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Modeling of Agro-Ecological Zones for Sustainable Agriculture Development in Halayeb Area, Egypt

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Abstract

The Halayeb area is one of the most important Egyptian places, occupying a portion of the country's southeastern desert zone and serving as a strategic border with Sudan. The major goal of this study is to combine existing data on landforms, soil qualities, and climate data to define agro-ecological zones (AEZ) that are suitable for agricultural development. Thirty-two soil profiles were dug throughout the study region to represent physiographic units, and a digital soil map was generated based on an analysis of the digital elevation model and Landsat 8 satellite data, as well as climatic data from nine sites within the study area. Using the Model Builder in ArcGIS software, AEZ were created based on overlay maps of topography, soil chemical and physical properties, temperature, and precipitation maps. Zone (I) represents highly suitable areas (2.6 percent), zone (II) represents suitable areas (12.4 percent), zone (III) represents moderately suitable areas (26.5 percent), and zone (IV) represents marginally suitable areas (37.3 percent) . highly suitable(S1), suitable (S2), and moderately suitable(S3) were the most appropriate classes for all of the crops studied. The findings will aid decision-makers in developing various development plans based on the research area's conditions. The study's methodology and findings can be used to evaluate which land is best suited for agricultural productivity growth.

Keywords*:* Agro-Ecological Zones; Model-Builder; Geoinformatic; Land sutability; Halayeb.

1. Introduction

Well assessment and management of soil will lead to achieve food security through helping to bridge the food demand gap (Shokr et al 2021). Since ancient times, agriculture has been an important part of Egypt's economy. This was helped by the fact that Egyptian soil comprises alluvial soils in the delta and valley, limestone soils along the coast, eastern and western deserts, (Hamdi and Abd-elhafez, 2001). The 2030 Sustainable Development Goals (SDGs) place a heavy emphasis on agricultural systems becoming more productive. As a result, sustainable farming techniques and food systems involving production and consumption should be prioritized. Many sustainable development goals can be achieved by utilizing land resources, through agriculture, (United Nations, 2021). The FAO agro-ecological zoning system's original goal is to analyze the suitability of various forms of land use for specific land uses. It's a great place to start if you're looking for a specific land use plan with a big picture of the overall region. It diagnoses the current state of farming and land use by categorizing, characterizing, and assessing the components of farming systems, (FAO, 1996).

Agroecology is the classification of land areas based on the physical characteristics of a region that is nearly the same in terms of environmental circumstances, with little variation in plant and

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animal diversity. Climate, slope, and soil properties are the primary components of agroecology, which support plant growth. Only if the land used for farming systems is managed acceptably can sustainable agricultural systems be accomplished. Will land production plummet and ecosystems be jeopardized if it isn't properly utilized? Appropriate land uses to ensure that, in addition to providing immediate benefits to the user, the land and natural resources are preserved for future generations. It is possible to determine the correct plants by taking into account the status of agroecology, land use, and production methods in the form of alternatives, (Suriadikusumah, 2014).

The scarcity of arable land is currently one of the most pressing issues confronting emerging countries, the most pressing of which is Egypt, and it is aggravated by a number of factors, including population increase, low soil fertility, and climate change. It is estimated that the desert covers 95% of Egypt's entire land area. In addition, Egypt's greatest difficulty is the population-to-land-resources ratio, (Mahmoud et al., 2019 and Abdellatif, 2021)

Agriculture ecological zone's structure comprises a comprehensive framework for land resource analysis and planning. The nature of the analysis, which entails combining layers of spatial data to establish zones, lends itself to the use of Geographic Information Systems(GIS**)**. Topographic maps, land resource maps, and contour maps are the most important components of a computerized GIS for activities like agro-ecological zoning and zonal resource information in mountain locations. Primary inputs are these maps, which comprise physiographic, geographic, and bioclimatic data, (Patel, 2003). In nine key regions of Asia, Africa, and America, GIS were utilized to determine several major crops agro-ecological zones with the dry weight of the harvest, (Sivakumar and Valentin, 1997). The GIS was used in commodity zoning to collect and analyze commodity zoning areas in Kandul North Barito Regency, Central Kalimantan, (Bhermana et al, 2004)

Multi-criteria such as geological and biophysical elements (i.e., geology, soil characteristics, relief, atmospheric conditions, vegetation, etc.) as well as economic and socio-cultural conditions are used in the multi-criterion evaluation of land suitability in the decision-making process (Joerin et al., 2001) to solve different land problems with multiple alternatives (Yu et al., 2011). Land evaluation in support of rational land use planning and suitable and sustainable use of natural and human resources is one part of the solution to land use problems, (Aldabaa, 2020). The ability of soil to produce crops in a sustainable manner is referred to as land appropriateness. Identifying the variables that limit agricultural production allows decision makers to adopt crop management strategies that result in higher land productivity, (Shalaby, 2017).To make plant planning and management easier, the technological package for farming systems should be based on a more thorough study of (AEZ) (Amien, 2000). Physiographic data, climatic characteristics (rainfall and temperature), internal soil condition (depth, moisture, texture, salinity, and natural fertility), and external soil conditions (slope, accessibility, and flooding) are all factors in determining the suitability of a site for agricultural development (Wang, 1994). For the site suitability assessment of agricultural land use, the weighted overlay method (WOM) in combination with the analytic hierarchy process produces a very reliable result. The method can be applied to numerous restrictions and criteria that have a multi-level hierarchical structure (Triantaphyllou and Mann, 1995). The analytical hierarchy approach is one of the most effective methods for determining the suitability of agricultural land based on individual factors through quantitative analysis (Khahro et al., 2014). Abou-Shleel et al. (2020) studied suitable crops for agro-ecological zones in the Sinai Peninsula and found thatlow production difficulties, are caused by one or more severe constraints that prevent land usage, necessitate specific management, or significantly limit the choice of crops. As a result, the agro-ecological zone can be thought of as a collection of applications that lead to a determination of land productivity potential based on climate, soil, and landforms. Moreover,Amin et al. (2022) used integrated soil, terrain, and climatic data to create AEZs for the Wadi El-Grawla region on Egypt's (NWCR) and found three management zones, land suitability for different crops was applied, which increases policymakers' ability to formulate appropriate development policies based on the availability of such categorization.

By combining remote sensing and GIS technologies to create digital maps of physiographic, slope, climate, surface, land use/land cover, and soil for better resource utilization in agricultural development, the current study uses the concept of AEZs, available data, remote sensing, and GIS capabilities to produce the AEZs map for Halayeb, Egypt. As a result, the land suitability models were applied to the majority of strategic crops grown in the research area.

