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Soil Thematic Mapping as the Base for Agricultural Development in the Northwestern Coast, Egypt

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THIS RESEARCH aims to create and analyze thematic soil maps for promising areas for agricultural expansion along the northwest coast of Egypt. The study area is 3151.671 km² and consists of a plateau and elevated areas merging into coastal lowlands. Remote sensing data were used with a digital elevation model to map the physiographic units and characterize land surface features. Five different physiographic entities are recognized; each mostly associated with the soil sub-great groups Typic Haplocalcids and Typic Torripsamments. Data collected through land survey and laboratory analysis were used to create thematic soil layers that were analyzed to determine land factors that limit agricultural development. The results showed that the land surface factors hinder agricultural development due to the steep slope and undulation of the land surface. Analysis of thematic soil maps showed that agricultural development in the region is mainly constrained by coarse soil texture, shallow soil depth, high $CaCO_3$ content, and low CEC. To achieve agricultural sustainability in the region, improved drainage, organic fertilization, and crop selection are required.

Keywords: Physiography, Thematic maps, GIS, RS, agricultural sustainability.

1. Introduction

In the context of sustainable development, agricultural advancement is recognized as the cornerstone of Egypt. This focus is particularly relevant as developing nations worldwide confront significant challenges to food security due to a confluence of factors: rapid population expansion and constraints on agricultural resources (Xiang et al. 2020 & Gerten et al. 2020). The land resources in Egypt are encountering significant obstacles due to the scarcity of arable land and the rise in population (Wael et al., 2022). Agriculture holds significant importance in Egypt and is recognized as a cornerstone in the pursuit of economic and social progress. Consequently, the government is implementing a series of large-scale agricultural development initiatives aimed at fostering equitable development across all regions in Egypt and expanding into the extensive desert areas to establish new communities (CAPMS, 2019 and Mohamed et al. 2022). Northwestern coast of Egypt is considered one of the most promising areas for agricultural, tourist, urban, and industrial development.(Abdelaty et al., 2023 & Karam et al., 2020). Ras El-Hekma and El-Dabaa area along the Mediterranean coast of Egypt, a multi-sectoral development area. Besides, the superiority of the area is highly dependent on its proximity to three development projects: the tourism and urban growth pole at Ras El-Hekma, the beachfront Alamain New Mega City, and the Nuclear Power Plant at El Dabaa (Elmasry 2024). The burgeoning inhabitants exert a substantial sway on agricultural incomes. It intensifies pressure on the already limited availability of arable land, posing a threat to worldwide food security (Xiang et al. 2020 & Gerten et al. 2020). Recognizing this urgency, the Egyptian government has implemented a program aiming to annually increase cultivated land by approximately 148,000 acres, Ismail et al. (2010).

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Egypt's national strategy for agricultural land expansion targets the addition of roughly 4.4 million acres across various regions, with land suitability and water resources serving as key selection criteria (Mohamed, 2018). The government has actively pursued numerous development programs targeting the northwest coastal zone. These efforts include the extension of pipelines transporting Nile water westward, the enhancement of existing wells for dual domestic and agricultural water use, and the implementation of large-scale projects.

A prime example is the construction of El-Alamein New City, envisioned to accommodate a population of one million. This development directly addresses the population surge and its associated demands for food and water security. Earth observation data and Geographic Information Systems (GIS) play a decisive role in mapping, assessing, and managing land capability classes (Ali and Shalaby 2012; Jalhoum et al. 2014). The requirement for efficient systems to assess land suitability for agriculture has emerged due to the growing population and higher food production demand (Yousif 2024). Physiographic mapping involves the identification and classification of landforms, topography, and geological features in a specific area (Adolfo and Manuel 2023). Remote sensing data and GIS can be instrumental in creating detailed physiographic maps. These maps provide critical insights into terrain variations, drainage patterns, and other land features that influence agricultural suitability. Soil mapping focuses on delineating different soil types and their spatial distribution across the landscape (Ali, and Moghanm 2013). These maps help in understanding soil fertility, moisture retention, and drainage characteristics, crucial factors for land-use planning and agricultural decision-making. Remote sensing provides a synoptic view of the landscape, allowing for efficient monitoring and analysis of physiographic and soil features. Through the integration of remote sensing and GIS, decision-makers can assess land suitability, plan optimal land use, and implement sustainable agricultural practices (AbdelRahman et al. 2016). The integration of physiographic and soil mapping by using Geographic Information Systems (GIS) fosters a holistic approach to land use management and crop selection. This approach entails a comprehensive analysis of the interplay between terrain features and soil characteristics, enabling stakeholders to achieve sustainable land management for various soil types. Such an assessment is critical for identifying areas optimal for cultivation, determining irrigation requirements, and deploying land management strategies that maximize agricultural productivity while minimizing environmental impact. Land evaluation for agricultural purposes encompasses the analysis of essential factors related to soil properties, climatic factors, and other land-related aspects (FAO, 1976 and Sys 1979).

All land evaluation systems aim to identify the optimal use of land among various alternatives based on the type and extent of limitations. The degree of limitations is primarily determined by inherent and relatively permanent soil characteristics. The classification scheme of soil limitations initially developed to include eight classes, ranging from I (low) to VIII (high) based on inherent limitations for agricultural use (Klingebiel and Montgomery, 1961; Dent and Young, 1981 and Rossiter, 1994). This emphasis on limitations ensures a comprehensive evaluation of land potential. Hence Land management is dependent on land surface analysis and soil-thematic mapping to achieve agricultural development (AbdelRahman, 2022).

In this context, the current study aims to delineate physiographic units and soil-thematic layers to identify land limitations areas to realize agricultural development on the northwestern coast of Egypt which is characterized by specific natural elements.

2. Materials and methods

2.1 Study area

Located in the Matrouh region (Fig. 1), the study area extends from west El-hammam to the east of Ras El-Hekma **(Fig. 1)**. The area occupies 3151.671Km2, (i.e. 750.4 Feddans) and extended between Latitudes 30^0 $10'$ $00''$ and 30^0 $50'$ $00''$ N and Longitudes 28^0 $80'$ $00''$ and 29^0 $20'$ $00''$ E.

Fig. 1. Location of the study area.

