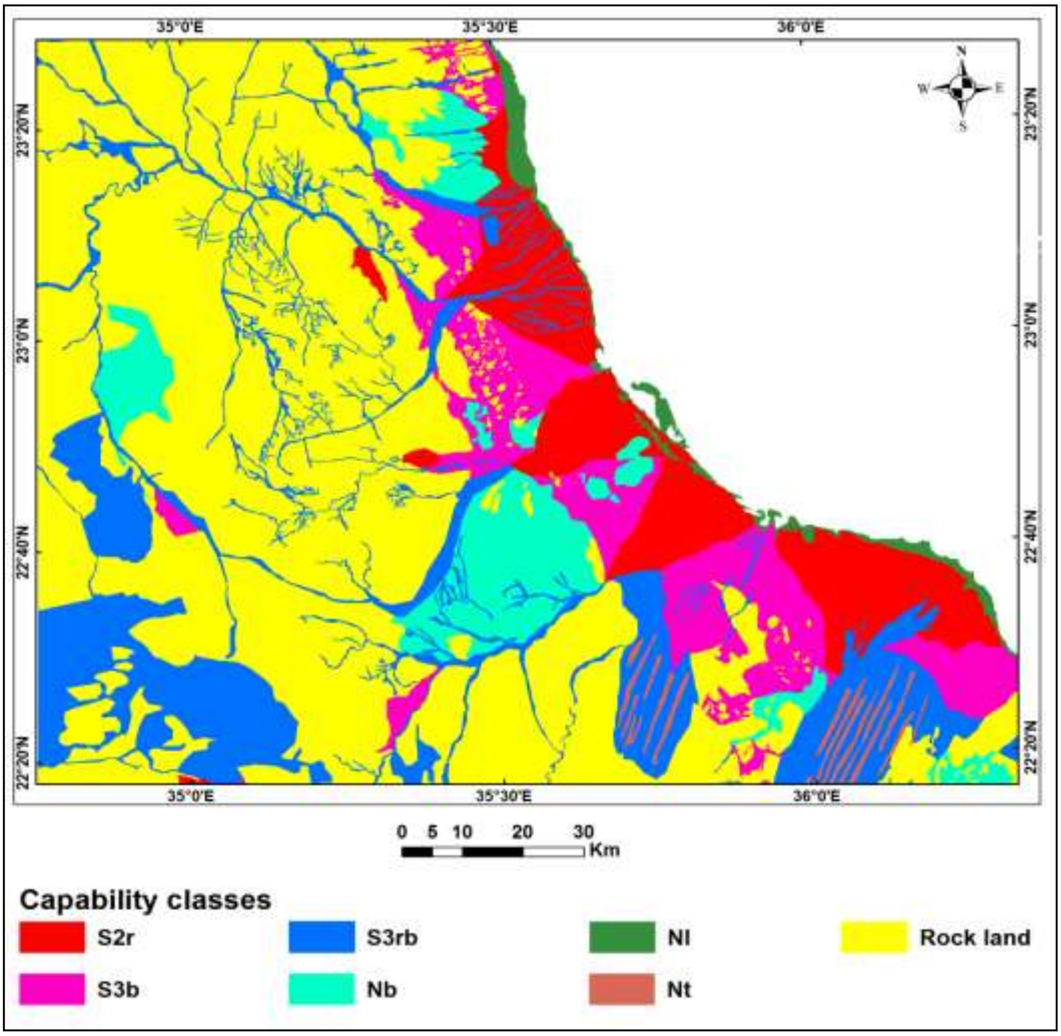

Fig. 5: Land capability classes of Hala'ib and Shalateen, South East Egypt.

Land suitability.

The MicroLEIS ALMAGRA model works interactively, comparing land characteristic values with the generalization levels designated for each suitability class. The classification is applicable to all lands inthe Mediterranean Region. The suitability is based on analysis of factors affecting productivity of eight traditional crops: wheat, maize, potato, sugar-beet, alfalfa, peach, citrus and olive. The following steps show application of the model.

1-Diagnostic criteria of factors of effective soil depth (p), texture (t), carbonate content (c), salinity (s), sodium saturation (a) degree of profile development (g) and drainage (d) (Figure 6).

