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Soil Classification and Land Capability Evaluation for Sustainable Agricultural Use in South Sinai, Egypt

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ABSTRACT

The study area capability evaluation was carried out using land mapping units characteristics compared to capability class critical limits. The study area soils were classified and identified into two soil orders; *Entisols* and *Aridisols*, characterized by eight great groups ▫"*Vertic Torriorthents,* ▫*Typic Calciorthids, Typic Paleorthens, Typic Torrifluvents,* ▫*Typic Torriorthens,* ▫*Typic Torripsaments, Lithic Calcic Gypsiorthids* and *Lithic Torripsaments"*. Soils were classified into four classes of land capability C3, C4, C5 and C6; Decantation Basin, Delta, Alluvial Fans and Dry Wadi were ranged between C3 which have good capabilities and can be manageable with minor impediments, and C4 (moderate capability) with moderate to low restrictions that limit the crops sets and soil particular maintenance and conservation techniques are necessary. While, Terraced Hills, Pediplains, Footslopes, Wet Sabkhas and some areas of Coastal Plain belonged between C5 with moderately severe limitations that limit the types of crops that can be grown with specific conservation, and C6 (low capability) with very severe limitations that reduce their usage in agricultural practices. These soils are suitable for growing forage crops, and agroforestry systems since they have low to marginal productivity. As a result, South Sinai soils have some sustainable soils that might potentially play a significant role in aiding decision-makers in modifying and creating sustainable programs and expanding the highly capable areas.

Keywords**:** Land capability; South Sinai; GIS techniques; Egypt.

INTRODUCTION

Land Capability Evaluation System (LLES) is a qualitative framework that assessed land capability for specified land uses and refers to land ability to preserve several predetermined land uses. Egypt Strategy Vision 2030 based on the United Nations (UN) Sustainable Development Goals (SDGs) focuses on the obstacles that face the potential sustainability development in Egypt according to a participatory strategic planning approach (MCIT, 2020). For that concept, land capability evaluation and mapping is essential for land management planning and sustainability because maintaining agricultural productivity is essential for ensuring food security and helping protection of the environment by stopping land degradation. Agriculture is the primary human use of land. Therefore, land capability evaluation and assessment data would enable decision-makers, scientists and soil conservers groups to make decisions for land use policy and improve land-use planning to achieve sustainable agriculture development, (Shokr *et al.*, 2021 and Adams and Engert, 2023).

Land capability denotes a land's ability to produce cultivated crops without degradation over time, (FAO, 1983). Land capability evaluation plays an indispensable role in sustainable agriculture planning and helps decision-makers in inaugurate a suitable land resources management. (Abuzaid and Fadl, 2016 and El-Sayed *et al.,* 2020). Such land evaluation serves evidence for land constraints assessment and management recommendations at various scales, including state and property planning levels, (Murphy *et al.*, 2004). Land capability evaluation encompasses a wide scope of primary landuse/landcover, including agriculture, forestry and livestock production. Land capability classification (LCC) is the most widely used category system for evaluation, with three major categories: classes, subclasses, and units (Dent and Young, 1981).

The landscape, slope, soil depth, texture, and acidity determine the class level. While the subclass is based on specific constraints such as wind erodability, excessive moisture, rooting zone matters, and climatic restrictions. Soils with similar yield levels and land management requirements are grouped together to form land capability units. LCC procedures necessitate the creation of detailed soil surveys as well as information on surface relief, wind erosion, and landuse/landcover. There are numerous methodologies and approaches in LCC that are based on data collected from soil samples and landuse/landcover. The first land capability approach (based on soil and land characteristic) was developed in Germany in the 1930s, followed by more detailed analyses and measurements of soil field properties collected from satellite image systems such as those interpreted by the Enhanced Thematic Mapper (ETM^+) and climate, texture, profile depth, soil $CaCO_3$ content, gypsum content, gravel, soil salinity, soil alkalinity, relief, and drainage pattern are all examples of such properties (Stori, 1964; Sys, 1991; Arnous and Hassan, 2006). Remote sensing (RS) and Geographic Information System (GIS) techniques

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are used to evaluate and assess such soil parameters (Panhalkar, 2011) and land capability uses GIS techniques for constructing land real conditions models based on digital database to simulate a given scenario is an important advantage.

The main objective of this study is to evaluate land capability of some soils in South Sinai, Egypt using the generally accepted MicroLEIS capability model CERVANATA and spatial analysis techniques, to produce multi-thematic maps, creating database that helps in land limiting factors assessing and plan appropriate suggestions for sustainable agricultural developments.

