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SOIL CLASSIFICATION OF BAHARIYA OASIS USING REMOTE SENSING AND GIS TECHNIQUES

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ABSTRACT

Bahariya Oasis is one of the most geologically important areas in the Western Desert. It is also a promising location for agriculture expansion projects due to the plenty and good quality of ground water for agricultural activities. The objective of this work was to develop a soil classification map of this area using remote sensing and GIS techniques. Spot image, acquired in 2011 and digital elevation model (DEM) were used to develop physiographic units. Three main physiographic units were identified in the oasis, which are plains, depression floor with low, moderately high and high lands and pediment. Thirty one soil profiles were dug throughout the oasis to represent soil physiographic units. These profiles were described, and sampled. Soil samples were analyzed for the physical and chemical characteristics. Soils in the studied area were classified under 11 soil map units (SMUs), which are: 1. *Sandy, siliceous, calcareous, thermic, Lithic Calcigypsids*, 2. *Sandy, siliceous, thermic, Lithic Haplogypsids*, 3. *Sandy, siliceous, thermic, Typic Haplogypsids, 4. Sandy, siliceous, thermic, Typic Aquisalids*, 5. *Sandy, siliceous, thermic, Typic Haplosalids*, 6. *Loamy, mixed, active, thermic, Typic Gypsiargids*, 7. *Sandy, siliceous, thermic, Typic Quartzipsamments*, 8. *Sandy, siliceous, thermic, Lithic Torripsamments*, 9. *Sandy, siliceous, thermic, Typic Torripsamments*, 10. *Loamy, mixed, super active, thermic, Typic Torrifluvents*, and 11. *Sandy skeletal, siliceous, thermic, Typic Torriorthents*. Calcium, gypsum, and salt accumulations were found in most of the studied soils. Few accumulations of silicate clays were also observed in certain areas of the depression.

Keywords: Bahariya Oasis, Remote sensing, GIS, Soil classification, Physiographic maps.

INTRODUCTION

Remote sensing can be defined as the measurement and recording of electromagnetic energy either reflected from or emitted by the earth's surface and relating of such measurements to the nature and properties of surface materials. In a general sense, remote sensing include all the activities of recording, processing, analyzing, interpretation and finally obtaining useful information from the data generated by the remote sensing system **(Shreathe, 1999)**. Remote sensing and digital image classification in particular is the fast advancing field, which provides access to spatial information and spatial data analysis. Remote sensing techniques have been applied in many disciplines including biology, geography, geology, geomorphology, hydrology, ecology and agriculture (Lillesand and Kiefer, 2003; De Jong and Van Der Meer, 2005; Hord *et al.*, 2006 and Schowengerdt, 2007).

Geographical information system (GIS) is a system for the collection, storage, management, query, analysis, and presentation of spatial data

(Bregt, 1997). GIS is used in many applications as a tool for spatial analysis Burrough and McDonnell (1998), Nehme and Simões (1999), Aronoff (2000) and Valenzuela (2004) explained that the most important characteristics of geographic information systems are their capabilities for data analysis and spatial modeling. These analysis capabilities include map overlaying, reclassification, proximity analysis, optimum correlation and other cartographic modeling techniques.

Bahariya depression is located nearly in the middle of the Western desert of Egypt and occupying a total area about 2100 km^2. The area falls under the arid condition as the total rainfall is 3-6 mm/year. Springs and wells are the two main groundwater resources for irrigation and civic purposes (Salem, 1987). It is 360 km southwest of Cairo and 180 km west of the Nile Valley. The depression is open from one or more sides and is being entirely surrounded by escarpments. It also has a great number of isolated hills scattered on its surface. Its greatest length is about 94 km and greatest width is about 42 km. The average depth from the surface of the plateau to the floor is less than 100 m (Al-Baraa, 2011). The depression surface is almost leveled with little or no local relief. It is formed from sandstone and layers of clay. Vegetation is concentrated in the northern parts close to the main villages such as Mandisha and El-Zabu. There are some bogs and salty lagoons in other parts of the depression due to the excessive evaporation (Darwish, 2004).

Soils in Bahariya Oasis are promising for agricultural activities due to the availability and good quality of ground water for irrigation (Salem 1980 and 1987, Sabry 1997). Rizk (2003) stated that the physicochemical analysis indicated that the Bahariya Oasis soils in general are coarse in texture, poor in organic matter content with a moderate alkaline reaction mostly exhibiting high content of both $CaCO_3$% and total suspended salts. Salem (1987) found that the soils of Bahariya Oasis can fit into two orders (Entisols *and* Aridisols), three sub-orders (*Psamments, Orthents* and *Fluvents*) and four sub-groups (*Typic Torripsamments, Lithic Torripsamments, Typic Torriorthents* and *Lithic Torriorthents).* However, more detailed soil classification to the family level is required for decision makers, and development managers.

The objectives of this work were to study the physical and chemical properties of soils in Bahariya Oasis, their spatial distribution, and develop a more detailed soil classification map.

MATERIALS AND METHODS

Site description of the study area:

Bahariya Oasis is located essentially between latitudes 27° 48' - 28° 30' N and longitudes 28° 35' - 29° 10' E as represented in Figure 1. It represents a great depression in the surface of the "Libyan plateau", but it is different from the other depressions of the western desert in being surrounded on all sides by high scarps and in having a great number of isolated hills scattered all over its surface.

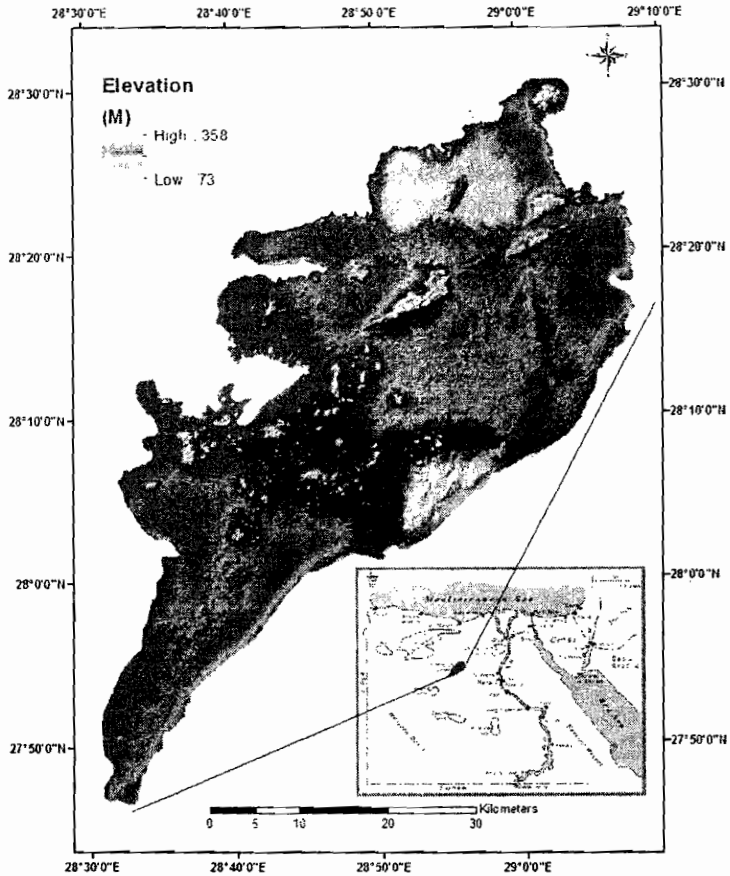

Fig.1: Location map of Bahariya Oasis showing topography of the studied area.