2.2 Satellite data

In the present study, remote sensing and GIS technologies were employed to create thematic maps of the research area **(Fig. 2).** It is recommended that this methodology is applicable for similar studies conducted in different regions (Mansour et al., 2017; Abd El-kawy and Darwish, 2019; Yousif and Ahmed 2019; Zayed et al., 2021; Abd El-kawy et al., 2023 & 2024; Yousif and Ahmed., 2024). Three Landsat-8 satellite images (2023) available from the website of the United States Geological Survey (USGS) were used with a digital elevation model for mapping the physiographic units and defining the land cover. The Landsat-8 images of 14.25 meters resolution panchromatic band are used to improve the image spatial resolution. The Identification numbers (ID) of the used images are:

- LC08_L1TP_178038_20230829_20230906_02_T1
- LC08_L1TP_179038_20230804_20230811_02_T1
- LC08_L1TP_179039_20231124_20231129_02_T1

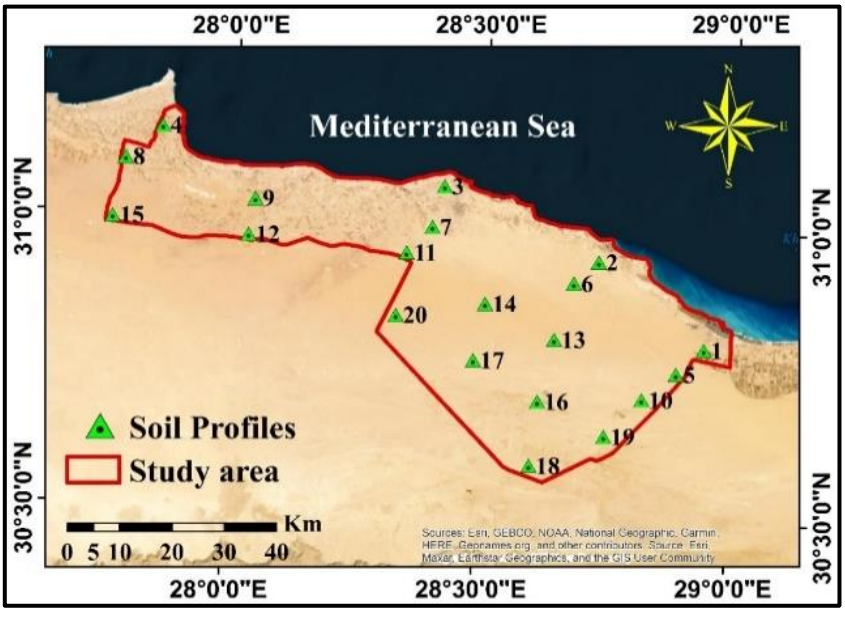

Fig. 2. The spatial distribution of soil profiles.

2.3 Elevations

The Shuttle Radar Topography Mission (SRTM) Digital Elevation Model (DEM) is a 3D automated model of terrestrial surfaces that offers an improved execution than the topographic maps (Brough, 1986). The SRTM is one of the most important space explorations Earth has ever undertaken, using radar to scan the land at intervals of 30 meters **(Fig. 3)**. A Digital Elevation Model (DEM) is a crucial tool in terrain analysis and remote sensing, significantly improving the quality and utility of imagery by providing detailed information about surface elevation and slope. As highlighted by Lee et al. (1988), the integration of a DEM into the analysis process enhances the interpretation and visualization of the land surface, enabling a more accurate representation of terrain features

2.3 Field work

A total of 52 Soil samples representing the study area were collected from 20 soil profiles **(Fig. 2)**. Soil samples were prepared and sent for laboratory analyses. Twenty soil profiles were excavated to a depth of 150 cm unless blocked by bedrock or the water table. According to FAO (2006), these soil profiles are described pedomorphologically. This was followed by observation, and checking the boundaries of soil units and some soil characteristics (depth, texture, cooler, and lime reaction).

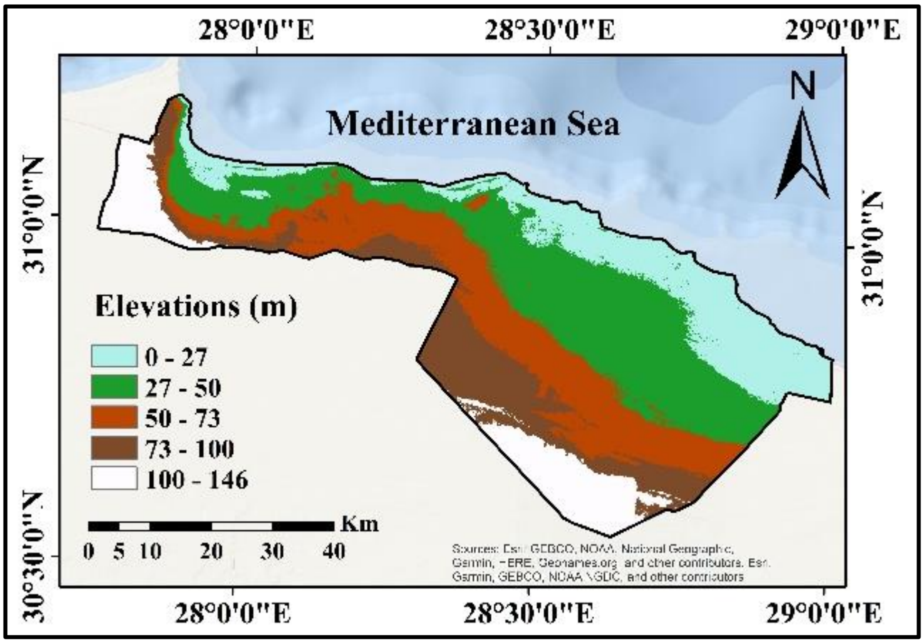

Fig. 3. Surface elevation.