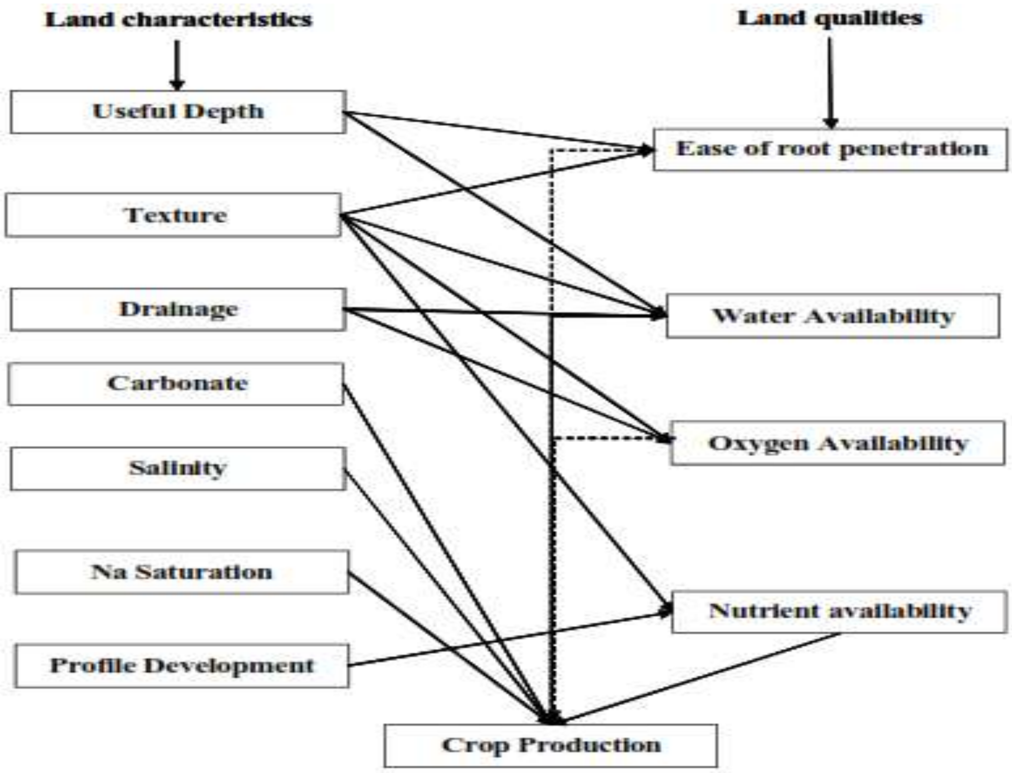

Fig.6: General scheme of the Almagra model, showing the direct and indirect effects of some soil characteristics and soil qualities.

2-Calculation of the mean weighted value for each soil property (V) of the profile calculated by multiplying the summation of (Vi) for each horizon by horizon thickness (ti) divided by the profile depth (T) according to the following equation:

$$V = (\frac{\sum_{i=1}^{n}(vi \times ti)}{T})$$

3-After final preparation of data, the properties were supplied to the Almagra Model (available at http://www.evenor-tech.com/ microleis/microlei/ microlei.aspx) **(MicroLEIS web-Based Program, 2009)** to run suitability classification for crops of wheat (W), maize (M), potato (P), and sugar-beet (S); alfalfa (A) and peach (Pe), citrus fruits (C) and olive (O) as perennials, (Figures 7-14). The spatial analysis function in ArcGIS 10.1 was used to create thematic layers of the most constrained factors. The suitability classification is presented in Table 6 and soil suitability classes for the selected crop are listed in Table 7. Land suitability varied from "Suitable" (S2) (14.94% of total area) to "Not suitable" (S5) (66.65% of total area) for all selected crops. "Unsuitable" class lands are due to one or more of limitation factors of texture, salinity, drainage, depth, sodicity, and $CaCO_3$ content.

Table 6. Factors and limitations used in land suitability of study area.

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

Table 7. Land suitability classes and limiting factors for study area.

Landform	Annual crop				Semiannual crop	Perennial crop			Area (%)
	Wheat (W)	Maize (M)	Potato (P)	Sugar beet (S)	Alfalfa (A)	Peach (Pe)	Citrus (C)	Olive (O)	
Wadi	S2tdc	S2td	S2td	S2tdc	S2tdc	S2dsg	S2dsg	S2dcs	6.48
Alluvial Fans &Deltas	S3t	S3t	S3t	S3t	S3t	S2td	S2td	S2tdc	8.46
Alluvial Plains	S4t	S4t	S4t	S4t	S4t	S3t	S3t	S3t	9.18
Alkali Flats	S5s	S5sa	S5sa	S4tds	S4tds	S5ds	S5ds	S5ds	1.16
Sand Sheets	S4t	S4t	S4t	S4t	S3tc	S2tdc	S3t	S3t	9.06
Plains with rock outcrops	S5t	S5t	S5t	S3t	S5t	S5t	S5t	S4ptd	6.80

S2 (suitable),S3(moderately suitable),S4 (marginally suitable),S5(not suitable), p(useful depth), t (texture), d (drainage), c (carbonate), s (salinity), a (sodium saturation), and g (profile development).