Geology of Bahariya Oasis was described by Ball and Beadnell (1937), Stromer (1944), Liebling (1959), Salem (1980 and 1987) and Khalifa (2006) stated that the stratigraphic rock units of the Oasis have been identified from greatest to lowest in this order: 1. Bahariya Sandstone and variegated Shale (Cretaceous), 2. El-Heiz formation, 3. El-Hufhuf formation, 4. Ain Giffara formation, 5. Khoman Chalk (Cretaceous), 6. Plateau Limestone (Upper Middle and Lower Eocene), and 7. Volcanic rock (Oligocene). Native vegetation in Bahariya oasis commonly associated with dry salt marshes could be distinguished into four communities dominated by *Sporobolus spicatus, Alhagi maurorum, Desmostachya bipinnata* and *Tamarix nilotica*.

The topography of Bahariya is essentially somewhat flat Sandstone floor, interrupted by a large number of isolated hills within the depression that usually rough and irregular. The floor is covered with dark large stones that consist of either Basalt or ferruginous Sandstone. The Hills within the

depression impede the visibility and give Bahariya an appearance quite different from the other depressions. This type of topography has been described by Peel (2001).Surface elevation of Bahariya Oasis varies from 73 to 358 m above sea level (ASL) (see Figure 1). The lowest part of the Oasis floor is in the neighborhood of El-Qasr, where the altitude is about 73 m ASL.

Air temperature of the Oasis varies from (10-20 °C) in winter and from (20-30 °C) in summer. According to the Soil Taxonomy (Soil Survey Staff, 1995) climate of Bahariya Oasis falls into the *hyperthermic* temperature regime and *torric* soil moisture regime.

Physiographic units and filed work:

Spot 4 images (acquired in 2011) and digital elevation model of the Oasis (developed from the SRTM data) were used to define the physiographic map in the studied area. Three physiographic units were developed, which are 1. Plains, 2. Depression floor with low, moderately high and high lands, and 3. Pediment as illustrated in Figure 2. Thirty one soil profiles were selected to represent the identified physiographic units. The exact locations of these profiles were precisely defined by using the Global Positioning System (GPS) as illustrated in Figure 2. Soil profiles were described in the field according to procedures described by the USDA-NRCS (2002) and they were classified according to U.S. soil taxonomy (Soil Survey Staff, 2010). A total of 68 soil samples, representing the different soil horizons of the selected profiles were collected, air-dried, crushed to pass through 2 mm sieve, and stored for physical and chemical analyses.

Laboratory analysis:

- **Physical analyses**

Mechanical analysis was carried out using the pipette method, whereas soil sample was treated by sodium hydroxide as dispersion solution (Kilmer and Alexander, 1949 and Gee and Bauder, 1986). Soil color under both dry and moist conditions was determined with the aid of Munsell's color charts (Munsell, 1975). Real density was determined according to the methods described by (Dewis and Freitas, 1970). Bulk density was determined using pycnometer as described by (Black *et at.,* 1965). Saturation percentage (SP %) and field capacity (FC %) of the soil were determined using method described by (Richards, 1954).

- **Chemical analyses**

Soluble cation and anions in the saturation paste extracts were determined according to the procedures described by Jackson (1975). Soil pH was measured in the saturated soil paste using a Gllenkamp pH meter as described by (Richards, 1954)]. Total soluble salts were measured in dS m^{-1} using electrical conductivity (EC) meter (EC meter Model TDScan 3) in saturation paste extract (Richards, 1954)]. Soil organic matter was determined using Walkely's rapid titration method (Jackson, 1967). Organic carbon was calculated by dividing the values of organic matter by 1.72. Calcium carbonate was determined using Collin's Calcimeter as described by Page *et al.,* (1982). Cation exchange capacity (CEC) was determined using sodium and ammonium acetate according to the method described by Hesse (1971).Gypsum was determined by acetone method according to Black (1965). Soil available nitrogen was extracted in using 2.0 M KCl according to

Hesse (1971), and determined by micro-kjeldahl apparatus. Available phosphorus was extracted using 0.5 N $NaHCO_3$ solution (pH 8.5) and determined using spectrophotometer at a wavelength of 725 nm after treated with ammonium molybdate and stannous chloride (Jackseon, 1973). Soil available potassium was extracted using 1.0 N ammonium acetate solution (pH 7) and determined using flame photometer (Hesse, 1971). Total nitrogen was determined by micro-kjeldahl apparatus (Jackson, 1967).

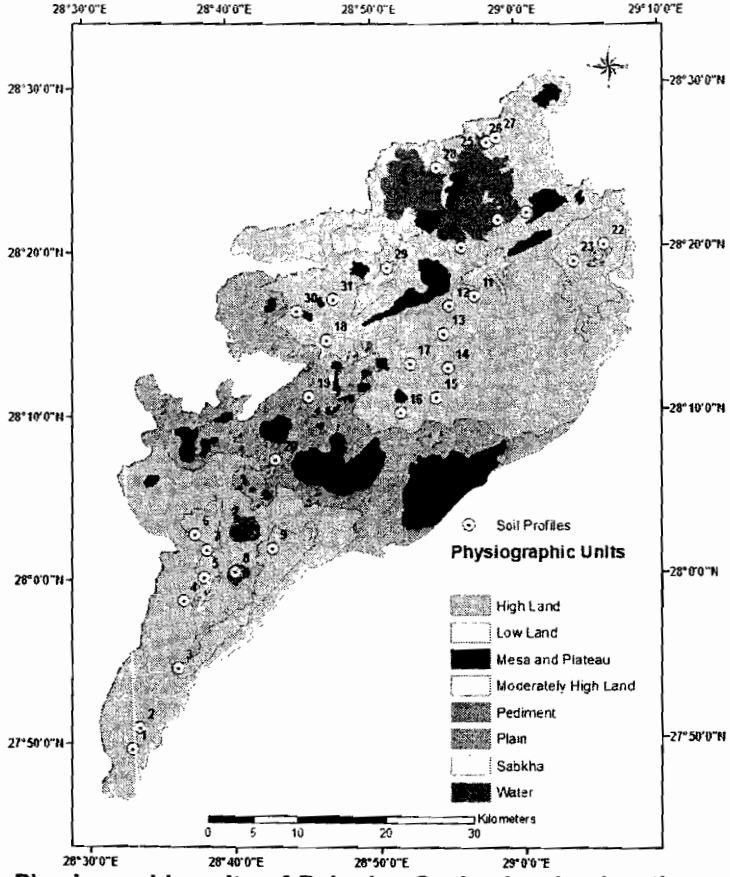

Fig.2: Physiographic units of Bahariya Oasis showing locations of soil profiles.