2.5. Geographic information system (GIS)

Spatial interpolation techniques are widely employed to generate continuous surfaces from data collected at discrete locations, such as soil profiles. Inverse Distance Weighting (IDW) represents a prevalent interpolation method that leverages the surrounding measured values to estimate unknown values at unsampled locations (Vasileios et al., 2023). Essentially, IDW assigns weights to nearby measured values based on their distance from the prediction site. Values closer to the prediction location exert a greater influence on the estimated value, with this influence diminishing with increasing distance. This study utilized the IDW functionality within ArcGIS 10.8 software to interpolate key soil properties, including soil depth, calcium carbonate content ($CaCO_3$), electrical conductivity (EC), cation exchange capacity (CEC), and exchangeable sodium percentage (ESP). These interpolated properties will subsequently be used to generate thematic maps depicting soil depth, $CaCO_3$ content, EC, CEC, ESP, texture, and erodibility. Each soil property was classified on the thematic map according to the framework for land evaluation detailed by FAO (1978).

3. Results

3.1 Land surface analysis

The surface elevation of the area is presented in Figure 4. The altitude of the area graduated in height ranges between 0 and 146 m a.s.l. classes and areas by kilometers and percentage are illustrated in **(Table 1**). The highest elevation values demonstrate the south part of the study area (73–146 m). This represents an area of about 32.21% of the total area. The lowest elevation areas are located on the north whereas the elevation value ranged from 0 to 27 m. There are some scattered high-elevated areas inside the low areas in the middle parts. The elevation gradually increases toward the south and reaches its maximum value (146 m a.s.l.) at the west of Ras El-Hekma.

Table 1. Altitude classification.

No.	Classification	Area (km^2)	Percent
1	0 -27	802.70	**26%**
2	27-50	1062	**33.65%**
3	50 -73	660.32	**21%**
4	73 -100	236.8	**7.5%**
5	100 -146	374.36	**11.85%**

Slope describes the degree of incline of a soil surface in relation to the horizontal plane. Expressed as a percentage, it signifies the change in elevation between two distinct points. Understanding slope is crucial as it directly impacts the potential for erosion (Taotao et al., 2020). Soil surface slopes that exceed 2 percent typically erode if cultivated (Brice et al. 2009). The slope of the investigated area ranges from flat to moderately steep as shown in Figure 4. The flat areas are characterized by a slope in the range of 0%–0.2%, which mainly located in the coastal plain and over the plateau surface. The level areas are dominated by a surface slope from 0.2% to 0.5% exhibiting the ends of pediments and the plateau surface. The near-level and gently slope surfaces are formed mainly in the coastal plain to the north of the study area as they have a slope range between 0.5% and 5%. Sloping to moderately steep surfaces characterize the surfaces of the Plateau, escarpment, and pediment. Aspect is the alignment of a slope measured from 0 to 360 degrees clockwise, where 0 is north, 90 is east, 180 is south, and 270 is west. Aspects affect the angle between surfaces, wind direction, and solar radiation that the ground receives, resulting in different values of light, temperature, and physical and chemical properties of the soils. Therefore, it affects the diversity and density of plant communities. Figure 5 represents the slope aspect of the study area. The data indicates that the surface is dominated by different aspects where the slope direction varies widely from one point to another. In general, the surface slope aspect in the coastal plain is mainly in the north direction. To the west of the study area, the slope direction is northeast.

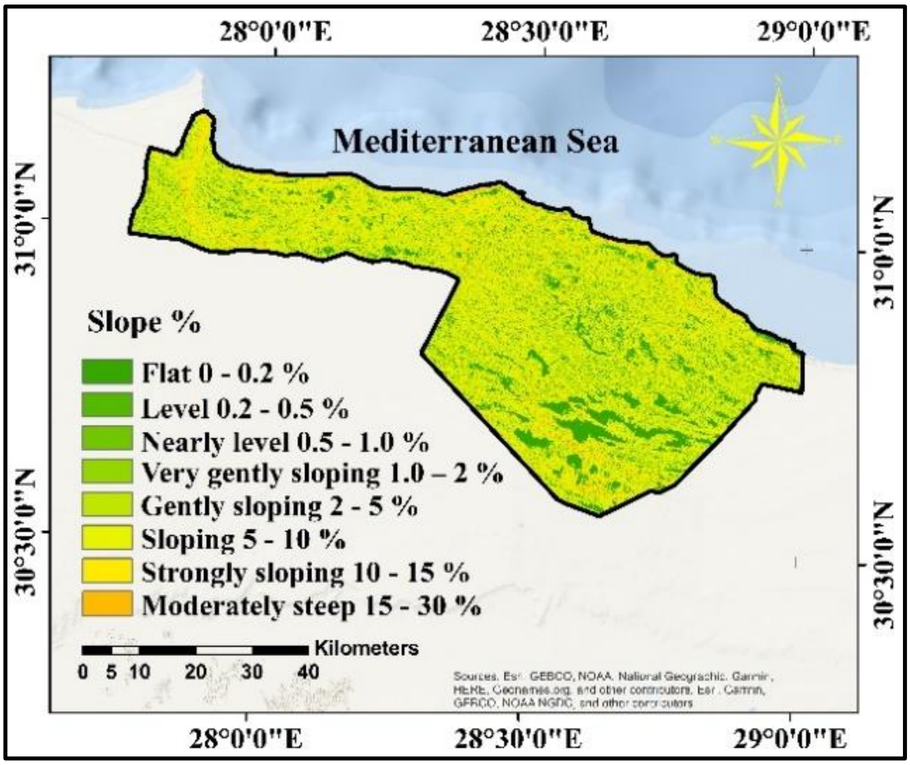

Fig. 4. Surface slope (percent).