Mateials and Methods

Study area

The research region is in the eastern desert of Egypt, on the southeastern side of the coastal zone (Fig. 1). It is situated between the cities of Shalateen in the north (41 km) and Abu Ramad in the south (15 Km). Between longitudes 35º 38' 14.9" and 36º 17' 39" E and latitudes 22º 13' 31.4" N and 22º 51' 36.7" N., it covers approximately 2837.4 km^2 (roughly 280459.6hectare). The climatic conditions of the Halayeb area are classified as semi-arid, with long hot rainless summers and mild winters with little or no rainfall, according to the Koppen classification system. During the winter, however, some unusual and irregular storms may occur over several locations. The annual average temperature is 25.7 °C, with maximum and minimum mean values of 33.4 °C and 17.9 °C, respectively, according to average meteorological data retrieved from historical weather simulation data and ground stations data over 30 years from nine sites in the research area. July and August had the greatest temperature of 42.0 °C, while January and February had the lowest temperature of 12.0 °C. The amount of precipitation varies greatly. The amount of precipitation varies greatly. It has a total annual average of about 8.0 mm in the coastal area and gradually increases to the west as the Red Sea Mountain ranges influence it. The yearly mean of relative humidity is 39.1 percent, with monthly fluctuations ranging from 26 to 55 percent. July had the lowest humidity (26 percent), while January and February were the most humid months (55 percent). Wind speed records range from 11.0 to 14.0 km/hr. From December to February, the highest monthly mean was recorded, while the lowest was recorded in August. The difference between mean summer and mean winter soil temperatures are 6 ^{o}C or at a depth of 50 cm from the soil surface, indicating a Hyperthermic soil temperature regime. Except for soils with a high-water table, which may have an Aquic moisture regime, the soil moisture regime is Torric or Aridic. (Jalhoum, 2019).

Data collection

Landsat 8 image data was acquired on 29-10-2020, a scene (Path / Row: 172 / 44), downloaded from the U.S. Geological Survey (USGS) tocover the study area. It was geometrically corrected and projected to the UTM zone 37N coordinate system using WGS 84 datum using EVNVI image processing software.the FLAASH module was used foratmospheric correction A shuttle radar topography mission (ALOS PALSAR) acquired 09/02/2009 and 10/03/2020 was used as the source data for elevation heights four scenes covering the study area with spatial resolution 12.5 m, (Fig. 2). The average meteorological data from ground stations and metoblue website during 30 years (1985 – 2015) was used the values of annual maximum and minimum temperatures, precipitation, and wind speed, extracted from nine sites from historical weather simulation data and ground stations data, with spatial resolution between 4 and 30 km.

Calculation of Normalized Difference Vegetation Index(NDVI)

This index is a dimensionless index that reflects the presence and vegetation density relied on the simulated red and NIR reflectance, as revealed in equation (1)

$$\mathrm{NDVI} = \frac{\mathrm{NIR} - \mathrm{R}}{\mathrm{NIR} + \mathrm{R}} \qquad (1)$$

where NIR is the near-infrared reflectance and R is the red reflectance.

Generation of landforms and fieldwork

All-terrain attributes were combined by overlying the classed grids indicating relief intensity, curvature, elevation, slope, and aspect, as well as image classification, (Chabala et al., 2013). The unsupervised classification and image visual interpretation base map of the study region was used in the field to check, confirm, correct, and alter the geomorphology mapping unit boundaries. Second, thirty-tow soil profiles were dug and described to identify the various land units (Fig. 3), and detailed morphological descriptions according to (Soil Survey Staff, 2017). The soil profile samples were chosen according to a sample area procedure that was suggested by (Zink, 1997). The collected disturbed soil samples were air-dried; ground gently, then sieved through a 2 mm stainless steel sieve, and gravel content was calculated (in volume %). The following soil properties were analysed : soil reaction (pH) in (1: 2.5) soil water suspension according to (Page et al. 1982)., salinity (electric conductivity) based on(Rhoades 1996). The acid-dichromate potassium and titration method was used for soil organic matter content (SOM) (Summer et al., 1996). Total calcium carbonate was determined volumetrically using Collin's calcimeter (Loeppert and Suarez, 1996). The particle size distribution and cation exchange capacity (CEC) were determined according to [Summer et al., 1996 and Gee,. And Bauder, 1986).

Creating interpolation maps

The inverse distance weighted (IDW) function in ArcGIS 10.7 software was utilized to produce interpolation of soil properties. This procedure is relied on grid note calculating by taking into account nearby points that are indoors of a user-defined search radius, according to the following equation (2)

$$z_p = \frac{\sum_{l=1}^{n}\left(\frac{z_i}{d_i}\right)}{\sum_{i=1}^{n}\left(\frac{1}{d_i}\right)} \qquad (2)$$

Where zp = value predicted at point P, zi = z value at the measured point i, and di is the= distance between point 0 and the point 'i'. This technique was utilized with 12 neighbouring samples for estimation of each grid point. A power of two was used to weight the nearest points.

Spatial modeling for agro-ecological zones

The locations of soil profiles were digitized to know the geographic coordinates and the weighted average value for each parameter belonging to each soil profile (soil depth, saturation percent (SP), pH, EC, organic matter (OM), $CaCO_3$, Gypsum, CEC, sand, silt, clay, and texture), in addition to the values of annual maximum and minimum temperatures, precipitation and wind speed. The interpolation for soil properties and climate data was carried out using Inverse Distance Weighting (IDW) interpolation method in ArcGIS 10.7.