RESULTS AND DISCUSSION

Physiographic units (landforms)

Three physiographic units were identified in Bahariya oasis based on digital image process, image interpretation, and digital elevation modal (DEM Fig.1). The presence of these units was verified during the field work and they were described. Soil profiles were carefully selected to represent these units. Also, soils on each physiographic unit were classified according to the U.S. soil classification system (Soil Survey Staff, 2010). Data in Table 1 show

the identified physiographic units, sub-great group of soils developed on each physiographic unit and their percent of the total area. The identified physiographic units are:

1. **Plains,** which occupy the majority of the north part in the Oasis. This landscape covers about100 km^2 (about 4.65% of the total area) as illustrated in Table 1 and Figure 2. The agricultural land and villages are concentrated in the plain landform in the northern part of the depression. Soils on this landscape are intensively cultivated by traditional crops due to their leveled surface and relatively good soil quality. Also, plantations of palm tree mostly occurred on the plain landforms of sand sheet, where the sand flat and sheet plain landforms provide large areas for cultivation. Isolated small sabkhas exist within shallow depressions. Aeolian sand deposits cover more than half of the surface in the form of sand sheets, dunes and hummocks.
2. **Depression floor:** According to the elevations in this major unit, three sub units were identified, which are: low lands, moderately high lands, and high lands. These units cover an area of about 208, 1182 and 391 km^2, respectively. This major unit is covering most of the depression floor (84.86% of the total area. High lands are located in the center of the depression and they separate the northern section from the southern one. The common features in this unit are salinity, sand dunes, and isolated hills. Water table is generally higher in some areas of this major unit due to surface irrigation, poor drainage, and excessive evaporation. Shale deposits resulted in the developed loamy to clay loamy soils covering certain areas in this unit.
3. **Pediment:** Pediments represent the rocky lands at the foot slope of scarps. It covers about 11 km^2 (about 0.54% of the total area). They are rocky in general covered with rocky fragments in some parts. These fragments are silicified and ferrogenated at the surface.

Soil Taxonomy of Bahariya Oasis

- **Soil Orders in Bahariya Oasis**

Soils in Bahariya Oasis are located under two main soil orders, Aridisols and Entisols as represented in Table 2. The spatial distribution of these soil orders is illustrated in Figure 3. Aridisols represent about 75.05 % of the soils in the Oasis, whereas Entisols represent about 15.04 % of the soils. Entisols, which are less developed soils, were mainly developed over sand dunes and recently alluvial deposits. Aridisols, which is the major soil order, were developed over relatively old soils in the Oasis.

The main diagnostic horizons of aridisols are clacic, gypsic, salic, and argilic horizons. Calcic horizon is common in most of the studied soils. However, it is mostly located in the middle parts of the Oasis. It is usually located at a shallow depth due to the very low rainfall in this very arid region. Gypsic horizon is usually associated with the calcic horizon and it relatively has the same behavior. Salic horizon usually exists in soils close to salt marches and poorly drained area in the Oasis. These areas mostly located in the northern parts of the Oasis close to El-Hara and Mandisha. Soils in these areas are cultivated under poor or no drainage system. Sabkhas and salt marshes are also common in these areas. Salic horizon is also located in the southern parts of the Oasis due to intensive evaporation.

Table 1: Identified physiographic units, sub-great group of soils developed on each unit and their percent of the total area

Physiographic Units		Soil Profile No.	Soil Taxonomy (Sub-great group)	Area Km^2	Area %
Plains		24	Typic Torripsamments	97.69	4.64 %
		26	Typic Torripsamments		
Depression Floor	Lowland	3	Typic Quartzipsamments	207.79	9.90 %
		5	Typic Torripsamments		
		6	Typic Aquisalids		
		9	Typic Quartzipsamments		
		22	Typic Aquisalids		
		23	Typic Quartzipsamments		
		29	Typic Torripsamments		
	Moderately High land	1	Typic Torriorthents	1182.09	56.31 %
		2	Typic Torriorthents		
		4	Typic Haplogypsids		
		7	Typic Aquisalids		
		10	Lithic Haplogypsids		
		11	Lithic Calcigypsids		
		12	Typic Torrifluvents		
		13	Typic Quartzipsamments		
		14	Lithic Torripsamments		
		15	Lithic Calcigypsids		
		16	Lithic Calcigypsids		
		17	Typic Quartzipsamments		
		18	Lithic Haplogypsids		
		21	Typic Torriorthents		
		25	Typic Haplogypsids		
		27	Typic Gypsiargids		
		28	Typic Haplogypsids		
		30	Lithic Haplogypsids		
		31	Lithic Haplogypsids		
	High land	19	Lithic Calcigypsids	391.6	18.66 %
		20	Lithic Calcigypsids		
Pediment		8	Lithic Calcigypsids	11.23	0.54 %

Argillic horizon was observed in one location in the north-west side of the Oasis. This horizon is rich in clay minerals with evidence of clay films over the bed surfaces. It is well known that argillic horizon is usually developed under humid and warm conditions, which currently don't exist in this region. This could indicate that the climatic condition in this region was different in the past than the current situation. In other words the climate in the Oasis was more humid.

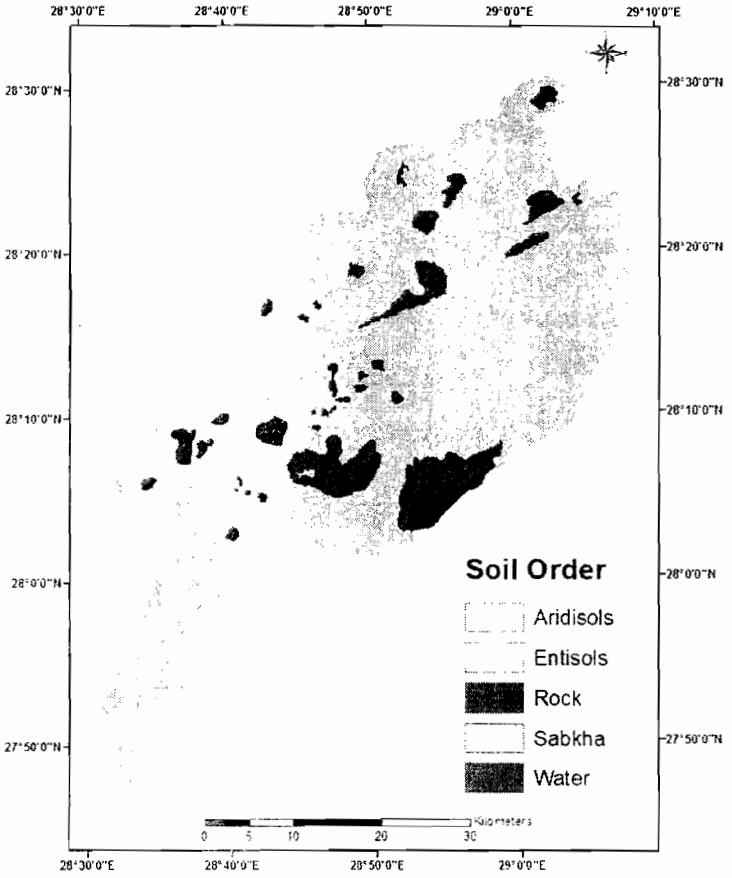

Fig.3. **Soil Order map of Bahariya Oasis.**

- **Soil Sub-orders in Bahariya Oasis**

Soil sub-orders under aridisols include: *Gypsids, Salids, Argids, Gypsids,* and *Salids*. On the other hand, there were three soil sub-orders under Entisols, which are *Fluvents*, *Orthents*, and *Psamments*. The percent of each soil sub-orders relative to the total is represented in Table 2, and the spatial distribution of these soil sub-orders is illustrated in Figure 4.

Table 2: Soil classification according to Us Soil Taxonomy (2006) and USDA-NRCS (2002).