MATERIALS AND METHODS

1.Location of the Study area:

The investigated area is located in the southern part of Sinai Peninsula, and lies between longitudes; 32° 25' 00" and 35° 15' 00" E and latitudes; 27° 45' 00" and 29° 57' 00" N, as shown in Figure 1.

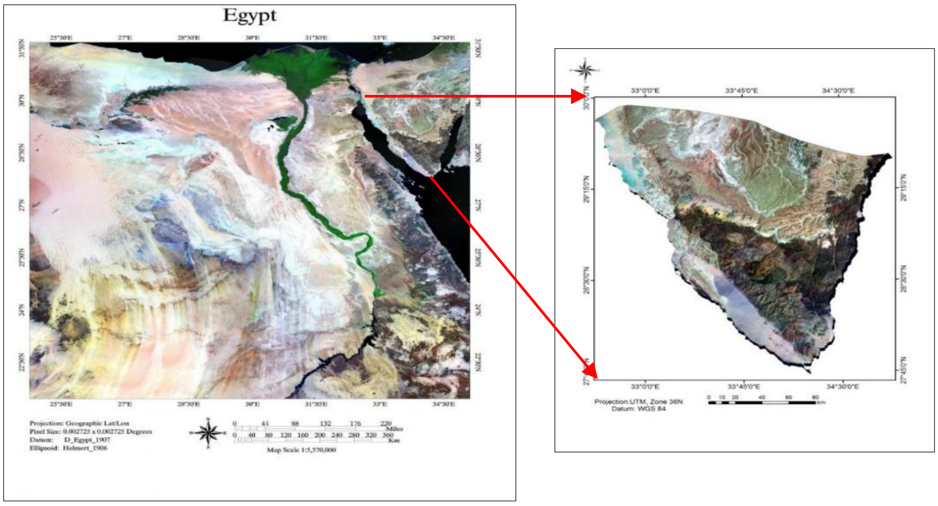

Figure 1. The study area location map

According to Zahran and Willis (2009), The Sinai region is a rugged, sparsely populated mountainous arid terrain with limited groundwater resources, poor soil quality, variable geomorphology, and many steep slopes. The annual rainfall is less than 100 mm. Precipitation falls almost entirely during the winter months and may fall as snow on the highest peaks. In some years, heavy rain storms followed by flooding are possible. The highest point is Saint Catherine Mountain. The average monthly temperature is from 5.4°C to 25.1°C, and the average monthly relative humidity ranges from 34.3 to 57.9%.

2. Digital image processing:

Three geometrically corrected landsat-8 satellite images were taken during 2021 for the study area, and the rectification method (image for map) was followed using a geometric model of second order polynomial. The nearest neighbor method is used for re-sampling. To overlay the images, a mosaic process was developed. The study's elevation heights were calculated using ASTER (Advanced Spaceborne Thermal Emission and Reflection radiometer) as a sensor of Digital Elevation Model (DEM) images. The mosaic image was utilized to identify and outline the physiographical map of the research area after being draped over the DEM to simulate natural 3D (ITT, 2014). Figure 2 shows the Digital Elevation Model of the South Sinai.

3. Production of maps

Using Arc GIS 10.2.2 software, a physiographic map, soils, and land capability were laid out, annotated, projected, and finally produced. (ESRI, 2014).

Field work and laboratory analysis

A South Sinai physiographic map was used for field work and ground proofing (Mohamed, 2013). According to USDA (2004), morphological descriptions of 60 soil profiles representing various geomorphic units were carried out. In the laboratory, Particle size distribution, bulk density, organic matter, EC., and pH were determined according to the Soil Survey Staff (2004).