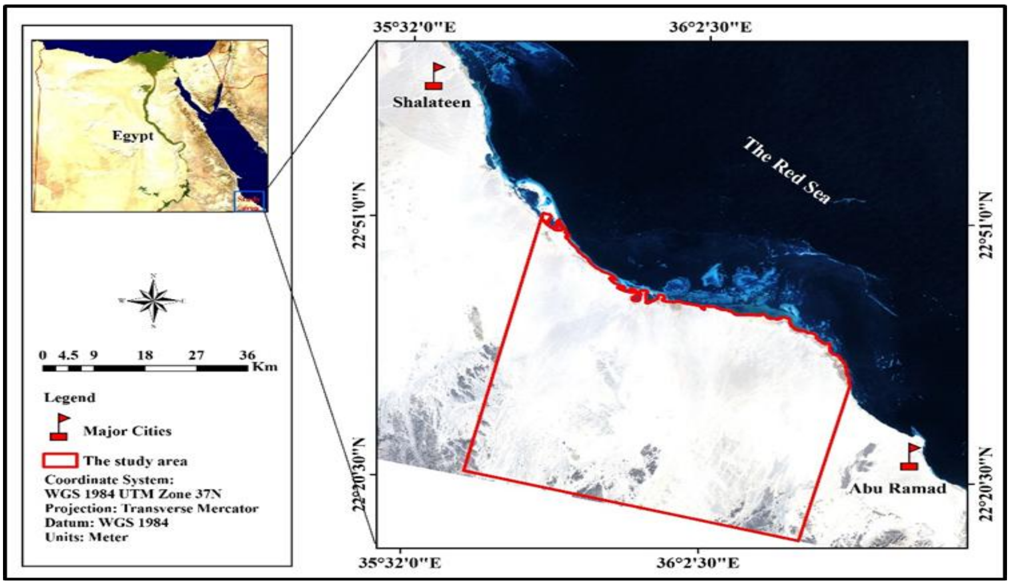

Fig. 1. Location of the study area

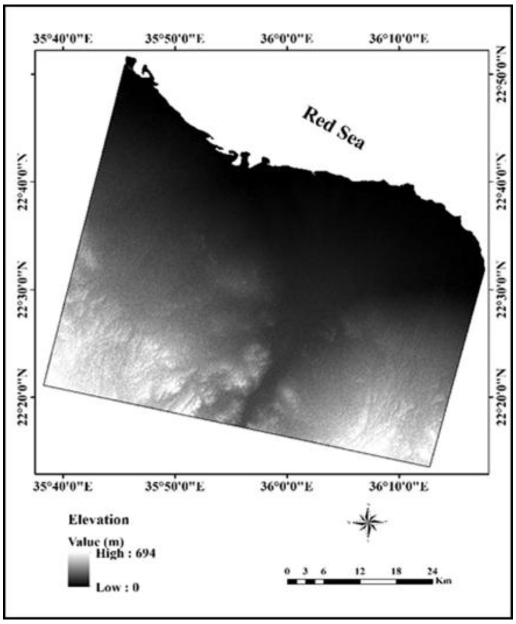

Fig. 2. Digital Elevation Model of the study area

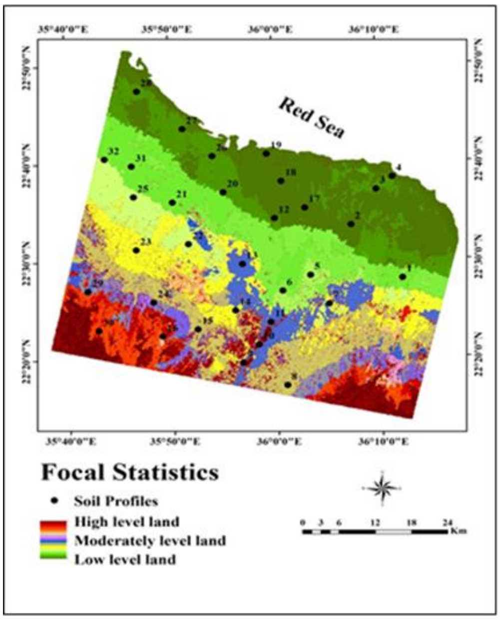

Fig. 3. Primary of landforms in the study area

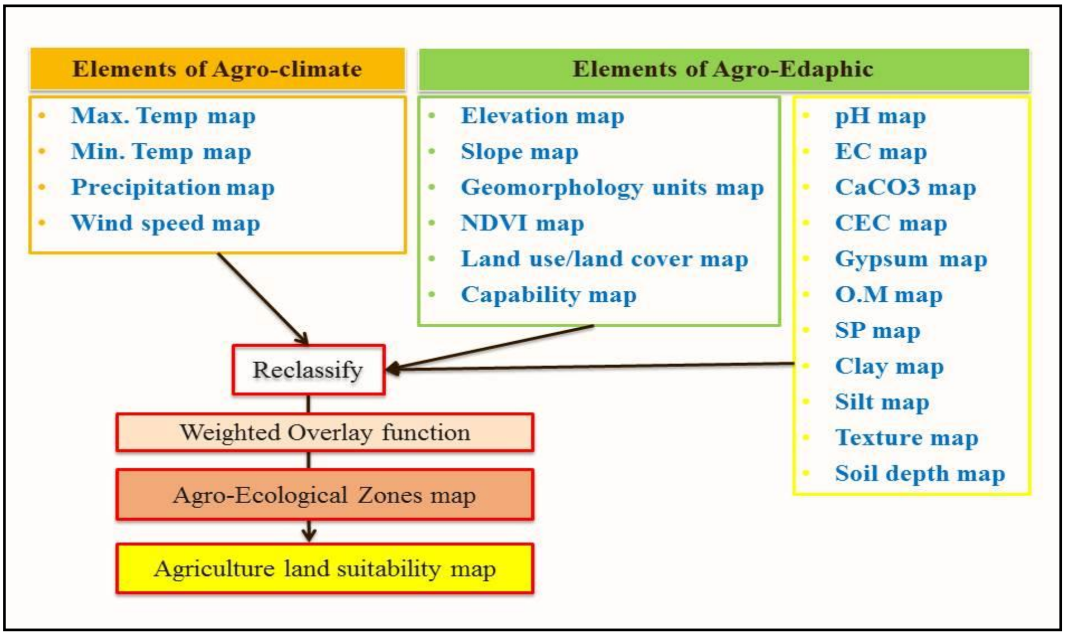

Fig. 4.The structure of agro-ecological zones model

Model Builder in ArcGIS consists of several steps:

The first step: Identifying and creating climate, soil resources, and land surface datasets to identify the priorities of agricultural development. Identifying which datasets are needed as inputs adequate form (raster format), This inputs chosen are: Geomorphology, NDVI, elevation, slope, aspect, soil texture, sand, silt, clay, soil depth, calcium carbonate content, gypsum content, organic matter, saturation percent, CEC, soil reaction (pH), soil salinity (ECe), soil depth, and climate elements (maximum and minimum temperature, precipitation and wind speed).

The second step: Reclassifying (scaling) datasets reclassifying each dataset to a common scale of values (i.e. from 1 to 5). Higher scale values are given to more suitable attributes.

Finally, each input dataset can be given a percentage impact based on how important it is to soil productivity, as specified; the overall influence for all datasets must equal 100%. Each input dataset's cell values are multiplied by their influence percentages (weight).