SMU No.	Soil Order	Total Area %	Soil Sub-Order	Total Area %	Soil Great Group	Total Area %	Soil Sub-Great Group	Total Area %	Profile(s) No.
1	Aridisols	75.05 %	*Gypsids*	68.53 %	*Calcigypsids*	19.18%	*Lithic Calcigypsids*	19.18 %	8,11,15,16, 19,20
2			*Gypsids*		*Haplogypsids*	49.35 %	*Lithic Haplogypsids*	34.44 %	10,18,30,31
3			*Gypsids*		*Haplogypsids*		*Typic Haplogypsids*	14.91 %	4,25,28
4			*Salids*	6.47 %	*Aquisalids*	2.76 %	*Typic Aquisalids*	2.76 %	6,7,22
5			*Salids*		*Haplosalids*	3.72 %	*Typic Haplosalids*	3.72 %	1,2
6			*Argids*	0.05%	*Gypsiargids*	0.05 %	*Typic Gypsiargids*	0.05 %	27
7	Entisols	15.04 %	*Psamments*	13.92 %	*Quartzipsamments*	5.79 %	*Typic Quartzipsamments*	5.79 %	3,9,13,17, 23
8			*Psamments*		*Torripsamments*	8.13 %	*Lithic Torripsamments*	0.14 %	14
9			*Psamments*		*Torripsamments*		*Typic Torripsamments*	7.99 %	5,26,29, 24
10			*Fluvents*	0.34 %	*Torrifluvents*	0.34 %	*Typic Torrifluvents*	0.34 %	12
11			*Orthents*	0.78 %	*Torriorthents*	0.78 %	*Typic Torriorthents*	0.78 %	21

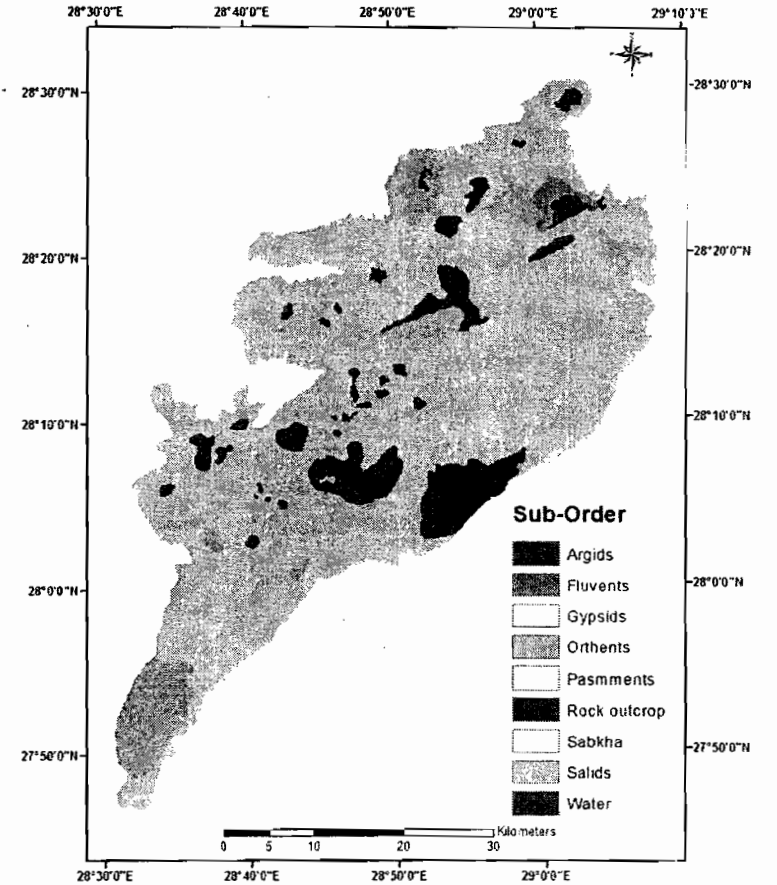

Fig.4. Soil Sub-Order map of Bahariya Oasis.

- **Soil Great Groups in Bahariya Oasis**

There were four great groups under both Aridisols and Entisols. Great groups under Aridisols include: *Aquisalids, Gypsiargids, Haplogypsids* and *Haplosalids*. Great groups under Entisols include: *Quartzipsamments, Torrifluvents, Torriorthents* and *Torripsamments*. The spatial distribution of these soil great groups is illustrated in Figure 5. Also, the percent of each soil great group to the total is represented in Table 2.

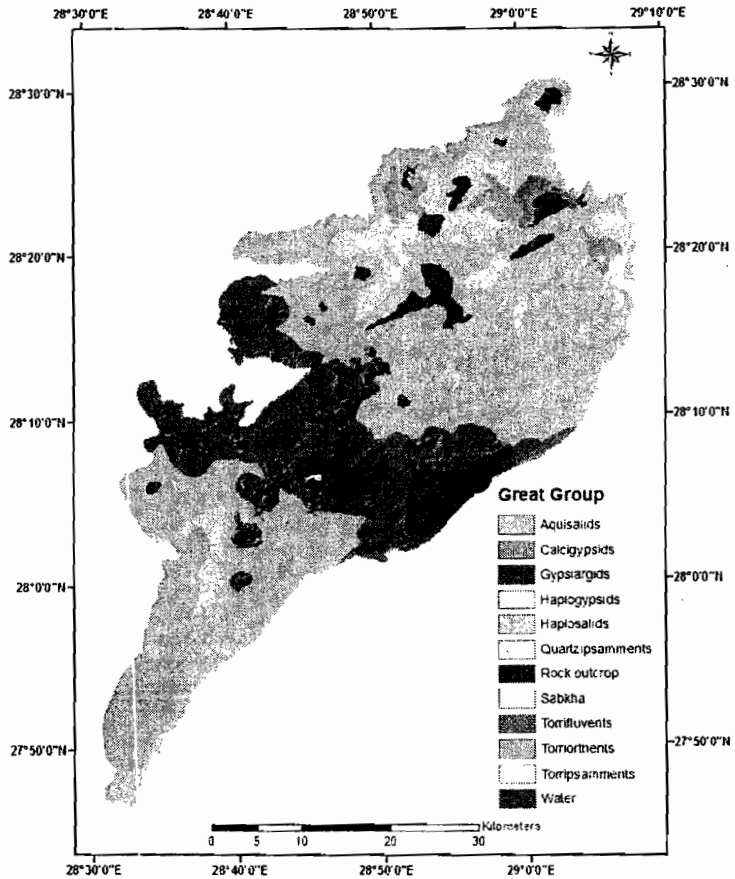

Fig.5. Soil Great Group map of Bahariya Oasis

- **Soil sub-Great Groups in Bahariya Oasis**

Soil sub-great groups under Aridisols include: *Lithic Calcigypsids, Lithic Haplogypsids, Typic Aquisalids, Typic Haplosalids, Typic Gypsiargids* and *Typic Haplogypsids.* Soil sub-great groups under Entisols include: *Lithic Torripsamments, Typic Quartzipsamments, Typic Torripsamments, Typic Torrifluvents* and *Typic Torriorthents.* The percent of each soil sub-great groups relative to the total is represented in Table 2, and the spatial distribution of these soil sub-great groups is illustrated in Figure 6.

- **Soil Families in Bahariya Oasis**

Soil families in the oasis were identified based on the particle-size distribution, mineralogy, cation-exchange activity, calcareous and reaction classes, soil temperature, and soil depth. It is found that most of the studied soils in the oasis are sandy in their texture; therefore they are siliceous in their mineralogy. Most of the soils have no cation-exchange activity, although

some little areas were super active in their cation-exchange capacity due to their higher clay content. Some soils were rich in their carbonate content (calcareous) and have strong effervescence with dilute HCL. The dominant soil temperature regime in the oasis is thermic. Also, some soils were shallow in their depth and have a root limiting layer.