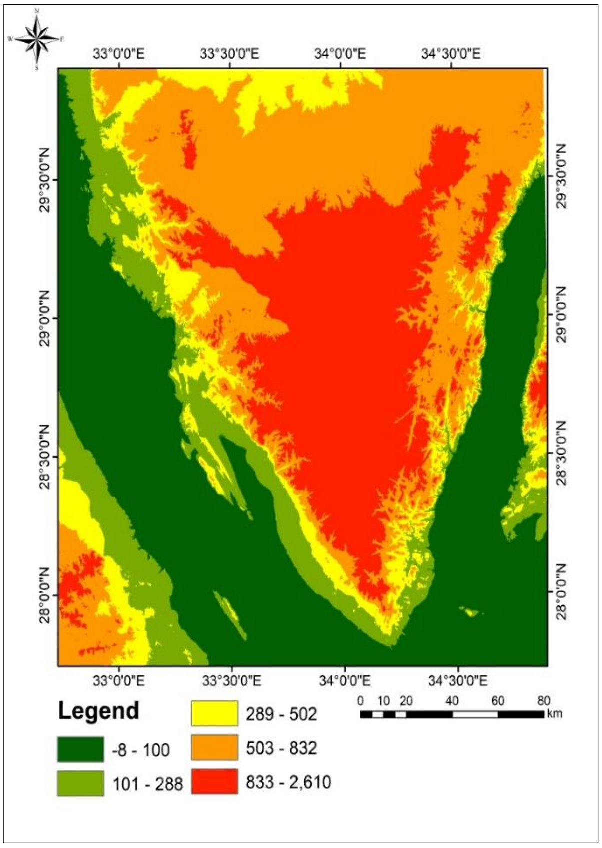

Figure 2. DEM of South Sinai

Land Capability Modeling

A land capability modelling procedure based on the widely accepted MicroLEIS capability model was used. CERVANATA (De la Rosa et al., 1992). The MicroLEIS CERVANATA model works interactively, compare the values of the land unit characteristics to be assessed with the generalization levels specified for the use of each capability class. Following these norms of land evaluation (FAO, 1976; Dent and Young, 1981; ONERN, 1982; Verheye, 1986), The CERVANATA model forecasts general land use capability for a wide range of agricultural purpose. Land capability modeling methodological standards refer to the system that was designed by (De la Rosa et al., 1992).

The CERVATANA Capability Model

The CERVATANA model predicted general land capability by (De la Rosa et al., 1992) with some modifications, and computer proceeds to automate the application model. The CERVATANA model compares unit values for land properties with the generalization scales established for each land capability class in an interactive manner (Figure 3). The most important aspects of this evaluation system are:

1- Land capability model uses traditional methods of predicting or indirectly estimating the general suitability of land to determine its use intensity.
2- Land unit is the model reference spatial unit, which includes both intrinsic soil properties and other environmental aspects (i.e., topography, climate conditions, landuse/landcover and vegetation density).
3- The land capability units are divided into six classes: C1, C2, C3 and C4, which includes lands deemed capable of continuous support and intensive agricultural use, and C5 and C6, which represents lands suitable only for grazing and forestry.

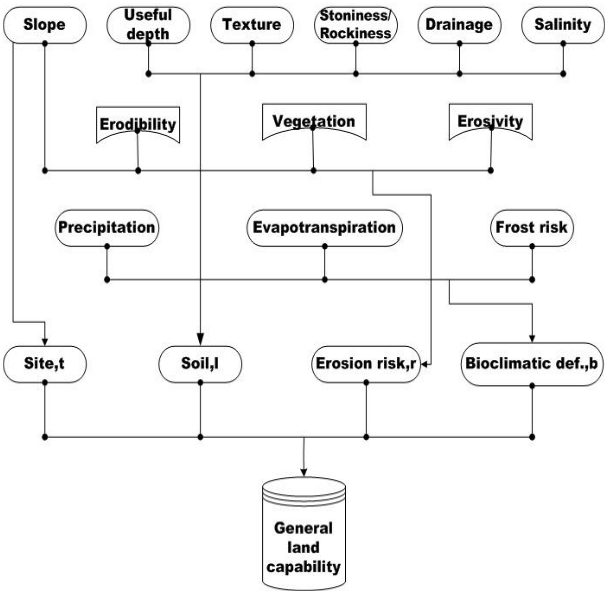

Figure 3. The CERVATANA capability model

4- Appropriate subcategories are determined based on the specific factors or diagnostic criteria used (site, soil characteristics, erosion hazard and bioclimatic reduction).

In every status, the most restrictive criteria are given priority, up to a total of six. The cap measure is used in conjunction with score matrices to relate land properties directly to capability classes.

RESULTS AND DISCUSSION

1.Geomorphological units of South Sinai

South Sinai geomorphology is essentially to genetic relationship evaluation between soils and landforms. (Gerrard, 1993). In South Sinai, there are major landforms namely Coastal Plains, Alluvial Fans, Wet Sabkhas, Pediplains, Decantation Basins, Wadis, Footslopes, Delta, Terraced Hills, Mountains and Plateau. Physiographic units are shown in Figure 4 and Table 1.