The resulting cell values are added together to create the final output dataset of this model which locates an area more suitable for soil productivity. Crop requirements for the selected crops were determined and adapted according to Sys et al. (1993), (Fig 4). Seventeenth crops have been selected into three categories: Field crops: Wheat, Maize, Barley, Soybean, Cotton, Alfalfa, and Sunflower; Vegetable crops: Onion, Watermelon, Pea, Potato and Tomato' Fruit crops: Date Palm, Fig, Olives, and Grape.

Results and Discussion

Geomorphologic and soil characteristics

The following lines indicate the features of ten geomorphic units discovered throughout the study region, as shown in Table (1) and Fig.(5):

- Sabkhas are a small region near the Red Sea that covers an area of 6871.63hectares (2.45 %). These soils could be characterized by moderately to deep soils (90 -120 cm). The texture class is sandy loam to loam. The $CaCO_3$ content ranges between 0.1- 3.4%,. Soil reaction (pH) is very important factor due to its effects on the nutrients availability to crop roots in addition, activity of microorganisms (Ostovari et al., 2018). Values of pH range between 7.1 and 8. The electric conductivity (ECe) is very high. Where the values range between 94 - 331 dS m^{-1}.
- Organic matter content ranges between 0.3 and 1.6 %. The CEC varies between 5.9 and 12.6 cmolc/kg soil. Gypsum content is high ranging between 8.7 and 15.9 %. The soils classification of the sabkhas is GypsicAquisalids.
- Delta and Delta Apex were discovered downstream of WadiDieb in a triangle configuration. They cover about 35420.75hectares (12.6 %). These soils could be characterized by deep soils (150 cm). The texture class is sandy loam to loam. Calcium

carbonate content ranges between 0.1- 0.9 %, values of pH range between 7.2 and 8.2. The ECe is quite low. While the values range between 0.9 - 1.9 dS m^{-1}. Organic matter content ranges between 0.1 and 0.4 %. CEC varies between 1.1 and 2 cmolc/kg soil. The low content of it is due to, course texture and lack of organic matter content as, CEC correlated positively with clay and OM% (Abdel-Fattah et al., 2021). . Gypsum content is low ranging between 0.5 and 1.6 %. These soils are classified as TypicTorrifluvents.

- Alluvial Fans are located at the down streams of coastal wades and wadiMaysa, covering about 31229.76hectares (11.14 %) and could be characterized by moderately deep to deep soils (80 to 100 cm). The texture class is sandy loam. The $CaCO_3$ content ranges between 0.5 - 5.9%, some soil contain high values of $CaCO_3$ which may creat hard layers impermeable to crop roots and water in addition phosphorus fertilizer fixation (von Wandruszka, 2006). Values of pH range between 7.2 and 8.3. The ECe is high and it ranges between 23 - 35 dSm^{-1} up to 55 dS/m to for subsurface layer profile 21, Main while ECe values 3.1 and 5.2 dSm^{-1} to surface layers to profiles 22 and 23 respectively. An organic matter content range between 0.1 and 0.6 %, Percentage of OM is very critical for conservation of soil structure, raising the nutrients availability leads to increasing of soil fertility (Shokr et al .,2021 . The study area suffers from lack of OM due to its location in arid and semiarid zones (Conant, et al 2011 and Moinet et al., 2020). The CEC varies between 1.6 and 2.6 cmolc/kg soil. Gypsum content is low ranging between 0.1 and 1.9 %. These soils are classified as TypicHaplosalids.

- Alluvial Plain is flat to almost flat and formed during flash floods that moved by many wadis spread over the area. They are covering areas of 28457.2hectares (10.15 %). These soils could be characterized by moderately deep to deep soils (70 to 120 cm), the texture class is sandy loam to loamy sand. The $CaCO_3$ content ranges between 0.2- 3.7%, values of pH range between 7.2 and 8.4, which reveals that some soils of investigated area are mildly/strongly alkaline (Baruah, and Barthakur1997). The ECe is low, it ranges between 1.1- 3 dSm^{-1} up to 8 dSm^{-1} for subsurface layer profile 46, main while ECe values 12 to 19 dS m^{-1} to subsurface layers in profiles 12 and 28. Salinized soil are spread widely in arid and semiarid zones due to low precipitation and high evaporation thus, leaching salts from soil utilizing high quality water is required for good management (Zalacáin et al 2018). Organic matter content ranges between 0.1 and 0.6 %. The CEC varies between 1.6 and 2.5 cmolc/kg soil. Gypsum content is low ranging between 0.9 and 2 %. These soils are classified as TypicTorrifluvents.

- Wadis are one of the predominant subunits of plains, between hills or mountains, covering areas of 19441.62 hectares (6.9 %). These soils could be characterized by deep soils (120 to 150 cm), the texture class is sandy loam to loamy sand and loam to some surface layer. The $CaCO_3$ content ranges between 0.8 - 3.3%, values of pH range between 7.2 and 8.5. The ECe is low for most profiles. Where, the values range between 0.4 - 1.5 dSm^{-1} and up to 3 dS/m in some layers profiles 5, 10, 11, and 14. Except for profile 14, ECe values up to 27 dS m^{-1}, the ECe increase in this soil profile may be attributed to it being close to a mountain or as a result to wind and water deposition for these layers or the origin of this unit. Organic matter content ranges between 0.1 and 0.8 %. The cation exchange capacity (CEC) varies between 0.6 and 3.3 cmolc/kg soil. Gypsum content is low ranging between 0.2 and 1.8 %. These soils are classified as TypicTorrifluvents.

- Aeolian Sand Plain is flat to gently undulating broad floors that are covered by sand, covering an area of 7776.64hectares (16.4 % of the total area) in the mid- study area. These soils could be characterized by very deep soils (120 to 150 cm), the texture class is sand for most layers of soil profiles and sandy loam for surface layers. The $CaCO_3$ content ranges between 0.1 - 1.2 %, values of pH range between 7.1 and 8.5. The ECe is low for most profiles. Where, the values range between 0.6 - 2.9 dSm^{-1} and up to 4 dS m^{-1} and 11 dS m^{-1}in subsurface layers profiles 13 and 24 respectively. Organic matter content ranges between 0.1 and 0.6 %. The CEC varies between 0.6 and 2.4 cmolc/kg soil. Gypsum content is low ranging between 0.1 and 1.5 %. These soils are classified as TypicTorripsamments.