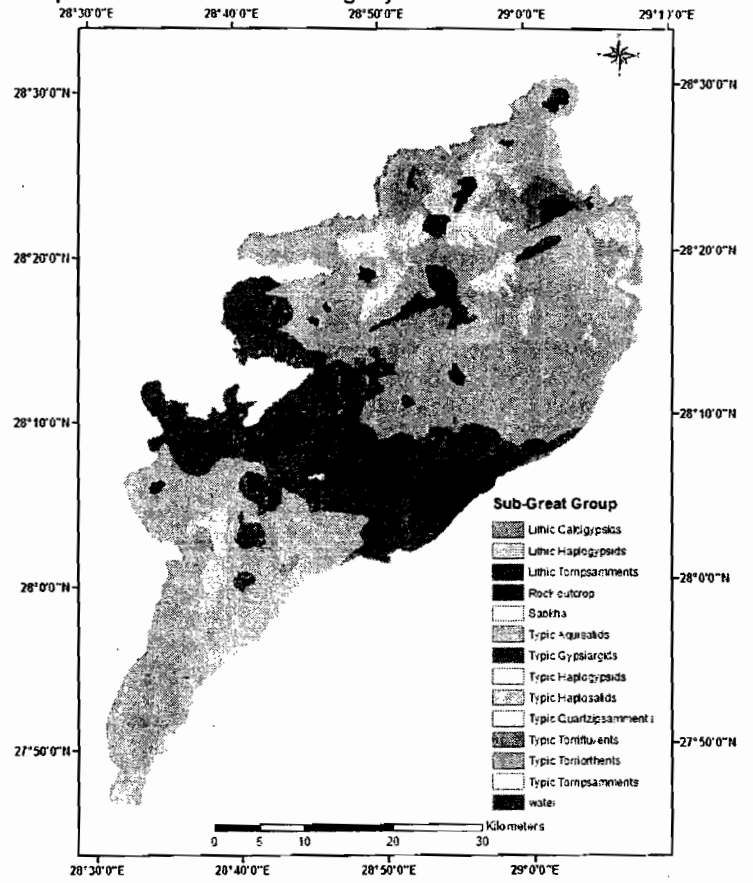

Fig.6. Soil Sub-Great Group map of Bahariya Oasis

Description of Soil Map Units:

Eleven soil map units were observed in the Bahariya Oasis. The description and characteristics of these map units are mentioned below:

- **Soil characteristics of soil map unit 1 (SMU1):**

Soil map unit 1 is represented by profile numbers 8, 11, 15, 16, 19 and 20. Physical and chemical properties of profile number 11 are represented in tables 3 and 4 as a representative profile for this SMU. Land surface is almost leveled. Soils are well drained, shallow, with sandy, loamy sand and sandy loam textures. Real density ranged between 2.47 to 2.71 g cm^{-3} with an average value of 2.62 g cm^{-3} and bulk density values varied from 1.36 to

1.92 g cm^{-3} with an average value of 1.71 g cm^{-3} and both have relation with sand and clay contents. Soils in this unit are slightly saline to extremely saline where the EC values varied from 2.80 to 46.30 dS m^{-1} with an average value of 14.59 dS m^{-1}. Sodium was the predominant cation in all horizons followed by calcium and magnesium (88.85, 33.91, and 21.91 meq/100 g soil in average, respectively. On the other hand, chloride was the dominant anions followed by sulphates and bicarbonate (84.37, 53.76, and 5.45 meq/100 g soil in average, respectively. Soils in this map unit ranged between slightly and moderately alkaline (soil pH ranged from 7.35 to 8.62, 8.05 in average) where, ESP ranged between 12.74 to 14.65 % (13.72% in average).

Soils are calcareous, where the total carbonate content ranged between 8.18 to 20.75 %, with an average of 15.14%). Soils also have lower content of soil organic matter (0.16 to 1.17 %, with an average of 0.57%). Gypsum content ranged between 3.14 to 8.95 % (5.94% in average). Cation exchange capacity of this soil map unit ranged between 3.19 to 16.43 meq/100 g soil (about 8.28 meq/100 g in average) due to their coarse texture. This map unit is low to moderate in available nitrogen and potassium, where they ranged between 16.60 to 54.20 ppm and 84.40 to 227 ppm, respectively. Whereas, available phosphorus content was low to high and ranged between 4.92 to 17.29 ppm.

According to Soil Survey Staff (2010), this map unit could be classified as *Sandy, Siliceous, calcareous, Thermic, Lithic Calcigypsids* and this map unit covered 402.67 km^2 (about 19.18 % of the total area). Soils in this unit are classified as shown in Table 2 and Figure 6.

Table 3: Physical and some chemical properties for one of the representative profiles of SMU1.

Prof. No.	Depth cm	Horizon	Particle size distribution (%)				Texture	$CaCO_3$ %	Gypsum %	O.M %	ρs g cm^{-3}	ρb g cm^{-3}
			Coarse sand	Fine sand	Silt	Clay						
11	0-5	A	3.98	85.88	5.93	4.21	Sandy	9.86	3.19	0.30	2.64	1.73
	5-13	Bky1	3.13	86.44	6.01	4.42	Sandy	15.91	7.22	0.36	2.54	1.68
	13-33	Bky2	2.91	86.25	6.13	4.71	Sandy	20.75	6.33	0.39	2.56	1.61
	33-46	CByk	2.40	85.42	7.11	5.07	Sandy	10.53	3.82	0.44	2.65	1.65

Table 4: Chemical Properties for one of the representative profiles of SMU1.

Prof. No.	Depth cm	Soluble cations (meq. L^{-1})				Soluble anions (meq. L^{-1})				EC dSm^{-1}	pH	CEC meq/ 100 g soil	ESP (%)
		Ca^{2+}	Mg^{2+}	Na^{+}	K^{+}	$CO_3^{=}$	HCO_3^{-}	Cl^{-}	$SO_4^{=}$				
11	0-5	98.9	41.2	194.7	0.18	-	15.8	143.0	176.2	31.4	7.44	5.0	14.8
	5-13	83.4	42.6	161.9	0.11	-	12.1	131.6	144.3	25.3	7.48	5.7	14.2
	13-33	60.3	30.9	122.7	0.06	-	8.3	103.0	102.7	19.2	7.52	5.9	13.8
	33-46	37.1	19.4	75.5	0.02	-	4.2	60.9	66.9	11.5	7.59	6.4	13.8

- **Soil characteristics of soil map unit 2 (SMU2):**

Soil map unit 2 is represented by profile numbers10, 18, 30 and 31. Physical and chemical properties of profile number 18 are represented in tables 5 and 6 as a representative profile for this SMU. Surface is nearly leveled. Soils are well drained, shallow, with sandy and sandy loam textures. Real density ranged between 2.43 to 2.63 g cm^{-3} with a an average of 2.54 g cm^{-3} and bulk density values ranged between 1.71 to 1.90 g cm^{-3} with a an average of 1.81 g cm^{-3}, both have relation with sand content. Soils in this unit are highly to extremely saline where the EC values varied from 9.90 to 36.60 dS m^{-1} with an average of 22.42 dS m^{-1}. Sodium was the predominant cation in all horizons followed by calcium and magnesium (128.87, 48.81, and 34.06 meq/100 g soil in average, respectively). On the other hand, chloride was the dominant anions followed by sulphates and bicarbonate (119.66, 86.15, and 6.08 meq/100 g soil in average, respectively). Soils are slightly alkaline to moderately alkaline (soil pH ranged from 7.73 to 8.33, 8.04 in average) and ESP ranged between 11.90 to 14.10 % (13.14% in average).