Table 1. Physiography of South Sinai:

No.	Geomorphological Unit	Code	Area (m^2)	Area (km^2)
1	Alluvial Fans	AF	146965	146.965
2	Coastal Plains	CP	167247	167.247
3	Decantation Basin	DB	53364210	53.36421
4	Delta	DT	48597	48.597
5	Footslopes	FS	732458	732.458
6	Plateau	PL	10601731	10601.731
7	Mountains	M	164346	164.346
8	Pediplains	PE	37782	37.782
9	Terraces Hills	TH	32734	32.734
10	Wadis	WA	2754852	2754.852
11	Wet Sabkha	WS	82419	82.419
	Total area		14822495210	14822.49521

2. Main features of the geomorphological units

1- Alluvial Fans: An alluvial fan is a triangle-shaped accumulation of gravel, sand, and even smaller sedimentary fragments, such as silt. The name of this material is alluvium. Alluvial fans are typically formed when flowing water interacts with mountains, hills, or sheer canyon walls. Rainwater trickles, swift-moving creeks, raging rivers, or even runoff from agriculture or industry can all be found in streams transporting alluvium. Sand and other debris known as alluvium are picked up by a stream as it runs down a slope. Alluvium is transported by the flowing water to a level plain where the stream exits its channel and spreads out. Alluvial fans occupy an area of 146.965 km^2 of the total area.

2- Coastal Plains: A coastal plain is a flat and low-lying land close to the sea. The boundary between a coastal plain and a piedmont region is frequently marked by a fall line. It can develop from silt deposits brought in by rivers and ocean currents. Erosion caused by waves is another possibility. Erosion also contributes to stony and uneven beaches. On the other hand, a shallow, sedimentary coast is frequently the result of sediment deposition. Coastal plains cover an area of 167.247 km^2.

3- Decantation Basins: Decantation Basins are low lands that elevated above depressions and are surrounded by higher lying areas. Decantation basins cover an area of 53.36421 km^2.

4- Deltas: Deltas are wetlands that develop when rivers discharge their water and sediment into a lake, ocean, or other body of water. Delta occupies an area of 48.597 km^2.

5- Footslopes: A Foot slope is represented the mountains foots. Surfaces of this unit have a propensity to roll to nearby sand sheets or peneplains. The foot slopes cover an area of 732.458 km2.

6- Plateaus: A high plain, also known as a tableland, is a highland area that consists of flat terrain. On one or more sides, deep hills or escarpments are common. Plateaus can form as a result of a variety of processes., such as, upwelling of volcanic magma, lava extrusion, water and glaciers erosion. It can be classified as intermountain, piedmont, or continental based on its surrounding environment. Plateau occupies an area of 10601.731km^2.

7- **Mountains:** The mountain is a high area of the Earth crust that typically has steep incline with a substantial amount of bedrock exposed. A mountain represents an area of 164.346km^2.
8- **Pediplains:** is an extensive plain formed by the convergence of pediments. Pediplains occupies an area of 37.782km^2.
9- **Terraced Hills:** This topography unit perfectly represents the final stage of water or wind erosion. A terraced hill occupies an area of 32.734km^2.
10- **Wadis:** A linear depression that formed as a result of water movement conductance during the "Pluvial" epoch when annual precipitation and surface runoff were dynamic. A wadi occupies an area of 2754.852 km^2.
11- **Wet Sabkhas:** Different coastal wetland ecosystems have different levels of dryness that are periodically flooded by seawater. Sabkhas occupies an area of 82.419 km^2.