- The pediment unit occupies a large portion to the north of the high terraces terrain and mountains area. They cover areas of 15677.64 hectares (5.5 %). These soils could be characterized by moderately deep (70 cm), the texture class is sandy loam, The CaCO3 content ranges between 8.2 - 25.7 % is increases with depth, values of pH range between 7.4 and 7.6. The ECe is high, it ranges between 24 - 54 dS m^{-1} ,where decreases with depth. Organic matter content ranges 0.3 %. Cation exchange capacity (CEC) varies between 1.1 and 2.3 cmolc/kg soil. Gypsum content is low ranging between 0.1 and 0.4 %. These soils are classified as Calcic Haplosalids.

- Terraces are located in the north of the high mountains area and are composed of meta-sediments, covering areas of 62569.24 hectares (22.3 %). It could be characterized by moderately deep to deep soils (80 to 100 cm), the texture class is sand, The $CaCO_3$ content ranges between 0.1 - 3.5 %, values of pH range between 7.4 and 7.9. The ECe is moderately saline. Where it ranges between 1 - 3.8 dS/m. Organic matter content ranges 0.1 - 0.4 %. CEC varies between 1.1 and 2.3 cmolc/kg soil. Gypsum content is low ranging between 0.1 for profile 30. These soils are classified as TypicTorriorthents.
- Dunes have an oblique direction with the prevailing wind direction. They are located east and west of the study area and cover about 9814.72 hectares (3.5 %).
- Mountains, Hills, and Rock outcrops are occupying the great of the study area as that locatedin the southern part. They are composed of igneous and metamorphic rocks. A mountain is generally much higher and steeper than a hill. They are covering areas of 24025.02hectares (8.6 %).

Geospatial analysis for input parameters

The spatial and non-spatial data on soils were converted into digital soil resource databases and climatic data for Agro-Ecological Zones (AEZ) using the IDW interpolation technique, and the obtained maps are shown in the Figures (6 and 7). The weighted average characteristics of the studied soil properties are presented in Table (2). Where soils differ in their properties according to a mode of geomorphologic position. The minimum values of Depth, SP, pH, EC, OM, CaCO3, Gypsum, CEC, Sand, Silt, and Clay were 70 cm, 17%, 7, 0.5 dS m-1, 0.02%, 1 %, 0.1 %, 0.5%, 50 %, 2 %, and 1.9% respectively. While the maximum values are 150 cm, 31%, 8.5, 198.5 dS m-1, 0.8%, 20.5%, 11%, 11%, 98%, 35%, and 23% respectively. The climatic data in the study area reveal annual average temperature maximum is 30.4 °C to 34.3 °C, while the annual average temperature minimum is 17.9 °C to 20 °C. Precipitation is very variable. Its increases gradually towards the west as it are affected by the Red Sea mountain ranges. Data indicate that the sum annual precipitation is 9 mm to 42 mm in the study area. Wind speed is variable in the study area, where it’s ranged from 7.17 to 12.83 km/hr. north and north western dry winds prevail in the study area.

Suitability for agro-ecological zones model

Agro-ecological zones included two categories; agro-climate and agro-edaphic. Agro-climate includes temperature maximum, temperature minimum, wind speed, and precipitation. While agro-edaphic includes land systems (elevation, slope, geomorphology, NDVI, soil properties, and soil capability). Based on the results of overlay maps of agro-climate and agro edaphic, and actual and potential Land suitability for certain crops in the study area was carried out according to Sys et al. (1991) by matching agro-ecological zones with the crop requirements . There were five obtained (5) agro-ecological zones AEZ, (Tables 2 and 3, Fig. 8 and 9). The model was applied to the agro-ecological zones layer, (Figures 10) as follows:

TABLE 1. Geomorphological units and mapping units of the study area

Geomorphologic units	Mapping units	Area (Hectare)	(%)
Sand beaches	Sb	994.37	0.35
Sabkhas	SK	6871.63	2.45
Delta apex	Da	25494.83	9.09
Delta	D	9925.91	3.54
Alluvial fans	AF	31229.76	11.14
Alluvial plain	AP	28457.2	10.15
Wadis	WD	7776.64	6.93
Aeolian sand plain	ASP	114893.79	16.39
Dunes	SD	9814.22	3.50
Pediment	Pd	15677.64	5.59
Terraces	RT	62569.24	22.31
Rock out crops	RC	2360.39	0.84
Rocky hill	RH	7878.85	2.81
Mountains	MN	13785.77	4.92
Total area		280459.96	100