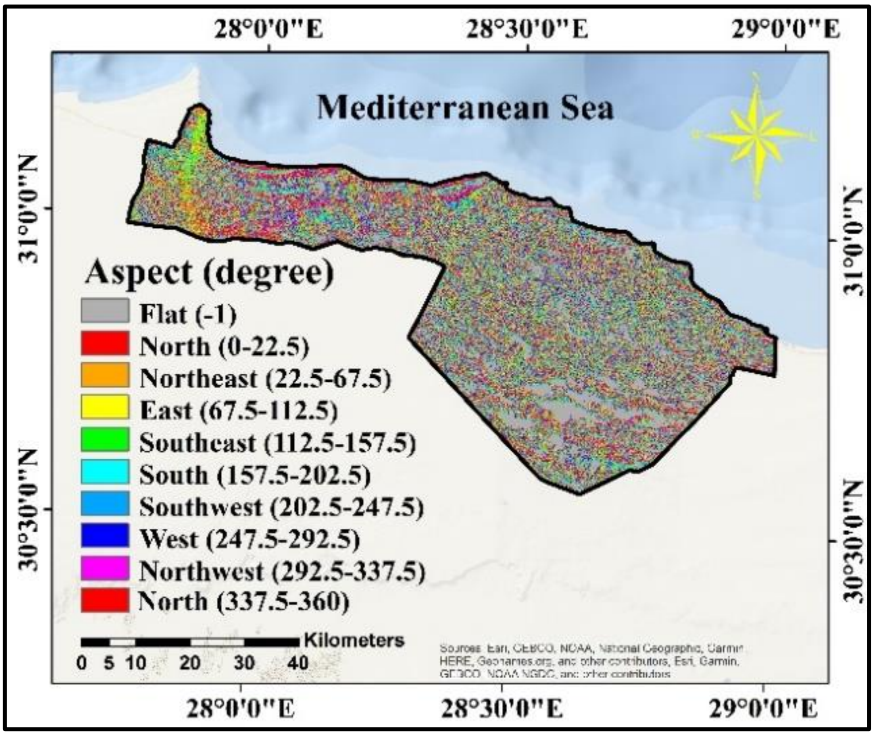

Fig. 5. Slope aspect.

Table 2. The main physiographic units and soils.

landscape	Origin	Landform	Elevation Slope	Symbol	Mapping subunit		Sum Mapping unit		Soil prof. no.	Soil tax.		
					Area (Km2)	%	Area (Km2)	%		Classification	%	Mapping units
Aeolian plain (A)	Aeolian deposits (a)	Sand sheet (1)	Low (1)	Aa11	681.74	21.63	1423.38	45.15	3,9 5, 6, 7, 10, 11,13, 14,16	Typic Haplocalcids. Typic Torripsamments	20 80	Association
			Moderate (2)	Aa12	380.17	12.02						
			High (3)	Aa13	361.47	11.5						
Coastal plain (C)	Marine deposits (m)	Sand sheet (1)	Low (1)	Cm11	110.79	3.5	802.69	26	1,2	Typic Haplocalcids	100	Consociation
			Moderate (2)	Cm12	283.17	9						
			High (3)	Cm13	408.73	13						
		Shore ridge (2)	High (3)	Cm23	15.58	0.5						
Pediment plain (P)	Limestone /Sandstone (s)	Pediment (1)	Gently slope (1)	Ps11	298.85	9.5	298.85	9.5	12 19	Typic Haplocalcids. Typic Torripsamments	50 50	Complex
Plateau (U)	Limestone (l)	Plateau surface (1)	Almost flat (1)	Ul11	134.00	4.25	611.16	19.35	4,8,18 15, 17, 20	Typic Haplocalcids. Typic Torripsamments	50 50	Complex
		foot slope (2)	Steep (2)	Ul22	240.36	7.6						
			Gently (3)	Ul23	236.80	7.5						
Total					3151.67	100		100				

1. Physiography and soils

1.1 Physiography

Figure (6) and Table (2) show the foremost physiography and soils of the study area. The data indicate that the area is characterized by different landforms as follows:

3.1.1 Sand sheet (Aa1)

Sand sheets are characterized by flat or gently undulating expanses of loose sand with surface grains potentially exceeding the size threshold for saltation (windblown sand transport). These features constitute roughly 40% of aeolian (wind-deposited) surfaces and develop in environments where either grain size is too large or wind velocities are insufficient for dune formation. Sand sheets can occur at various elevations, categorized as low, moderate, or high. Based on origin and landscape the sand sheets were divided into two different types, the first type of sand sheet is originally aeolian deposit and covers an area of 1423.38 Km^2 i.e., 45.15% of the total area. The second type is formed from a marine deposit origin and covers an area of 802.69 Km^2 i.e., 25.50% of the total area.

3.1.2 Shore ridges (Cm2)

Shore ridges, also known as beach ridges, are a type of wave-built landform characterized by a triangular or convex shape and alignment parallel to the swash zone. These ridges are formed in the backshore by the combined action of swash (uprush) and storm waves. It's important to distinguish shore ridges from other coastal features. Shore ridges are not relict features but can be considered semi-parallel, multiple landforms built by waves and wind within the intertidal and wind within the intertidal and supratidal zones. These landforms are found mainly to the north of the study area and cover an area of 15.58 Km^2 i.e., 0.5% of the total area.

3.1.3 Pediment (Ps1)

A gently sloping erosional surface or low-relief plain formed by flowing water in arid or semiarid areas at the base of a plateau front is also known as a concave slope with a slope ranges from 0.5° to 7°. In the study area, the pediment is close to the plateau foot slope and dominates an area of 298.85 Km^2 i.e., 9.5% of the total area.

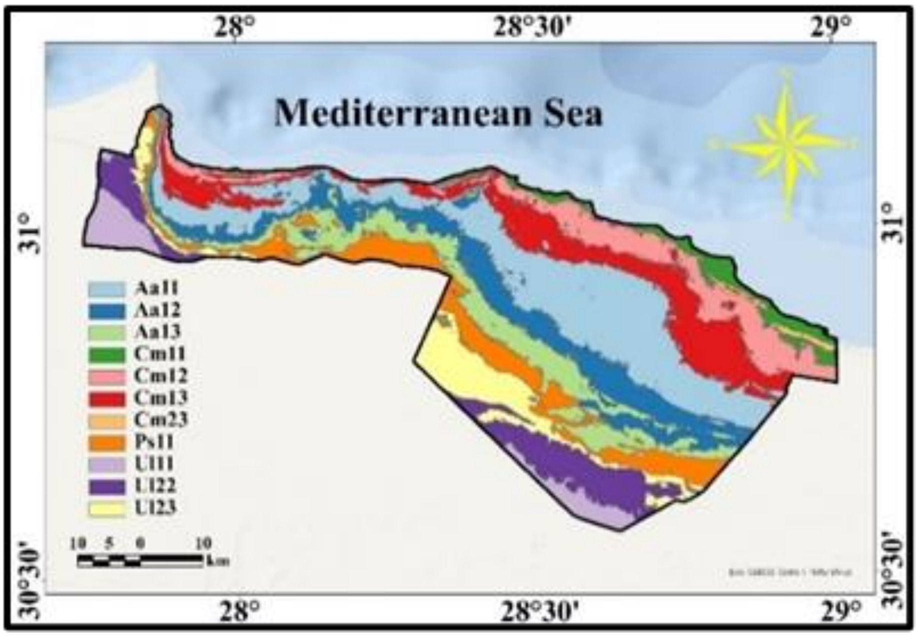

Fig. 6. The main physiographic units of the study area.