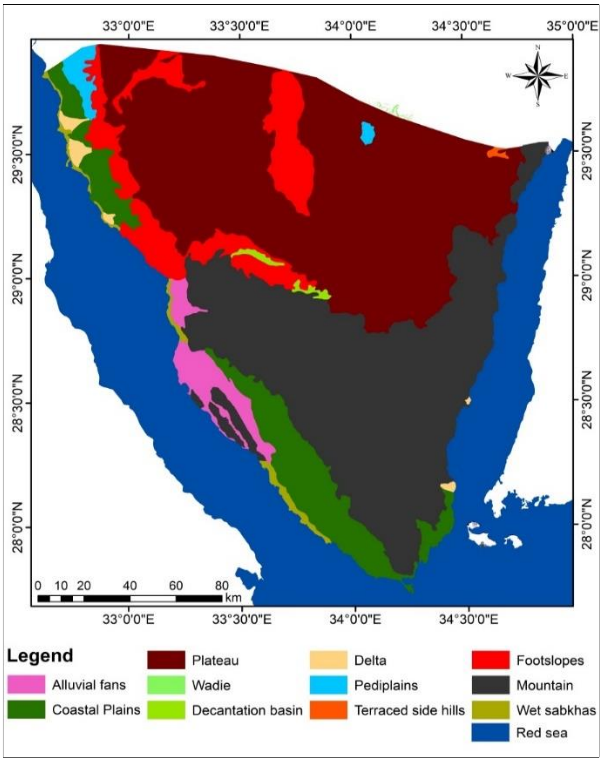

Figure 4. Geomorphological map of South Sinai

Soils of South Sinai

The analytical data of the soils of South Sinai are shown in the following classes, as shown in Table 2 and Figure 5.

Soils of the Coastal Plains:

Landscape of this soil is almost flat and chemical analysis data of the saturated extract indicates that these soils are slightly alkaline (pH 7.5- 8.3), high in $CaCO_3$ content (10.2-23.5 g/kg), low in organic matter and gypsum content varies between 1.6- 5.9 g/kg. Soluble salts are found in different amounts expressed as Electrical Conductivity (EC) and their values vary between 1.7 and 4.1 dS/m depending on the topography of the site. The soil of this geomorphic unit was classified as *Typic Torrifluvents*.

Soils of the Alluvial Fans:

These soils are basically formed of calcareous deposits mostly of alluvial sediments. The soil profiles are deep, with silty clay texture and highly affected with salts. Soil pH is slightly alkaline (7.8-8.2), $CaC0_3$ is 37 g/kg in all profile layers, and organic matter recorded a very low values. The cation exchange capacity (CEC) is high (22-25 cmolc/ kg soil) due to its high clay content. The soils of this unit are classified as *Vertic Torriorthents*.

Soils of the Wet Sabkhas:

These soils showed flat to almost flat surfaces, mostly covered with salt crust in wet sabkhas and fine textured surface crust (3cm thickness) in dry sabkhas. Morphological description shows that, the dry sabkhas soils are deep, relatively moist, with light yellowish brown colour. The texture is sandy in the upper 30 cm and overlies sandy loam layers. While wet sabkhas soils are shallow (50 cm) underlain by ground water table, slightly gravelly sand in texture, Calcium carbonate contents constitute 6.9-17.91 g/kg of the total soil mass. Organic matter content occurs in low amount varying between 0.065 g/kg and 0.73 g/kg, this may possibly be due to accumulation of organic matter resulting from the decay of natural vegetation. Gypsum content is present mainly in the lagoon deposits and varies between 0.49 g/kg and 5.84 g/kg with the highest content in the upper layer.▫ The soils are very strongly saline as the EC values reach a high of 8.5 dS/m at 25°C. The cation exchange capacity varies widely from 2.2 to 26.9 cmolc/kg soil. The clay horizons have the highest values while the sandy horizons have the lowest ones. Soil classification of this unit is *Oolitic Torripsamments*.

Soils of Footslopes:

The morphological features and the particles size distribution in these soils show that, sand is main the texture in the successive profile layers; $CaCO_3$ recorded more than 10.1 g/kg in the different profile layers. The organic matter content is low (less than 0.05 g/kg). Soil salinity values reveal that, soil (EC) is more than 4 dS/m. The soil pH value is 7.9 in the successive layers of the studied profiles. CEC recorded a value of 5.4 cmolc/kg soils. Soil classification of this unit is *Lithic Calcic Gypsiorthids*.

Soils of Wadi:

The morphological description shows that dry wadi is deep, light colour, and composed essentially of a mixture of both carbonate, quartz sand and a high amount of gravel. Soil pH is slightly alkaline, which vary from 7.8 to 8.6. $CaCO_3$ content is high (29-79 g/kg), the highest values are detected in these soils. Soil OM content is less than 0.1 g/kg. Gypsum content is detected mainly in wadi and relatively increases with depth. ̆(EC$_e$) ranges between (2.3 - 9.5 dS/m). ̆CEC values range between 3.05 - 4.65 cmolc/kg soil due to its coarse texture. Mg^{+2} Ca^{+2} and are the dominate exchangeable cations. Soil classification of this unit is *Typic Torripsamments*.

Soils of the Delta:

The normal soils of the delta plain are deep, light colour, sandy textured, and gravel content differ widely through the subsequent layers (4-48%). The soils are loose, single grain structure. $CaCO_3$ is dominate in Oolitic forms. Topography is undulating and barren from natural vegetation. pH values range between 7.6 and 8.2. Because of the calcareous nature of the parent materials the content of $CaCO_3$ ranges between 28 – 64 g/kg. The content of oganic matter is very low and the highest value is 0.42 g/kg. Soil classification of this unit is *Oolitic Torripsamments*.