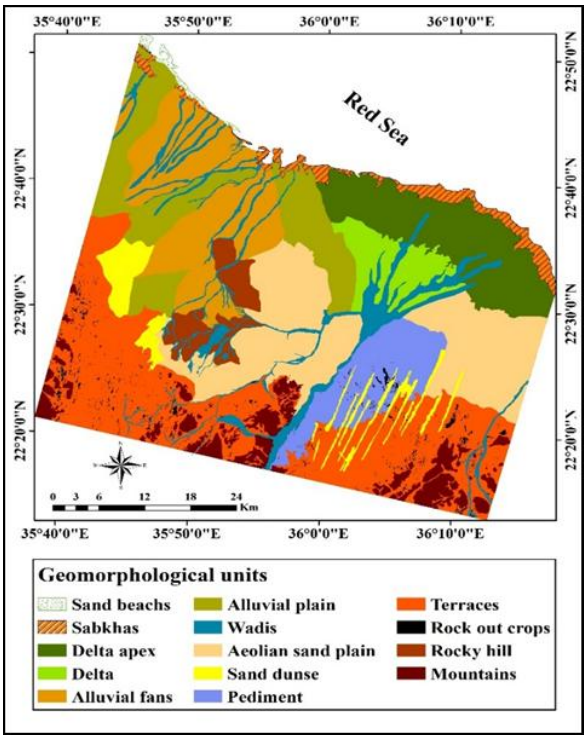

Fig. 5.Geomorphological units for the studied area

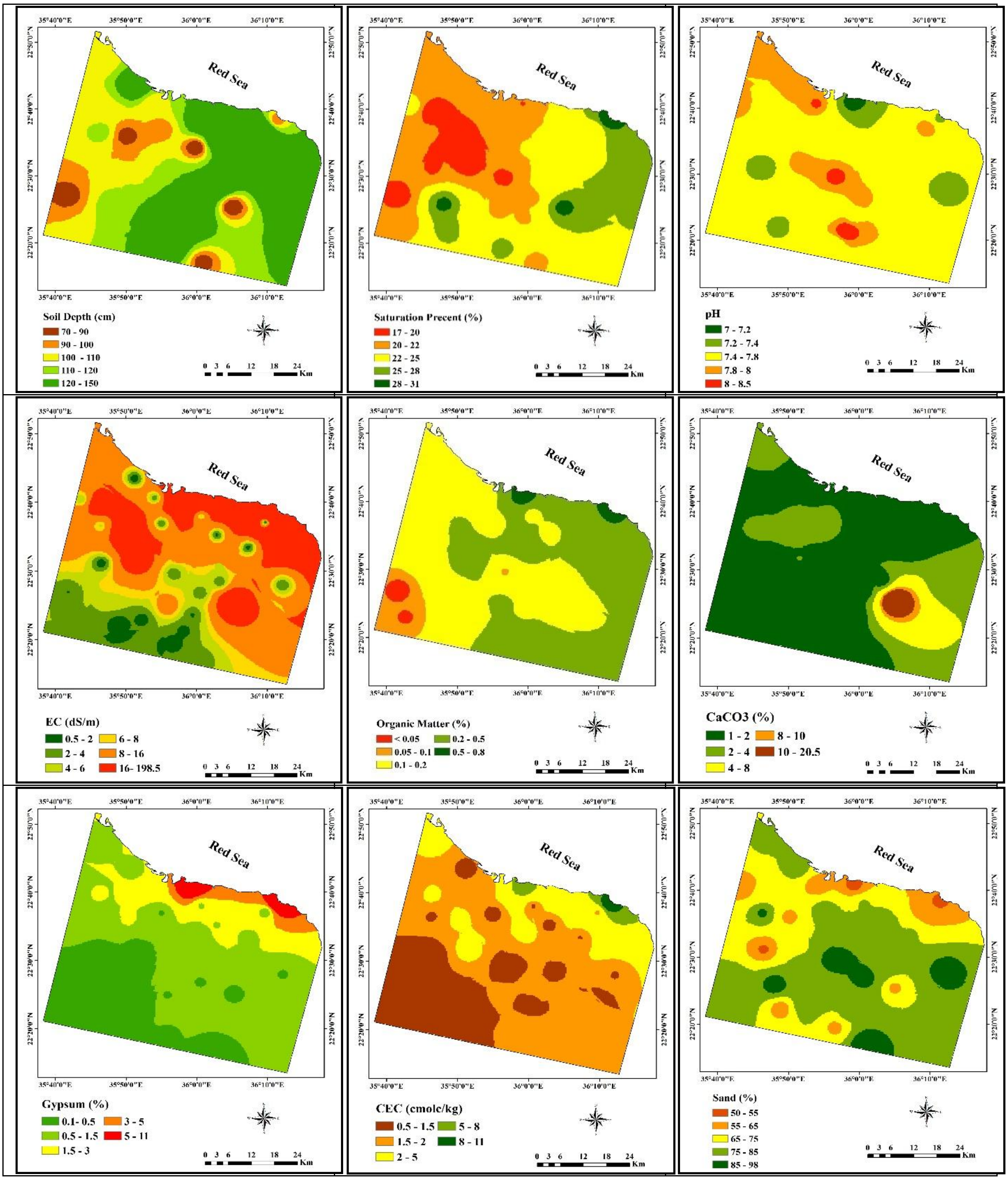

Fig. 6. Spatial distribution of some soil properties

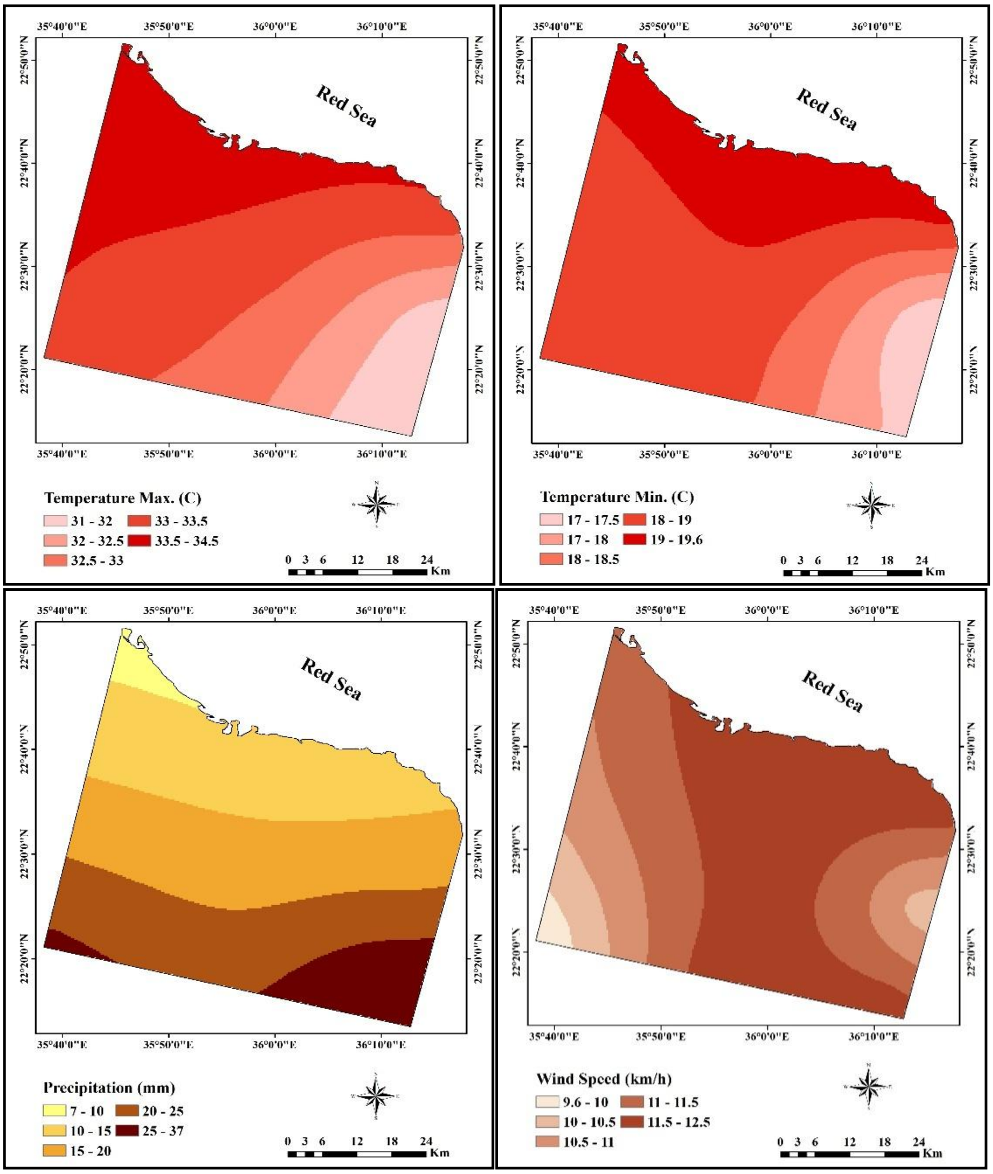

Fig.7. Spatial distribution of temperature, precipitation, and wind speed

Zone (I): They have very good suitability for most crops. Where was highly suitable (S1) for all crops which it is covering about 100 %. This zone is characterized by deep soil and high clay content. Their contents from salinity, carbonate, and gypsum are very low with slopes < 1%. It appears in delta apex and some wadis units. This zone is covering about 17987.14 acres (2.57 %).

Zone (II): This zone is defined by deep to relatively deep soils with a sandy loam to loamy texture. It has a moderately alkaline and moderately salinity effect, with electric conductivity values ranging from 2 to 4 dS/m. Their carbonate concentration ranges from 2 to 4%, while gypsum content is low, ranging from 0.5 to 1.5 percent with slopes of 2%. It can be found in the delta, alluvial plains, and wades units. This zone covers around 86846.81 acres (12.39 percent). Wheat, barley, cotton, sunflower, watermelon, tomato, date palm, olive, fig, and grape were extremely suited (S1) in a zone (II), which covers about 58.8% of the studied area. The soil properties the requirements of mentioned crops and this is agree with (Yousif, 2018; Mohamed, et al 2015 and Elbasyoni, 2018). It was suitable (S2) for maize, soybean, onion, alfalfa, potato, pear, and citrus. And it is covering about 41.2 % of the zone area.

Zone (III): This zone covers around 185747.64 acres (26.49 percent). This zone was characterized by being somewhat deep and having a moderately alkaline effect. The electric conductivity ranges from 4 to 6 dS/m, and the clay content is minimal. Their carbonate and gypsum compositions are mild, with slopes of less than 10%. It can be found in alluvial fans, plains, and some wades units. It was highly appropriate (S1) for tomato, olive, and fig, which accounted for 17.6% of the zone's total area. For wheat, barley, cotton, sunflower, watermelon, alfalfa, potato, date palm, and grape, suitable (S2) covers about 53% of the zone area. For maize, soybean, onion, pea, and grape, the moderately suitable (S3) zone covers around 29.4 percent of the zone area.