Soils are non-calcareous (total carbonate content varied from 4.45 to 5.41 % and 4.85% in average) and have low organic matter which ranged between 0.23 to 0.72 %, with an average of 0.45%. Gypsum content ranged between 3.32 to 8.70 %, about 5.33% in average. Cation exchange capacity of this soil map unit ranged between 4.05 to 10.30 meq/ 100 g soil due to their coarse texture. Soils in this map unit are low in their available nitrogen and potassium, where they ranged between 18.90 to 38.10 ppm and 94.00 to 168 ppm respectively. Whereas, available phosphorus content was moderate to high and ranged between 10.62 to 16.16 ppm.

According to Soil Survey Staff (2010), this map unit could be classified as *Sandy, Siliceous, Thermic, Lithic Haplogypsids* and it covers about 722.80 km^2 (about 34.44 % of the total area).

Table 5: Physical and some chemical properties for one of the representative profiles of SMU2.

Prof. No.	Depth cm	Horizon	Particle size distribution (%)				Texture	$CaCO_3$ %	Gypsum %	O.M %	ρs g cm^{-3}	ρb g cm^{-3}
			Coarse sand	Fine sand	Silt	Clay						
18	0-3	A	6.1	84.0	5.8	4.1	Sandy	5.1	3.0	0.3	2.5	1.7
	3-19	By	5.6	84.1	5.9	4.4	Sandy	5.0	8.7	0.3	2.6	1.7
	19-35	CBy	5.1	83.9	6.2	4.8	Sandy	4.8	6.3	0.4	2.6	1.8
	35-46	C	4.3	83.3	7.2	5.2	Sandy	4.5	3.4	0.5	2.6	1.9

- **Soil characteristics of soil map unit 3 (SMU3):**

Soil map unit 3 is represented by profile numbers 4, 25 and 28. Physical and chemical properties of profile number 28 are represented in tables 7 and 8 as a representative profile for this SMU. Soils in this map unit are almost leveled, well drained, and deep, with sandy, loamy sand and sandy loam textures. Real density ranged between 2.47 to 2.70 g cm^{-3} with an average of 2.60 g cm^{-3} and bulk density values varied from 1.31 to 2.11 g cm^{-3} with an average value of 1.83 g cm^{-3} and both have relation with their sand and clay

contents. Soils are highly to extremely saline, where the EC values varied from 9.80 to 38.40 dS m^{-1} with an average value of 21.11 dS m^{-1}.

Table 6: Chemical Properties for one of the representative profiles of SMU2.

Prof. No.	Depth cm	Soluble cations (meq. L^{-1})				Soluble anions (meq. L^{-1})				EC dSm^{-1}	pH	CEC meq/ 100 g soil	ESP (%)
		Ca^{2+}	Mg^{2+}	Na^{+}	K^{+}	$CO_3^{=}$	HCO_3^{-}	Cl^{-}	$SO_4^{=}$				
18	0-3	55.8	52.9	203.1	0.2	-	5.6	212.4	94.0	29.8	8.2	4.8	14.1
	3-19	41.9	42.7	143.2	0.1	-	4.9	153.2	69.8	21.3	8.2	5.3	14.0
	19-35	35.4	28.8	125.6	0.2	-	2.4	138.6	49.0	16.7	8.3	6.1	13.8
	35-46	19.7	18.5	69.8	0.0	-	1.5	79.1	27.4	9.9	8.3	6.7	13.8

Sodium was the predominant cation in all horizons followed by calcium and magnesium (117.88, 57.83, and 30.49 meq/100 g soil in average, respectively). On the other hand, sulphate was the dominant anions followed by chloride and bicarbonate (111.22, 91.16, and 3.96 meq/100 g soil in average, respectively. Soils are slightly alkaline (soil pH ranged from 7.51 to 7.89, 7.68 in average) and ESP ranged between 11.96 to 13.25 % (12.31% in average).

Soils in this unit are non-calcareous, where the total carbonate content ranged between 2.89 to 4.26 %, with an average of 3.59%). Soils also have lower content of soil organic matter (0.77 to 1.10 %, with an average of 0.90%). Gypsum content ranged between 2.18 to 9.25 % (5.92% in average). Cation exchange capacity ranged between 10.92 to 15.40 meq/100 g soil (about 12.69 meq/100 g in average). This map unit is low to moderate in available nitrogen, phosphorus and potassium, where their values ranged between 39.70 to 51.20 ppm, 6.24 to 10.29 ppm and 173 to 220 ppm, respectively.

According to Soil Survey Staff (2010), this map unit could be classified as *Sandy, Siliceous, Thermic, Typic Haplogypsids* and it covers about 313 km^2 (about 14.91 % of the total area).

Table 7: Physical and some chemical properties for one of the representative profiles of SMU3.

Prof. No.	Depth cm	Horizon	Particle size distribution (%)				Texture	$CaCO_3$ %	Gypsum %	O.M %	ps g cm^{-3}	pb g cm^{-3}
			Coarse sand	Fine sand	Silt	Clay						
28	0-3	A	8.2	58.3	17.3	16.3	Sandy Loam	4.2	3.0	0.8	2.5	2.0
	3-21	By	7.7	56.1	19.1	17.1	Sandy Loam	4.0	7.0	0.8	2.6	2.0
	21-56	C	6.1	55.4	20.1	18.4	Sandy Loam	3.5	3.2	0.9	2.5	2.1

Table 8: Chemical Properties for one of the representative profiles of SMU3.

Prof. No.	Depth cm	Soluble cations (meq. L^{-1})				Soluble anions (meq. L^{-1})				EC dSm^{-1}	pH	CEC meq/ 100 g soil	ESP (%)
		Ca^{2+}	Mg^{2+}	Na^{+}	K^{+}	$CO_3^{=}$	HCO_3^{-}	Cl^{-}	$SO_4^{=}$				
28	0-3	27.2	13.4	68.2	0.2	-	1.7	51.9	55.4	17.1	7.5	11.2	12.1
	3-21	21.9	13.8	52.3	0.1	-	1.5	44.3	42.3	14.2	7.6	11.4	12.0
	21-56	13.6	8.4	34.9	0.1	-	1.1	26.3	29.6	9.8	7.6	12.7	12.0

- **Soil characteristics of soil map unit 4 (SMU4):**

Soil map unit 4 is represented by profile numbers 6, 7 and 22. Physical and chemical properties of profile number 6 are represented in tables 9 and 10 as a representative profile for this SMU. Surface is nearly leveled, poorly drained, and deep, with loamy sand and sandy loam textures. Real density ranged between 2.65 to 2.72 g cm^{-3} with an average value of 2.69 g cm^{-3} and bulk density values varied from 1.23 to 1.59 g cm^{-3} with an average value of 1.40 g cm^{-3}. Soils in this unit are extremely saline where the EC values varied from 35.10 to 45.60 dS m^{-1} with an average value of 41.40 dS m^{-1}. Sodium was the predominant cation in all horizons followed by calcium and magnesium (289.48, 81.76, and 60.38 meq/100 g soil in average, respectively). On the other hand, chloride was the dominant anion followed by sulphate and bicarbonate (305.98, 112.54, and 13.29 meq/100 g soil in average, respectively). Soils in this map unit are moderately alkaline (soil pH ranged from 8.01 to 8.79, 8.35 in average) and the ESP ranged between 11.89 to 13.17 % (12.55% in average).