Soils of Terraces Hills:

These soils have flat surface covered with some small sandy hummocks. The texture class of these soils is loam at the surface and sand in the deep layers. $CaCO_3$ contents in soils of terraces vary widely between 12 to 48.7 g/kg. Organic matter content is generally low (0.06 - 0.4 g/kg). Soils of this unit have high salinity pattern as the EC values range between 2.6 and 9.3 dS/m. The loamy soils of some terraces region have CEC values vary between 6.17 and 12.89 cmolc/kg soils. The classification of this unit is *Typic Torriorthents*.

Soils of Pediplains:

Soil texture is sand and sandy loam in the all profile layers. $CaCO_3$ varies between 28 g/kg - 55.9 g/kg. Organic matter content is low (less than 0.5 g/kg). The soil salinity values reveal that, the electrical conductivity (EC_e) is more than 4 dS/m. The pH values recorded 7.1 in the successive profile layers. The soils of this unit are classified as *Typic Paleorthids*.

Table 2. Soils of South Sinai

No.	Unit	Code	Taxonomy	Area/km^2
1	Alluvial Fans	AF	*Vertic Torriorthents*	146.965
2	Coastal Plains	CP	*Typic Torrifluvents*	167.247
3	Decantation Basin	DB	*Typic Calciorthids*	53.36421
4	Delta	DT	*Oolitic Torripsamments*	48.597
5	Footslopes	FS	*Lithic Calcic Gypsiorthids*	732.458
6	Plateau	MP	Plateau	10601.731
7	Mountain	M	Mountain	164.346
8	Pediplains	PE	*Typic Paleorthids*	37.782
11	Terraces Hills	TH	*Typic Torriorthents*	32.734
13	Wadi	WA	*Typic Torripsamments*	2754.852
14	Wet Sabkhas	WS	*Oolitic Torripsamments*	82.419
Total area: 14822.49521 km^2				

Soils of Decantation Basin:

The soil texture is loamy and loamy sand in the successive profile layers. The calcium carbonate varies between 24.5- 61.4 g/kg. OM content is low with a value of 0.4 g/kg. EC is less than 5 dS/m. The pH values ranged between 7.6 - 8.4 in the all soil profiles layers. The classification of these soils is *Typic Calciorthids*.

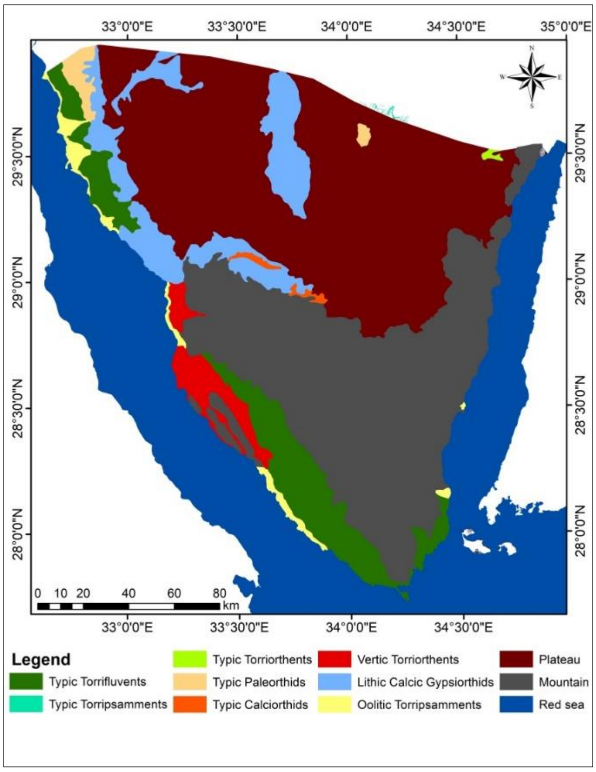

Figure 5. Soils of South Sinai

3. Land Capability Modeling

A method of qualitative evaluation or comprehensive interpretation of the following factors: relief, soil, climate, current usage, and vegetation can lead to the prediction of general land use capability. Figure (6) shows the flow chart of land capability model. The land characteristics were chosen as the diagnostic criteria or limiting factors, and the relevant generalization levels were established along with the capacity classes using gradation matrices. With the aid of degree matrices and the maximum limitation technique, it was possible to tie the characteristics of the land to the various capability classes. Matching tables were created and linked to the GIS modelling environment using database engine fields with the attribute of identifier key feature.