Zone (IV): This zone is found in the majority of the research region, comprising approximately 261343.54 acres (37.27 percent). It has some limits, such as salinity, with electric conductivity values ranging from 6 to 8 dS/m, moderately tolerant crops for salinity can be cultivated in this zone in addition, implement excess water for leaching and prevent salinity raising (Ayers and Westcot, 1994). Low clay content, and relatively high carbonate and gypsum contents, with carbonate contents up to 10% and gypsum values ranging from 3 to 5%. To improve its existing state, this zone needs effective management methods. As a result, somewhat rigorous management techniques can improve this zone's current capability. Where it was suitable (S2) for wheat, barley, cotton, sunflower, date palm, olive, and fig and it is covering about 41.2 % of the zone area. while, the moderately suitable (S3) is covering about 41.2 % of the zone area for maize, watermelon, alfalfa, potato, tomato, citrus, and grape. As for the rest of the zone was not suitable (NS).

Zone (V): non-suitable locations with severe or extremely severe limits that cannot be overcome, such as sandy to sandy loam texture, high salinity values > 30 dS/m,. To adapt salinity in this zone, cultivation salt-tolerant crops, adding fertilizers that contain sulfur and organic materials are required (Osman, 2018). High carbonate contents up to > 15%, gypsum values ranging from 5 to 11 percent, and a shallow soil profile of 50 to 70 cm. As a result, this zone's present capabilities cannot be improved. All crops that appear in sabkhas, pediments, and some terraced units were not acceptable (NS) in this zone. This zone covers approximately 62138.28 acres (8.87%).

TABLE 2. Total area for Agro-Ecological Zones

Agro-Ecological Zones in Halaieb						
Zones No.	Zone I	Zone II	Zone III	Zone IV	Zone V	Restricted area
Area (Acre)	17987.14	86846.81	185747.64	261343.54	62138.28	87086.51
Percentage (%)	2.57	12.39	26.49	37.27	8.87	12.41

TABLE 3. Land suitability for agro-ecological zones

Agro-Ecological Zones		I	II	III	VI	V
Field Crops	Wheat	S1	S1	S2	S2	NS
	Maize	S1	S2	S3	S3	NS
	Barely	S1	S1	S2	S2	NS
	Soybean	S1	S2	S3	NS	NS
	Cotton	S1	S1	S2	S2	NS
	Sunflower	S1	S1	S2	S2	NS
	Alfalfa	S1	S2	S2	S3	NS
Vegetable	Onion	S1	S2	S3	NS	NS
	Watermelon	S1	S1	S2	S3	NS
	Potato	S1	S2	S2	S3	NS
	Tomato	S1	S1	S1	S3	NS
	Pea	S1	S2	S3	NS	NS
Fruits	Citrus	S1	S2	S3	S3	NS
	Date palm	S1	S1	S2	S2	NS
	Olive	S1	S1	S1	S2	NS
	Grape	S1	S1	S2	S3	NS
	Fig	S1	S1	S1	S2	NS

Note: S1is highly suitable cass, S2 is suitable class, S3 is moderately suitable class and NS is not suitable class