Soils are non-calcareous, where the total carbonate content ranged between 2.06 to 6.01 %, with an average of 3.79%). Soils also have lower content of soil organic matter (1.10 to 1.57 %, with an average of 1.29%). Gypsum content was nil in all horizons. Cation exchange capacity ranged between 15.68 to 20.05 meq/100 g soil (about 17.74 meq/100 g soil in average). Soils in this map unit are moderate in available nitrogen and potassium, their values ranged between 51.80 to 66.80 ppm and 223.90 to 264 ppm, respectively. However, available phosphorus is low and ranged between 2.37 to 5.93 ppm.

According to Soil Survey Staff (2010), this map unit could be classified as *Sandy, Siliceous, thermic, Typic Aquisalids* and this map unit covers about 57.83 km^2 (about 2.76 % of the total area).

Table 9: Physical and some chemical properties for one of the representative profiles of SMU4.

	Depth cm	Horizon	Particle size distribution (%)				Texture	$CaCO_3$ %	Gypsum %	O.M %	ps g cm^{-3}	pb g cm^{-3}
			Coarse sand	Fine sand	Silt	Clay						
6	0-5	A	6.3	75.4	14.2	4.1	Loamy sand	2.7	N.D	1.1	2.7	1.3
	5-70	Bz	2.4	80.9	10.5	6.2	Loamy sand	5.9	N.D	1.1	2.7	1.2

Table 10: Chemical Properties for one of the representative profiles of SMU4

Prof. No.	Depth cm	Soluble cations (meq. L^{-1})				Soluble anions (meq. L^{-1})				EC dSm^{-1}	pH	CEC meq/ 100 g soil	ESP (%)
		Ca^{2+}	Mg^{2+}	Na^{+}	K^{+}	$CO_3^{=}$	HCO_3^{-}	Cl^{-}	$SO_4^{=}$				
6	0-5	91.2	76.1	324.5	0.2	-	29.6	335.4	127.0	45.6	8.0	17.1	13.2
	5-70	77.1	58.3	277.4	0.2	-	25.3	289.6	98.1	39.8	8.1	15.7	12.9

- **Soil characteristics of soil map unit 5 (SMU5):**

Soil map unit 5 is represented by profile numbers 1 and 2. Physical and chemical properties of profile number 2 are represented in tables 11 and 12 as a representative profile for this SMU. Land surface is almost leveled. Soils are well drained, and deep, with a sandy clay loam texture. Real density ranged between 2.68 to 2.73 g cm^{-3} with an average value of 2.71 g cm^{-3} and bulk density values varied from 1.45 to 2.02 g cm^{-3} with an average value of 1.65 g cm^{-3}. Soils in this unit are extremely saline where the EC values varied from 29.90 to 41.70 dS m^{-1} with an average of 35.83 dS m^{-1}. Sodium was the predominant cation in all horizons followed by calcium and magnesium (258.53, 78.50, and 42.87 meq/100 g soil in average, respectively). On the other hand, chloride was the dominant anions followed by sulphates and bicarbonate (291.97, 71.85, and 16.23 meq/100 g soil in average, respectively). Soils are slightly alkaline (soil pH ranged from 7.84 to 7.96, 7.90 in average) and ESP ranged between 12.85 to 13.77 % (13.46% in average).

Soils are calcareous, where the total carbonate content ranged between 2.35 to 14.36 %, with an average of 6.39%). They are low in their content of soil organic matter (1.07 to 1.41 %, with an average of 1.28%). Gypsum content was about 4.15 %. Cation exchange capacity ranged between 15.13 to 18.62 meq/100 g soil (about 17.32 meq/100 g soil in average) due to their coarse texture. This map unit is moderate in available nitrogen and potassium, their values ranged between 50.70 to 62.70 ppm and 216.70 to 241.20 ppm respectively. On the other hand, available phosphorus content is low and ranged between 3.12 to 6.31 ppm.

According to Soil Survey Staff (2010), this map unit could be classified as *Sandy, siliceous, thermic, Typic Haplosalids* and it covers 78 km^2 (about 3.72 % of the total area).

Table 11: Physical and some chemical properties for one of the representative profiles of SMU5.

Prof. No.	Depth cm	Horizon	Particle size distribution (%)				Texture	$CaCO_3$ %	Gypsum %	O.M %	ρs g cm^{-3}	ρb g cm^{-3}
			Coarse sand	Fine sand	Silt	Clay						
2	0-3	A	5.0	38.8	29.0	27.3	Sandy Clay Loam	2.5	N.D	1.4	2.7	1.5
	3-35	Bz	4.8	38.6	29.1	27.6	Sandy Clay Loam	2.4	4.2	1.4	2.7	1.5

Table 12: Chemical Properties for one of the representative profiles of SMU5.

Prof. No.	Depth cm	Soluble cations (meq. L^{-1})				Soluble anions (meq. L^{-1})				EC dSm^{-1}	pH	CEC meq/ 100 g soil	ESP (%)
		Ca^{2+}	Mg^{2+}	Na^{+}	K^{+}	$CO_3^{=}$	HCO_3^{-}	Cl^{-}	$SO_4^{=}$				
2	0-3	75.9	37.6	265.3	0.2	-	15.2	294.3	69.5	35.9	7.8	18.2	13.8
	3-35	65.8	29.9	218.4	0.1	-	9.7	252.1	52.4	29.9	7.9	18.6	12.9

- **Soil characteristics of soil map unit 6 (SMU6):**

Soil map unit 6 is represented by profile number 27. Physical and chemical properties of profile number 27 are represented in tables 13 and 14 as a representative profile for this SMU. Land surface is almost leveled. Soils in this map unit are well drained, and deep, with sandy, sandy clay loam and clay loam textures. Real density ranged between 2.46 to 2.70 g cm^{-3} with an average value of 2.59 g cm^{-3} and bulk density values varied from 1.48 to 2.39 g cm^{-3} with an average value of 1.94 g cm^{-3}. Soils in this unit are moderately to extremely saline, where the EC values varied from 7.70 to 22.30 dS m^{-1} with an average value of 14.68 dS m^{-1}. Sodium was the predominant cation in all horizons followed by calcium and magnesium (90.35, 42.95, and 23.80 meq/100 g soil, respectively. On the other hand, sulphates were the dominant anions followed by chlorides and bicarbonates (82.69, 72.78, and 1.78 meq/100 g soil, respectively. Soils are slightly alkaline (soil pH ranged from 7.12 to 7.31, 7.23) and ESP ranged between 11.79 to 11.97 % (11.86% in average).

Soils are calcareous, where the total carbonate content ranged between 8.16 to 13.71 %, with an average of 10.97%). Soils also have lower content of soil organic matter (0.51 to 1.27 %, with an average of 0.86%). Gypsum content ranged between 4.12 to 8.16 % (6.53% in average). Cation exchange capacity ranged between 7.19 to 17.59 meq/100 g soil (about 12.10 meq/100 g soil in average). This map unit is low to moderate in available nitrogen and potassium, where their values ranged between 29.30 to 59.30 ppm and 139 to 234 ppm, respectively. In contrast, available phosphorus is low to moderate and ranged between 3.96 to 13.25 ppm.

According to Soil Survey Staff (2010), this map unit could be classified as *Loamy, mixed, active, thermic, Typic Gypsiargids* and this it covers about 1.05 km^2 (about 0.05% of the total area).

Table 13: Physical and some chemical properties for one of the representative profiles of SMU6.