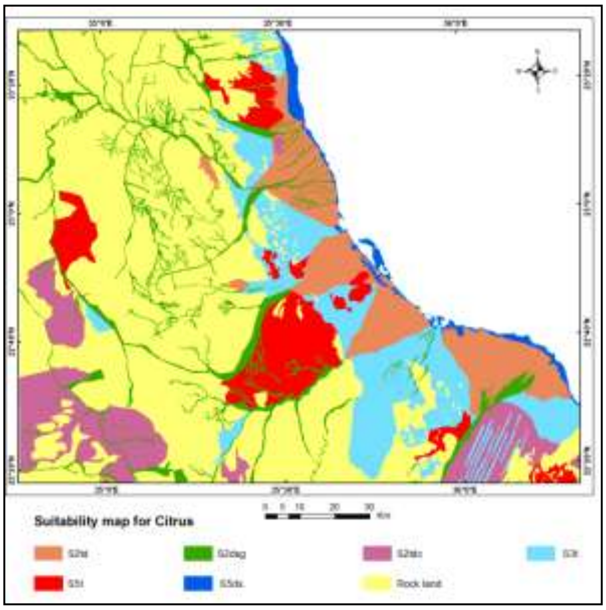

Fig. 7: Land suitability map for citrus.

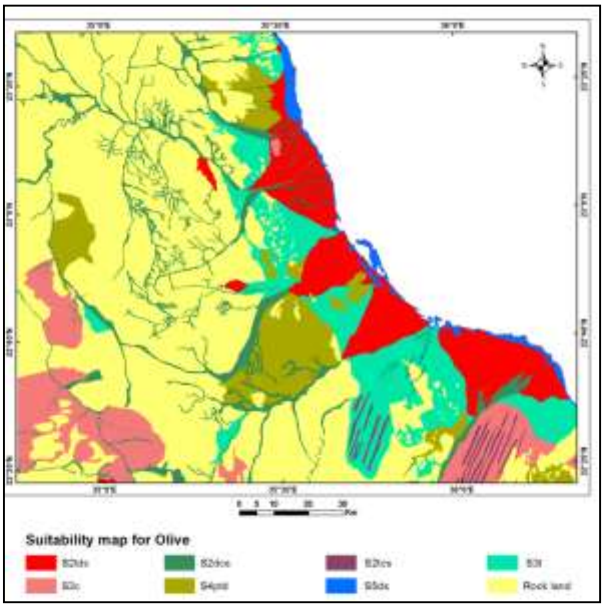

Fig. 8: Land suitability map for Olive.