3.1.4 Plateau surface (Ul11)

A plateau surface is a flat, elevated landform that rises sharply above the surrounding area on at least one side. Plateaus are a ubiquitous feature found in every region, covering approximately one-third of the Earth's land surface. They constitute one of the four primary landforms, alongside mountains, plains, and hills. In this study plateau surface exhibits an area of 611.16 Km^2 i.e., 4.25% of the total area.

3.1.5 Foot slope (Ul2)

The foot slope is the depositional colluvium part of the slope. Water, sediment, and dissolved components may accumulate in soils at the base of hillslopes. It dominates an area of 477.16 Km^2 i.e., 15.1% of the total area.

3.2. Soils

Tables 3 and 4 represent the mean physical and chemical characteristics of the studied soil profiles, the soils of the different landforms in the study area could be detailed as follows:

3.2.1 Soils of sand sheet

a. Aeolian deposits

The sand sheet landform of the aeoline plain originally consisted of aeoline deposits, ten soil profiles (i.e., 3,9,5,6,7,10,11,13,14, and 16) represent the soil of this landform. The soil depth ranged from 50 cm to 150 cm indicating that these soils are graduating from moderate to deep soil profiles. The soil texture classes of this area change from sandy loam (60%), sand (30%), and sandy claloam (10%) as indicated by the mean values of sand, silt and clay of the soil profile. Calcium carbonate ranged from 16.28% to 49.80%, with mean values approaching 30.58%, indicating that the soils herein are calcareous soils. The soil pH ranged from 8.15 to 8.56. The soil salinity ranged in wide limit from non-saline (1.12 dSm^{-1}) to high saline (7.09 dSm^{-1}). ESP values are less than 15% ranging between 2.46% and 12.88%. The data of CEC ranged from 1.86 cmol/kg to 12.15 cmol/kg soil and the OM ranged from 0.04% to 0.20% indicating that the soils are extremely poor in respect of the fertility status. The soil taxonomy of this landform is associated with 80% Typic Torripsamments and 20% Typic Haplocalcids.

b. Marine deposits

The sand sheet landform of the coastal plain mainly consists of marine deposits. Two soil profiles (i.e., 1 and 2) representing this landform showing that the depth ranged from 70 cm to 100 cm indicates that these soils are graduating from moderate to deep soils. The soil texture of this area is rounded from sandy loam to sand as indicated by the mean values. Also, the mean value of calcium carbonate is 35.35% indicating a calcareous soil. The pH mean value is 8.3, the soil salinity of these soils ranged in wide limit from non-saline (1.12 dSm^{-1}) to saline (4.92 dSm^{-1}), and ESP values ranged between 2.55% and 14.91%. The data of CEC ranged from 2.35 cmol/kg to 8.43 cmol/kg, and the mean value of OM is 0.215% indicating that the fertility of the soil is very poor. The soils are dominated by the Typic Haplocalcids sub-great group consequently it is defined as a consociation soil set.

3.2.2 Soils of the pediment landform

The pediment landform mainly consists of limestone/sandstone. Two soil profiles (i.e., 12 and 19) representing this landform show that the mean depth value is 130 cm indicating that these soils are deep. The soil texture of this area is sand as indicated by the mean values of particle size analyses. Also, the mean value of calcium carbonate is 41.33% indicating a high calcareous soil. The pH mean value is 8.41, the soil salinity is 3.5 dSm^{-1}, ESP mean value is 6.67%. The data of CEC ranged from 2.31 cmol/kg to 4.07 cmol/kg, and the mean value of OM is 0.08% indicating that the fertility of the soil is extremely poor. The soil set in the pediment is complex including the soil sub great groups of Typic Haplocalcids (50%), and Typic Torripsamments (50%).

3.2.3 Soils of the plateau

a. The plateau surface soils

The plateau surface soil mainly consists of Limestone. Two soil profile numbers (i.e., 15 and 18) represent the plateau surface showing that the depth value ranges from 50 cm to 120 cm indicating that these soils vary between shallow and deep soils. The soil texture of this area rounds from sandy loam to sand as indicated by the mean values, calcium carbonate mean value is 50.21% indicating a very high calcareous soil. The pH mean value is 8.44, the soil salinity ranged in wide limit from non-saline (1.54 dSm^{-1}) to saline (5.05 dSm^{-1}), and ESP is less than 15% ranging between 3.13% and 7.14%. The CEC value ranged from 2.32 cmol/kg to 5.75 cmol/kg, and the value of OM ranges between 0.05% and 0.13% indicating that the fertility of the soil is very poor. The soil set of the plateau surfaces is considered as complex as it includes Typic Haplocalcids (50%), and Typic Torripsamments (50%).

b. The foot slope soils

The foot slope soils are represented by four soil profile numbers (i.e., 4, 8, 17, and 20) showing that the mean depth value is 95 cm indicating that these soils are moderately deep soils. The soil texture classes of this area change from sandy loam 50%, sand 25%, and sandy clay loam 25% as indicated by the mean values. The Calcium carbonate mean value is 40.22% indicating a very high calcareous soil. The pH mean value is 8.34, the soil salinity mean value is 2.35 dSm^{-1}, and the ESP value is 4.35%. The CEC value is 7.14 cmol/kg, and the value of OM is 0.13% indicating that the fertility of the soil is poor. The soil set of the foot slope is complex where the soils include Typic Haplocalcids (50%), and Typic Torripsamments (50%).

Table 3. The mean physical characteristics of the studied soils.