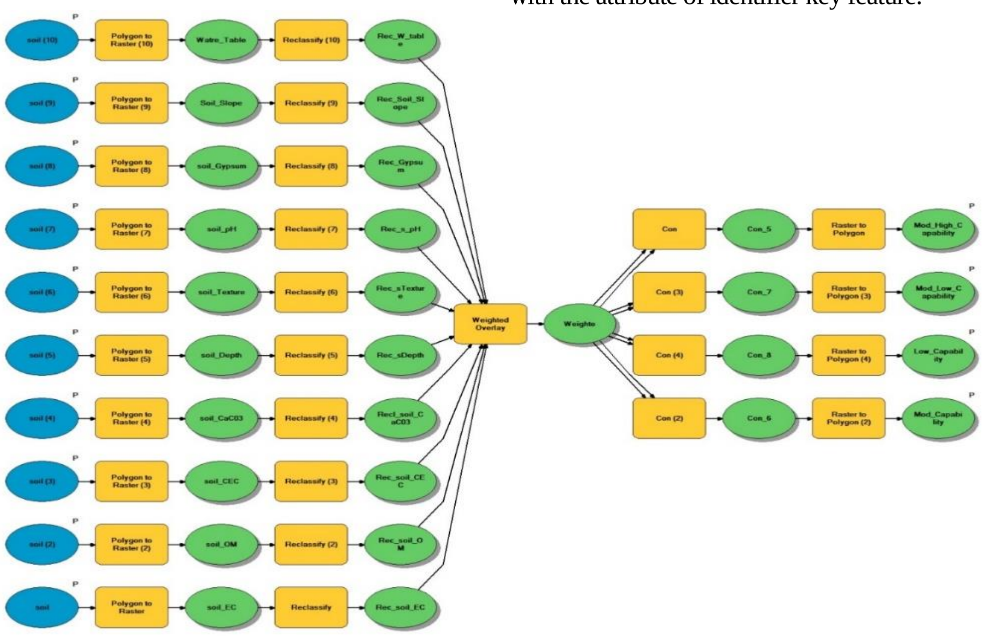

Figure 6. Land capability model flow chart

4. Land capability classification

Applying this methodology on south Sinai soils of the current study, the following results have been obtained (Figure 7 and Table 3).

A) Soils of the Delta and Decantation Basins are C3 (moderately high capability). This land has good capability and can be managed without much difficulty. These lands require careful management. They are moderately to highly productive for a wide range of crops when managed properly.

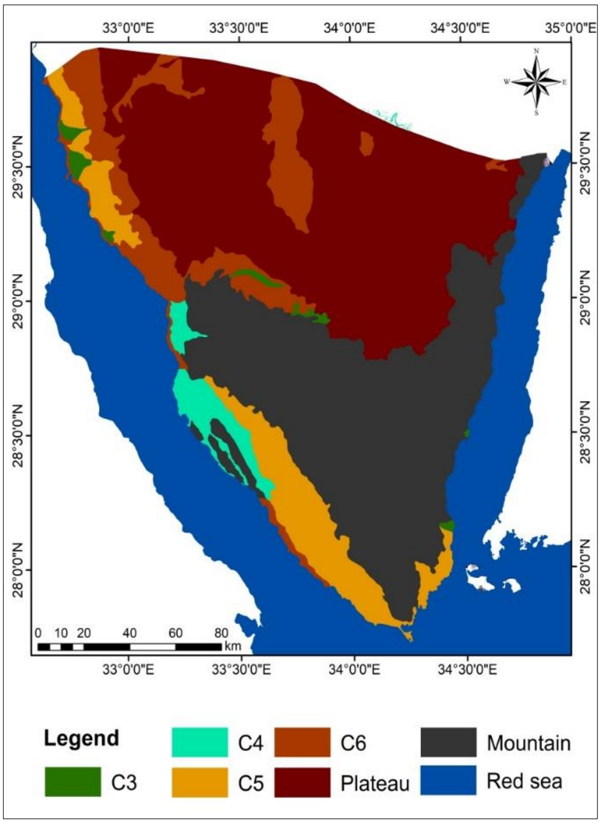

Figure 7. Land capability classification of the study area

Table 3. Land capability classes

No.	Geomorphological Unit	Code	Capability class	Area/ km²
1	Alluvial Fans	AF	C4	146.965
2	Coastal Plains	CP	C5	167.247
3	Decantation Basin	DB	C3	53.36421
4	Delta	DT	C3	48.597
5	Footslopes	FS	C6	732.458
6	Plateau	MP	Plateau	10601.731
7	Mountain	M	Mountain	164.346
8	Pediplains	PE	C6	37.782
11	Terraces Hills	TH	C6	32.734
13	Wadi	WA	C4	2754.852
14	Wet Sabkhas	WS	C6	82.419
Total area (km²): 14822.49521				