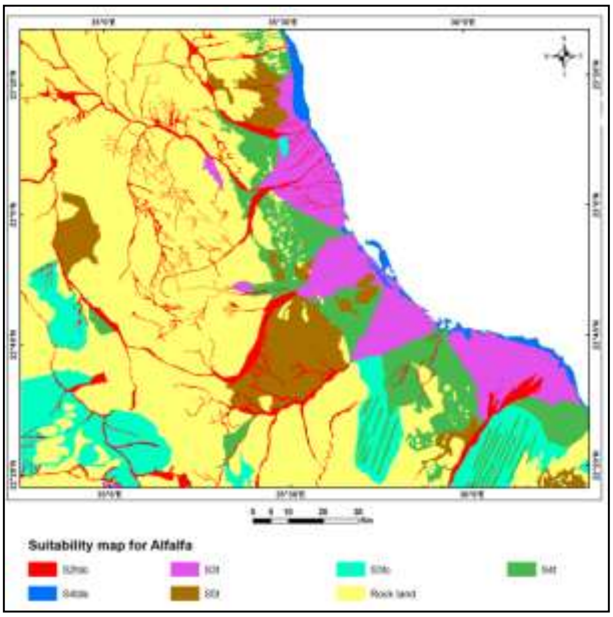

Fig. 9: Land suitability map for Alfalfa**.**

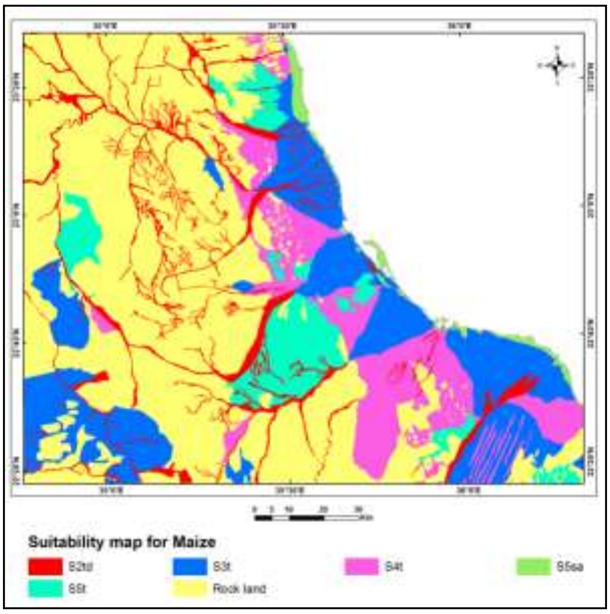

Fig.10: Land suitability map for Maize.

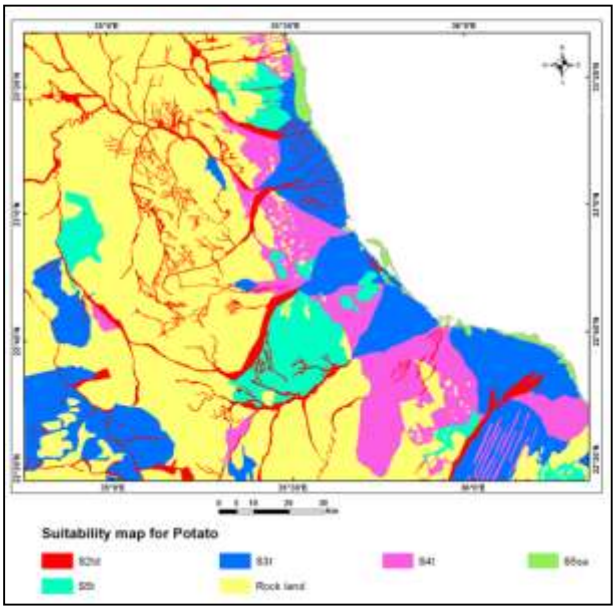

Fig. 11: Land suitability map for Potato.