Prof. No.	Depth, cm	Sand, %	Clay, %	Silt, %	Texture class	$CaCO_3$(%)
1	70	81.03	12.66	6.31	Sandy loam	35.18
2	100	93.34	3.35	3.31	Sand	35.53
3	90	80.40	15.22	4.38	Sandy loam	30.74
4	100	75.51	18.15	6.34	Sandy loam	41.72
5	80	81.19	13.43	5.38	Sandy loam	16.92
6	60	82.62	12.32	5.06	Sandy loam	30.60
7	70	73.85	18.83	7.33	Sandy loam	26.69
8	120	72.00	20.64	7.36	Sandy clay loam	55.70
9	150	71.71	21.58	6.71	Sandy clay loam	33.88
10	60	77.86	15.92	6.22	Sandy loam	49.80
11	100	80.33	12.21	7.46	Sandy loam	24.13
12	130	88.30	6.26	5.44	Sand	38.04
13	110	71.29	21.96	6.75	Sandy clay loam	29.12
14	50	90.49	4.97	4.54	Sand	47.70
15	50	91.66	3.68	4.67	Sand	56.36
16	140	91.53	2.91	5.56	Sand	16.28
17	90	92.17	3.34	4.49	Sand	28.47
18	120	80.10	11.93	7.98	Sandy loam	44.06
19	130	92.36	3.24	4.39	Sand	44.59
20	70	80.39	7.73	11.88	Sandy loam	34.99

Table 4.The mean chemical characteristics of the studied soils.

Pro. no.	pH	EC dS/m	Ca^{2+}	Mg^{2+}	Na^{+}	K^{+}	HCO_3	Cl^-	$SO42^-$	CEC	ESP%	O.M%
1	8.29	4.92	3.23	17.34	23.24	1.35	1.83	14.45	28.88	8.43	14.91	0.21
2	8.31	1.70	1.56	7.23	8.35	0.95	1.08	6.46	10.55	2.35	2.55	0.22
3	8.27	4.52	2.95	13.43	18.55	1.45	1.90	15.23	19.26	8.71	6.57	0.19
4	8.41	1.86	1.54	7.63	7.39	1.18	1.09	6.33	10.32	11.94	4.26	0.25
5	8.21	4.88	2.35	17.36	21.48	1.42	2.25	18.49	21.88	9.28	6.85	0.11
6	8.15	1.12	1.36	4.58	4.90	0.71	0.63	3.87	7.05	8.10	2.46	0.12
7	8.17	5.49	2.33	17.63	24.44	1.29	1.63	20.64	23.41	10.94	7.94	0.08
8	8.50	1.12	1.12	4.52	3.48	0.35	1.32	3.79	4.61	10.85	2.85	0.11
9	8.30	1.34	1.69	5.07	5.59	0.41	1.12	5.01	6.63	11.25	3.52	0.20
10	8.56	3.63	2.17	17.70	13.65	1.40	1.68	14.97	18.29	7.61	6.05	0.10
11	8.21	4.01	2.56	14.69	16.65	1.33	2.08	13.49	19.65	8.16	7.48	0.17
12	8.31	3.63	2.30	12.11	18.06	1.42	1.99	14.67	17.23	4.07	6.40	0.09
13	8.16	7.09	3.71	22.85	32.05	2.32	2.29	26.08	32.56	12.15	12.88	0.09
14	8.46	1.30	1.34	5.48	6.09	0.36	0.98	3.63	8.67	3.21	2.88	0.04
15	8.51	1.54	1.50	5.30	8.05	0.64	1.02	6.93	7.54	2.32	3.13	0.13
16	8.19	1.96	1.35	7.78	8.74	0.61	1.39	7.55	9.54	1.86	4.26	0.06
17	8.29	4.69	3.45	17.82	19.20	2.12	2.18	17.41	23.00	2.06	7.28	0.10
18	8.36	5.05	2.65	18.12	24.58	1.81	2.18	20.82	27.50	5.75	7.14	0.05
19	8.51	3.37	2.58	11.11	14.69	1.38	2.26	11.83	15.68	2.31	6.94	0.07
20	8.19	1.79	1.57	7.58	7.66	1.41	1.28	6.59	10.34	3.73	3.03	0.09

3.2 Statistical analyses

As shown in Table 5, the statistical analysis of soil properties revealed the following main features:

Soil Depth: The maximum soil depth within the study area is 150 cm, while the lowest depth is 50 cm. The regular soil depth is 94.5 cm, with a standard deviation of 30.51 cm.

Soil Texture: Soil texture varies across the study area as it widely varies from sand (35%) to sandy loam (50%) and sandy clay loam (15%). The extreme percentage of sand recorded is 92.36%, with the smallest is 71.29%. The average sand content is 82.3%, with a standard deviation of 7.43. Clay content exhibits a similar range, with a maximum of 21.96%, a minimum of 1.56%, an average of 11.43%, and a standard deviation of 6.82%. Silt content follows a comparable pattern, with a maximum of 11.88%, a minimum of 4.38%, an average of 6.28%, and a standard deviation of 1.76%.

Slope and Erodibility: The surface slope in the study area is generally less than 5%, indicating a relatively flat landscape. Correspondingly, soil erodibility is classified as slight to non-existent (Murad, 2009; Mohamed et al., 2013).The key chemical properties of the investigated soils are summarized by their statistical parameters.

Soil pH: pH ranges from 8.09 to 8.56, with an average of 8.31 and a standard deviation of 0.14. Organic matter content exhibits a similar range, varying from 0.04% to 0.73%, with average of 0.15% and a standard deviation at 0.15%.

Calcium carbonate: $CaCO_3$ content demonstrates a wider variation from 16.28% to 56.99%. The mean $CaCO_3$ is 37.10% with standard deviation at 12.29%.

Electrical conductivity (EC): EC measurements range from 1.12 dS/m to 7.09 dS/m. The average EC value is 3.34 dS/m with standard deviation approaching 1.75 dS/m.

Cation exchange capacity (CEC): CEC follows a similar pattern, with a minimum value of 0.54 meq/100g soil and a maximum of 12.15 meq/100g soil. The average of CEC is 6.66 meq/100g and the standard deviation is 3.85 meq/100g soil.

Exchangeable sodium percentage (ESP): ESP exhibits the greatest range varying from 2.46% to 14.91%. The average ESP value is 6.16%, with a standard deviation of 3.23%.