B) Soils of the Alluvial Fans, Delta and Wadis are assigned with C4 (moderate capability). This class has moderate to low restrictions that limit the variety of crops and particular conservation techniques are necessary. For a variety of crops and improvement techniques, the productivity of these soils ranges from low to fair.

C) Soils of Coastal Plains are assigned with C5 (moderately low capability). This class has moderately severe restrictions that limit the types of crops that can be grown or call for particular conservation measures. The productivity of these lands for various crops and development techniques ranges from low to fair.

D) Soils of Pediplains, Wet Sabkhas, Footslopes and Terraced Hills are assigned with low capability (C6). These lands have very severe constraints that limit their usage in agricultural practices. These lands are suitable for growing forage crops, and agroforestry systems, since they have low to marginal productivity.

CONCLUSION

To generate the geomorphological mapping units, soil mapping units, and land capability mapping units for this study area, advanced techniques including GIS and remote sensing were used. The results showed two soil orders; *Entisols* and *Aridisols*, which are denoted by eight great groups "*Vertic Torriorthents*, *Typic Calciorthids*, *Typic Paleorthens*, *Typic Torrifluvents*, *Typic Torriorthens*, *Typic Torripsaments*, *Lithic Calcic Gypsiorthids* and *Lithic Torripsaments"*. The study area was categorized into four classes of land capability (C3, C4, C5 and C6). The Decantation Basins, Delta, Alluvial Fans and Wadi were classified to C3 and C4. The Terraced Hills, Pediplains, Footslopes, Wet Sabkhas and areas of Coastal Plains with classes of C5 and C6. Therefore, these South Sinai soils have some sustainable areas, which might have potential importance that support the decision makers in adapting and developing sustainable programs and increasing the high capability areas. Integration between remote sensing data and digital soil characteristics maps, using GIS techniques, can produce a land capability classification map.

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تصنيف التربة وتقييم قدرة الأراضي للإستخدام الزراعي المستدام في جنوب سيناء، مصر

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الملخص

تقيَّم القدرة الإنتاجية لمنطقة الدراسة بمقارنة خصائص وحدة رسم خرائط الأراضي بحدود حرجة لكل فئة من فئات القدرة الإنتاجية وتم تحديد رتبتين للتربة: Entisols و Aridisols، يمثلهما ثماني مجموعات عظمى " *Vertic Torriorthents, Typic Calciorthids, Typic Paleorthens, Typic Torrifluvents, Typic Torriorthens, Lithic Calcic Gypsiorthids, Typic Torripsaments*و *Lithic Torripsaments* وتم تصنيف التربة إلى أربع فئات على حسب قدرة الأرض ؛ تراوحت بين C3 ،C4 ، C5 و C6. حيث تراوحت قيم القدرة الإنتاجية لكل من الأحواض التجميعية و الدلتا و المروحة الطمية و الأودية الجافة بين C3 و التى تتميز بقدرة إنتاجية جيدة و يمكن إدارتها بأقل درجات الصعوبة ،C4 و التى تتميز بمعيقات متوسطة إلى قليلة السبخات الرطبة وبعض مناطق السهل الساحلي تنتمي إلى فئتي C5 المتميزة بمعيقات متوسطة الحدة لزراعة بعض المحاصيل مع إجراء بعض العمليات الزراعية و C6 الى تتميز بوحود معيقات حادة للإستخدام الزراعى و لكن يمكن إستغلالها فى زراعة محاصيل الأعلاف أو الغابات. مما تقدم توجد مناطق واعدة للإستخدام الزراعى المستدام لأراضى جنوب سيناء و التى يمكن أن تساعد صناع القرار فى وضع برامج مستدامة تتيح توسيع رقعة الأراضى مرتفعة القدرة الإنتاجية الزراعية.

الكلمات الرئيسية: تقييم التربة، قدرة الأرض الإنتاجية جنوب سيناء، نظم المعلومات الجغرافية، تصنيف الأراضى؛