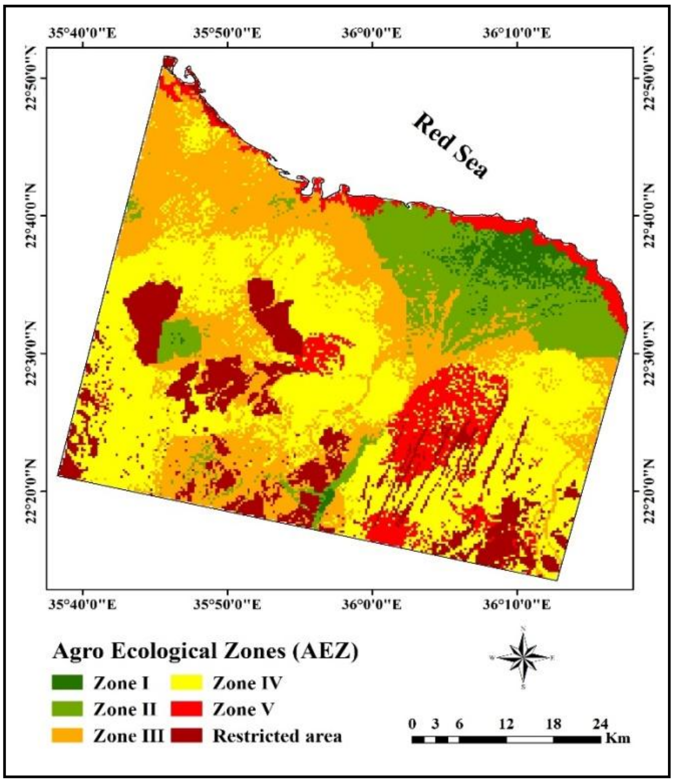

Fig. 8.Agro-Ecological Zones of the studied area

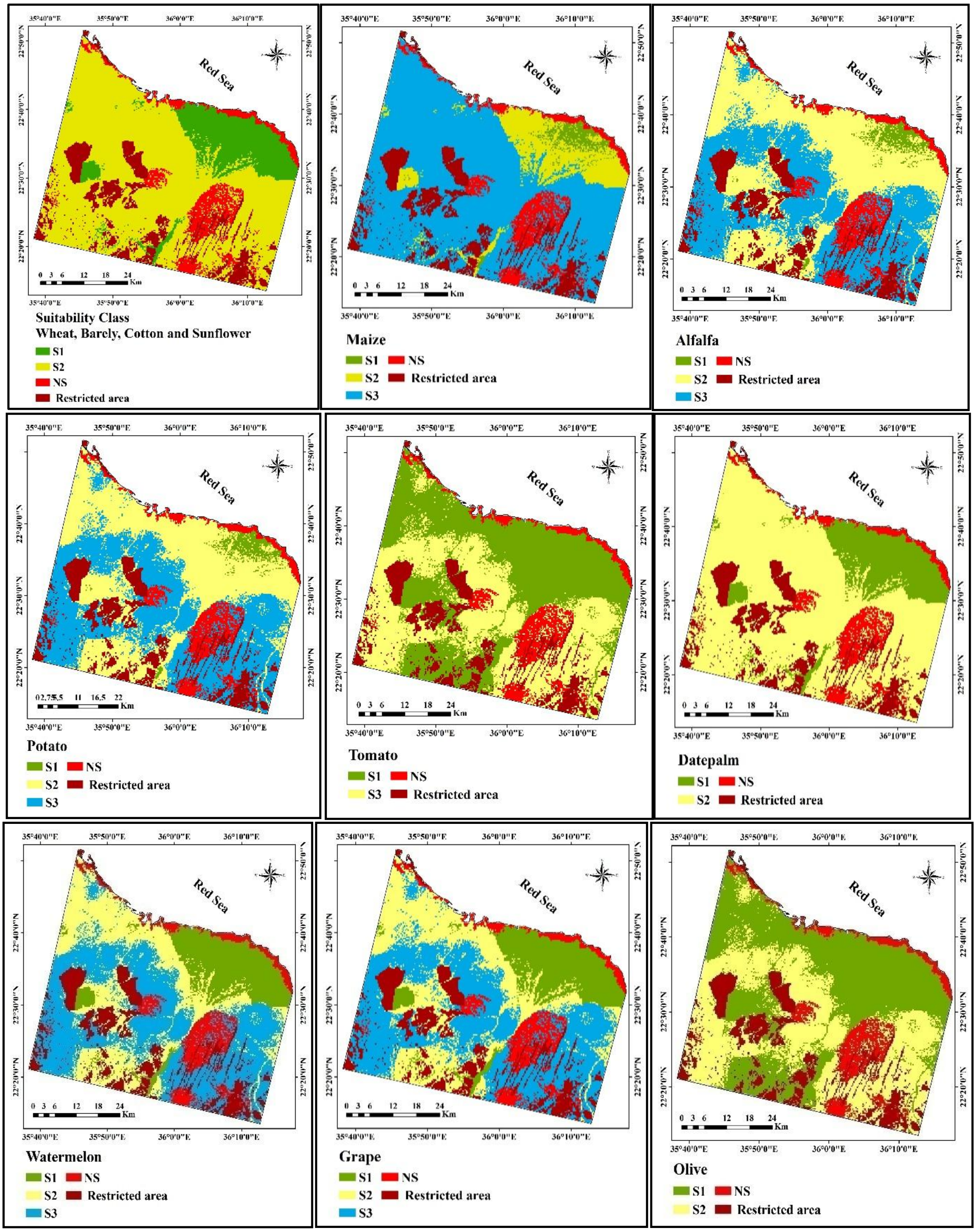

Fig. 9 Suitability of some crops in the study area

Fig10.The model of Ago Ecological Zones for the study area

4. Conclusion

The combined use of Remote Sensing (RS) data and Geographic Information Systems (GIS) data helps planners and decision-makers organize land resources data and soil maps in the research region by giving the necessary information. The AEZs for Egypt's Halayeb were created by combining soil, topographical, and climate data. Furthermore, land suitability for various crops was considered, which improves policymakers' ability to establish appropriate development plans based on such categorization.

In this context, AEZ can be thought of as a collection of applications that leads to a determination of land suitability and prospective production in terms of climate, soil, and landform conditions. If appropriate reclamation methods and management practices were used, natural resources in the Halayeb area may have a bright future for agricultural expansion projects. The acquired results indicated that zones I, II, and III were the best-suited zones for agricultural growth in the Halaieb area, which covered around 290581.6 acres of the total area. The study area's land suitability rating classes were: high suitable (S1), suitable (S2), moderate suitable (S3), and not suitable (NS), with texture, drainage, carbonate, salinity, sodium saturation, and profile depth as restriction variables. The most suitable crops are (Wheat, Maize, Barely, Tomato, Cotton, Sunflower, Date palm, Grape, Fig, and Olive). The results of the study are important contributions to national and regional digital soil databases; thatch as, Governmental Affairs, Ministry of irrigation and water resources, and Ministry of State for Scientific Research, Ministry of Agriculture and Land Reclamation, Private Sector and Investors.

Conflicts of interest

The authors declare no conflict of interest

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