3.3 Soil thematic maps

Soil property data are used in GIS to create thematic maps of the soils. Based on the spatial variation in soil texture, the area was classified as Grade (I), (II) (III), and (IV) representing 13%, 62%, 11% and 14%)of the total area, respectively. Regarding variation of soil depth, the area was classified as class (I) covering 26%, (II) extends 62%, and (III) represents 12% of the area. Concerning to EC, the area was classified as grade I (36%), grade II (34%), and grade III (30%). Considering the $CaCO_3$ content, the area was divided into class IV (38%), and class V (62%). The soil CEC of the area is low (average of CEC is 6.66 meq/100g) due to the coarse texture, lack of organic matter, and dry climate so the CEC started with class III.

The CEC grades were divided into:

(III) represents 39%, (IV) exhibits 35%, and (V) dominates 27% of the total area.

The ESP changes from (I) and (II) classes representing 47% and 53% of the total area. Figure 7 demonstrate the different layers of soil thematic maps of the srudy area.

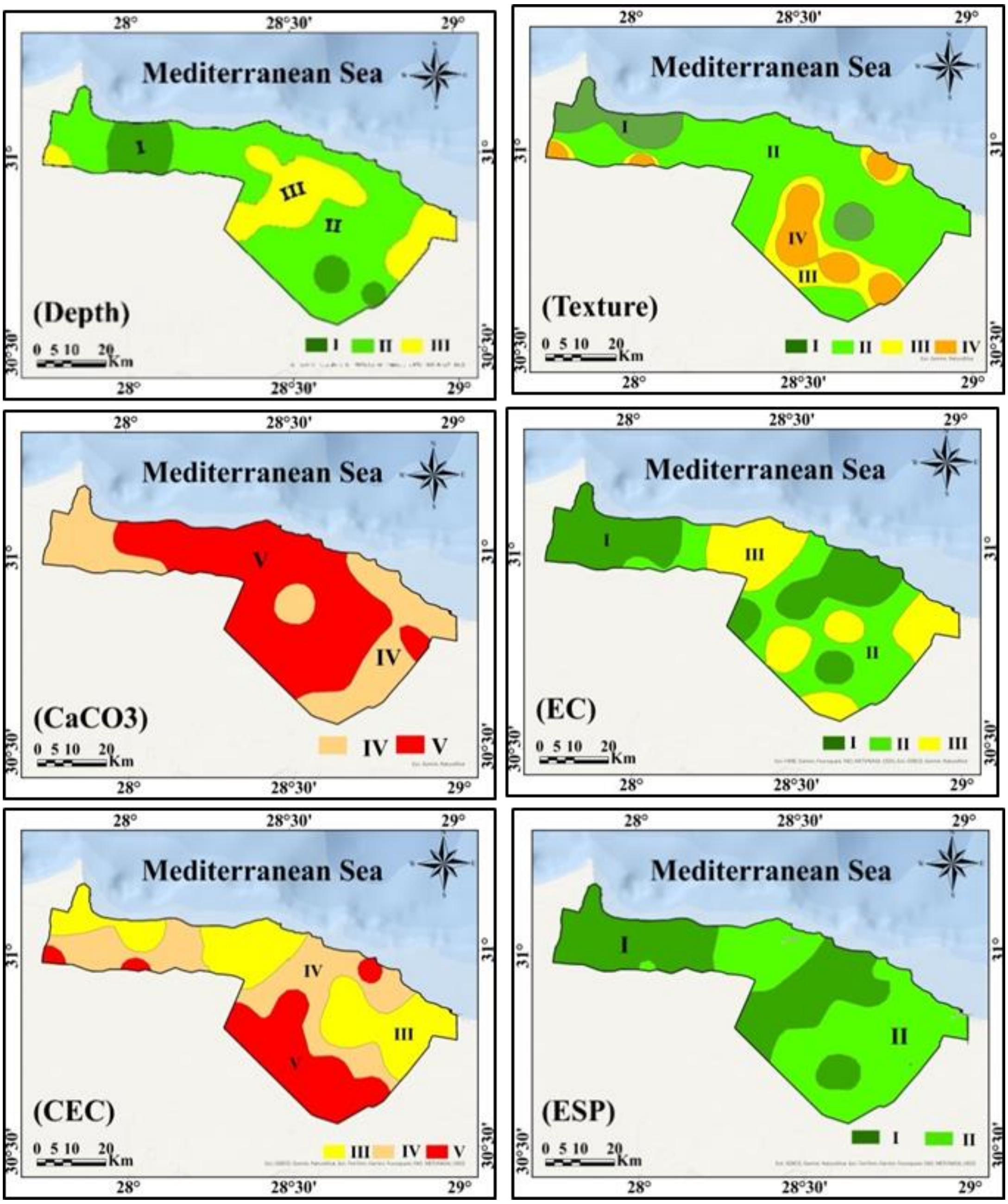

Fig. 7. Thematic maps for soil properties.

Table 5. Some statistics of soil properties.

	Depth (cm)	Sand, %	Clay, %	Silt, %	$CaCO_3$, %	O.M, %	pH	EC, dS m^{-1}	CEC (meq/100 g soil)	ESP
MAX	150.00	92.36	21.96	11.88	56.99	0.73	8.56	7.09	12.15	14.91
MIN	50.00	71.29	1.56	4.38	16.28	0.04	8.09	1.12	0.54	2.46
AVR	94.50	82.30	11.43	6.28	37.10	0.15	8.31	3.34	6.66	6.16
Median	95.00	80.71	12.27	6.26	35.08	0.11	8.29	3.56	7.85	6.36
Std. dev.	30.51	7.43	6.82	1.76	12.29	0.15	0.14	1.75	3.85	3.23

4. Discussion

The northwest coast of Egypt presents a promising prospect for agricultural expansion, particularly for field crops, given the critical role of irrigation water in sustaining agricultural growth. This study employed Geographic Information Systems (GIS) to map soil properties and assess land capability. The landform analysis identified distinct units encompassing sand sheets (45.15%), marine deposits (25.5%), shore ridges (0.5%), piedmonts (9.5%), plateau surfaces (4.25%), and foot slopes (15.1%) of the total area. Soil management of landforms involves tailored practices that consider the unique characteristics and challenges posed by different types of landforms. So, Effective soil management tailored to specific landforms ensures the long-term sustainability and productivity of the land, mitigating environmental impacts and enhancing agricultural productivity (Tesfahunegn and Paul, 2014).