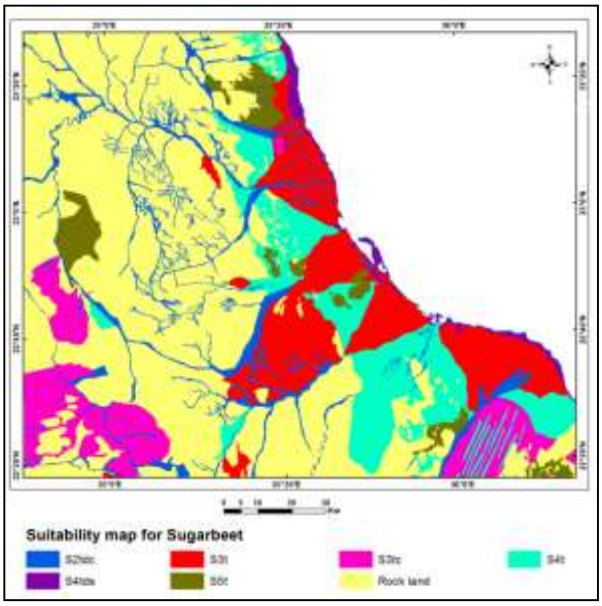

Fig. 12: Land suitability map for Sugarbeet

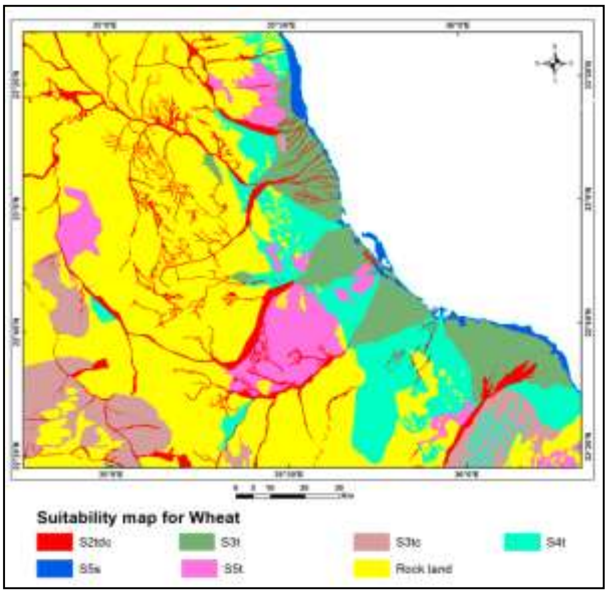

Fig. 13: Land suitability map for Wheat

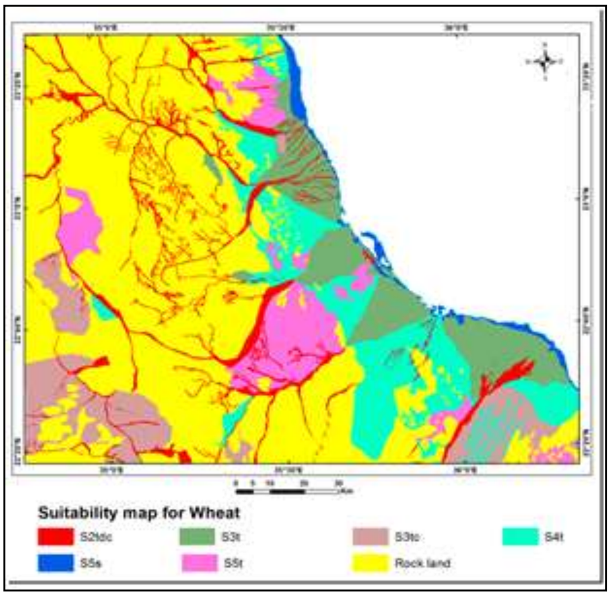

Fig. 14: Land suitability map for Peach.

Conclusion

Remote sensing and GIS were manipulate and quantitatively evaluates land capability and suitability of Hala'ib and Shalateen regions, South Eastern Desert of Egypt east of Red Sea. Results indicate a possibility of agricultural expansion .About one third of the area is good to moderately good for agriculture utilization. The main capability limitations are slope, soil, erosion and bioclimatic deficit. Land suitability shows suitability for eight growing crops: wheat, maize, potatoes, sugar beet, alfalfa, peach, citrus, and olive. The regions can benefit if development is planned and executed in a manner that takes advantage of the natural resources without threatening their quality.

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تقييم وملائمة الاراضى بمنطقة حلايب وشلاتين– مصربالاستخدام المتكامل لتقنيات نظم المعلومات الجغرافية و الاستشعار من بعد

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تم تقييم ملائمة الارض وقدرتها الانتاجية بالاستخدام المتكامل بين تقنيات الاستشعار من بعد ونظم المعلومات الجغرافية بمنطقة حلايب وشلاتين التى تقع فى جنوب شرق الصحراء الشرقية بمصر. وهى واحدة من المناطق ذات اولوية عالية للتنمية.وقد اتاحت الدراسة الحالية انتاج خرائط رقمية لملائمة الارض للمحاصيل المختارة. وقد تم اخذ عشرة قطاعات تربة ممثلة للوحدات الجيومورفولوجية المختلفة بمنطقة الدراسة. الخرائط الطبوغرافية ونموذج المرتفعات الرقمية(DEM) بالاضافة الى الزيارات الميدانية ومنها تم انتاج الخرائط الجيومورفولوجية. وتم التعرف على ثمانية وحدات جيومورفولوجية رئيسية وهى كالتالى (1) الاودية، (2) المراوح الفيضية و الدلتاوات، (3) السهول الفيضية، (4) الفرشات الرملية، (5) الكثبان الرملية، (6) السبخات، (7) سهول النتؤات الصخرية و(8) المرتفعات العالية. استخدم نموذج السيرفاتانا فى برنامج الميكروليز لتقييم القدرة الانتاجية للتربة. وبينت النتائج ان 8.5% من الاراضى ذات قدرة جيدة ، 24.7% من الاراضى ذات قدرة متوسطة و 9.1% من الاراضى هامشية القدرة.وكانت نسبة الأراضي الغير صالحة 57.7% . ومن اهم محددات القدرة الانتاجية للاراضى هى الصخريةوالملوحة ومخاطر النحر.واستخدم ا نموذج الماجرا لتحديد الانتاج الامثل لمحاصيل القمح، البطاطس، الذرة وبنجر السكر(كنباتات حولية)، والبرسيم (كنبات نصف حولى) و الخوخ، اشجار الحمضيات والزيتون (كاشجار معمرة). ومن اهم المحددات هى واحدة او اكثر الملوحة ، الصودية، ضحالة عمق القطاع وانخفاض الخصوبة.