The analyses of land surface produce digital maps of elevation, slope, and aspect. These variables play a critical part in deciding the appropriateness of a region for agricultural purposes, as well as affecting different administration choices. In general the surface slope differ from 0 to 2% except some parts of the shore ridge (Cm23) and foot slope (U122) units where the slope increased to (5-10%) and (10-15%) respectively. So, the topographical factors hinder the agricultural development in such areas due to the steep slope and undulation of the land surface. This means that the surface topography hinders agricultural development in an area of 256.94 km2 i.e. 61,665.6 feddans mainly located in the shore ridge and foot slope units. This could be explained in view of the effect of elevation on surface temperature, and air pressure, and consequently limits the types of crops that could be grown in the area. Altitude also affects the length of the growing season and influences the selection of appropriate cultivars (Martin et al., 2019).

As a result of this study, the topographical factors hinder the agricultural development in coastal plain shore ridge (Cm23) and plateau foot slope (U122) units due to the steep slope and undulation of the land surface. This means that the surface topography hinders agricultural development in an area of 256.94 km^2 i.e. 61,665.6 feddans. This could be explained in view of the effect of elevation on surface temperature, and air pressure, and consequently limits the types of crops that could be grown in the area. Altitude also affects the length of the growing season and influences the selection of appropriate cultivars.

Furthermore, slope is an important factor that influences water runoff, erosion, and availability of agricultural equipment. Steep slopes increase the risk of soil erosion and water runoff. Also, it affects the availability of sunlight, as abrupt slopes can create shades and influence the microclimate within the cultivated lands(Seyfried et al., 2016, Corrao et al., 2017). The slope direction (aspect) affects sunlight spreading, wind patterns, and temperature gradients in cultivated lands. The south-facing slopes receive more sunlight and heat, creating a warmer microclimate and potentially influencing crop selection and field practices. Surface characteristics of the area control its natural drainage pattern, well drainage is essential to aerate the soil, provide nutrients, and avoid the rising of the soil water table (Gutiérrez and Vivoni, 2013). Surface features also govern the soil depth and texture in agricultural areas, where the soil depth can vary depending on the degree of slope, (areas of steep slopes have thinner soil) The quantities of sand, silt, and clay in soil can vary significantly depending on various land surface factors (Alhamed et al., 2014).. Managing land surface effectively is crucial for farmers to improve crop yield, preserve their lands, and implement sustainable agricultural practices (Shah F. and Wu, 2019).. By implementing these sustainable land management practices, farmers can enhance crop yields, preserve the health of their land, and contribute to long-term agricultural sustainability. These strategies not only ensure food security but also protect natural resources and support environmental health (Koohafkan, et al., 2012). The quantities of sand, silt, and clay, also vary depending on the land surface factors. Managing land surface allows farmers to improve crop yield, preserve their lands, and implement suitable agricultural practices to realize sustainable agriculture.

As the most important component of the landscape, soil characteristics are mostly dictated by the landforms they form on. The soil-landform relationship develops as a result of the acknowledged physiographic influence on soil properties. Since the landform is easily identifiable and was created by the same processes that provided the soil materials, it is the most important feature in this context. In this study the dominant soil taxonomic units within the landforms are Typic Torripsamments and Typic Haplocalcids with three main soil groups known as (1) complex soil set inhabiting the plateau surface and pediment landforms with a total area of 910.01 km², (2) consociation soil set existing in the coastal landforms with an area of 818.27 km², and finally (3) association soil set that spreads the Aeolian plain unit (1423.39 km²).

Thematic maps of measurable soil properties indicate that the coarse soil texture (III & IV) characterizes 35% of the total investigated area hence low soil qualities are anticipated. The digital layer of soil depth indicates a limited soil depth in 12% i.e. 90,768.12 feddans. The spatial distribution layer of soil salinity shows that 226,920.31 feddans representing 30% of the total area are affected by high salinity (class III). Distribution of $CaCO_3$ over the study area refers to very high content calcium carbonates (class V) that affect 38% of the total area. Cation Exchange Capacity (CEC) is in general low as it is mostly associated with soil texture and organic matter. In view of these findings, the agriculture development in the area is mainly constrained by coarse soil texture, shallow soil depth, high content of $CaCO_3$, and low CEC.

Improved drainage, organic fertilization, and crop selection are necessary to attain agricultural sustainability in the area. Therefore, achieving agricultural sustainability in the area can indeed be significantly enhanced through improved drainage, organic fertilization, and strategic crop selection. By focusing on these key areas, the agricultural sustainability of the area can be significantly improved, leading to healthier ecosystems, more resilient farming practices, and better economic outcomes (Lago-Olveira et al,. 2023).

5. Conclusions

The northwest coast of Egypt presents excellent opportunities for agricultural growth. Given that irrigation water is an essential component of sustainable agricultural growth, the area has a great deal of potential for agriculture. Geographic Information System (GIS) was used in this work to support agricultural development.

Landform units were identified as follows: sand sheet (45.15%), marine deposits (25.5%), shore ridges (0.5%), piedmont (9.5%), plateau surface (4.25%) and foot slope (15.1%) of the total area. The study area only includes the Typic Torripsamments and Typic Haplocalcids sub-great group.. The complex soil set characterizes the plateau and the pediment plain (910.01Km^2), the consociation soil set is interrelated with the coastal plain (818.27 Km^2) while the association soil set spreads out the Aeolian plain (1423.39 Km^2).

Digital maps of elevation, slope, and aspect variables are created through land surface analyses. These maps are essential for determining whether a region is suitable for agriculture.

Geographical Information System (GIS) was used to create thematic layers representing soil depth, texture, $CaCO_3$ content, EC, CEC, and ESP. Analysis of these layers indicates that the agriculture development in the area is mainly constrained by coarse soil texture, shallow soil depth, high content of calcium carbonates, and low soil fertility.

Declarations

Declarations

Ethics approval and consent to participate

Consent for publication: The article contains no such material that may be unlawful, defamatory, or which would, if published, in any way whatsoever, violate the terms and conditions as laid down in the agreement.

Author contribution:

- Essam-Eldine M. Tealab: Methodology, Conceptualization, Data curation.
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