Prof. No.	Depth cm	Horizon	Particle size distribution (%)				Texture	$CaCO_3$ %	Gypsum %	O.M %	ρs g cm^{-3}	ρb g cm^{-3}
			Coarse sand	Fine sand	Silt	Clay						
27	0-3	A	7.7	80.3	6.7	5.3	Sandy	8.2	4.1	0.5	2.7	1.7
	3-16	Bt1	5.9	50.6	22.0	21.5	Sandy Clay Loam	10.5	8.2	0.6	2.7	1.5
	16-41	Bt2	2.5	28.1	33.2	36.2	Clay Loam	11.5	7.0	1.1	2.5	2.2
	> 41	C	3.5	22.6	34.1	39.7	Clay Loam	13.7	6.9	1.3	2.5	2.4

Table 14: Chemical Properties for one of the representative profiles of SMU6.

Prof. No.	Depth cm	Soluble cations (meq. L^{-1})				Soluble anions (meq. L^{-1})				EC dSm^{-1}	pH	CEC meq/ 100 g soil	ESP (%)
		Ca^{2+}	Mg^{2+}	Na^{+}	K^{+}	$CO_3^{=}$	HCO_3^{-}	Cl^{-}	$SO_4^{=}$				
27	0-3	66.2	31.5	138.1	0.2	-	2.6	114.0	119.4	22.3	7.1	7.2	12.0
	3-16	47.1	25.8	97.9	0.2	-	1.9	79.6	89.5	15.9	7.2	8.7	11.8
	16-41	35.8	21.3	75.8	0.1	-	1.4	58.4	73.2	12.8	7.3	14.9	11.8
	> 41	22.7	16.6	49.6	0.1	-	1.2	39.1	48.7	7.7	7.3	17.6	11.8

- **Soil characteristics of soil map unit 7 (SMU7):**

Soil map unit 7 is represented by profile numbers 3, 9, 13, 17 and 23. Physical and chemical properties of profile number 17 are represented in tables 15 and 16 as a representative profile for this SMU. Soils in this map unit are almost leveled, well drained, and deep, with a sandy texture. Real density ranged between 2.49 to 2.61 g cm^{-3} with an average of 2.56 g cm^{-3} and bulk density varied from 1.76 to 1.93 g cm^{-3} with an average of 1.85 g cm^{-3}. These soils are moderately to highly saline where the EC values varied from 4.90 to 14.90 dS m^{-1} with an average value of 7.96 dS m^{-1}. Sodium was the predominant cation in all horizons followed by calcium and magnesium (55.84, 17.46, and 14.68 meq/100 g soil in average, respectively). On the other hand, chloride was the dominant anion followed by sulphate and bicarbonate (64.70, 19.70, and 3.64 meq/100 g soil in average, respectively). These soils also vary from slightly to moderately alkaline (soil pH ranged between 7.79 and 8.50, 8.07 in average) and ESP ranged between 12.15 to 13.80 % (13.04% in average).

Soils in this map unit are calcareous, where the total carbonate content ranged between 4.26 to 6.12 %, with an average of 5.29%). Soils also have lower content of soil organic matter (0.14 to 0.54 %, with an average of 0.26%). Gypsum content was 6.14 %. Cation exchange capacity ranged between 2.71 to 7.71 meq/100 g soil (about 4.34 meq/100 g soil in average) due to their coarse texture. Soil in this map unit are poor in available nitrogen and potassium, were their values ranged between 15.30 to 30.70 ppm and 78 to 144.20 ppm, respectively. On the other hand, available phosphorus varied from moderate to high and its values ranged between 12.75 to 18.17 ppm.

According to Soil Survey Staff (2010), this map unit could be classified as *Sandy, siliceous, thermic, Typic Quartzipsamments* and it covers about 121.53 km^2 (about 5.79 % of the total area).

Table 15: Physical and some chemical properties for one of the representative profiles of SMU7.

Prof. No.	Depth cm	Horizon	Particle size distribution (%)				Texture	$CaCO_3$ %	Gypsum %	O.M %	ρs g cm^{-3}	ρb g cm^{-3}
			Coarse sand	Fine sand	Silt	Clay						
17	0-100	C	1.9	89.9	5.2	3.1	Sandy	-	N.D	0.1	2.5	1.9

Table 16: Chemical Properties for one of the representative profiles of SMU7.

Prof. No.	Depth cm	Soluble cations (meq. L^{-1})				Soluble anions (meq. L^{-1})				EC dSm^{-1}	pH	CEC meq/ 100 g soil	ESP (%)
		Ca^{2+}	Mg^{2+}	Na^{+}	K^{+}	$CO_3^{=}$	HCO_3^{-}	Cl^{-}	$SO_4^{=}$				
17	0-100	29.7	29.4	101.9	0.1	-	3.5	113.6	44.0	14.9	7.9	2.7	13.7

- **Soil characteristics of soil map unit 8 (SMU8):**

Soil map unit 8 is represented by profile number 14. Physical and chemical properties of profile number 14 are represented in tables 17 and 18 as a representative profile for this SMU. Soil surface of this map unit is nearly leveled, well drained, and shallow, with a sandy texture. Real density is 2.52 g cm^{-3} and bulk density is 2.15 g cm^{-3} and both have relation with sand content. Soils in this unit are moderately saline (EC value was 7.60 dS m^{-1}). Sodium was the predominant cation in this soil profile followed by calcium and magnesium (59.60, 16.80, and 11.60 meq/100 g soil, respectively). On the other hand, chloride was the dominant anions followed by sulphates and bicarbonate (65.40, 17.54, and 5.10 meq/100 g soil, respectively). Soil is moderately alkaline, where pH was 8.25 and ESP was 13.77 %.

Soils are non-Calcareous (total carbonate content was 3.44 %) and have low organic matter content (1.16 %). Gypsum content was nil in this profile. Cation exchange capacity of this soil map unit was 15.95 meq/100 g soil due to their coarse texture. This map unit was moderate in available nitrogen, potassium, where their contents were about 52.70 and 226.20 ppm, respectively. Although, these soils were low in available phosphorous (5.76 ppm).

According to Soil Survey Staff (2010), this map unit could be classified as *Sandy, Siliceous, Thermic, Lithic Torripsamments* and it covers about 3 km^2 (about 0.14 % of the total area).

Table 17: Physical and some chemical properties for one of the representative profiles of SMU8.

Prof. No.	Depth cm	Horizon	Particle size distribution (%)				Texture	$CaCO_3$ %	Gypsum %	O.M %	ρs g cm^{-3}	ρb G cm^{-3}
			Coarse sand	Fine sand	Silt	Clay						
14	0- 43	C	3.2	84.4	8.2	4.2	Sandy	3.4	N.D	1.2	2.5	2.2

Table 18: Chemical Properties for one of the representative profiles of SMU8.

Prof. No.	Depth cm	Soluble cations (meq. L^{-1})				Soluble anions (meq. L^{-1})				EC dSm^{-1}	pH	CEC meq/ 100 g soil	ESP (%)
		Ca^{2+}	Mg^{2+}	Na^{+}	K^{+}	$CO_3^{=}$	HCO_3^{-}	Cl^{-}	$SO_4^{=}$				
14	0-43	16.8	11.6	59.6	0.0	-	5.1	65.4	17.5	7.6	8.3	16.0	13.8

- **Soil characteristics of soil map unit 9 (SMU9):**

Soil map unit 9 is represented by profile numbers 5, 24, 26 and 29. Physical and chemical properties of profile number 24 are represented in tables 19 and 20 as a representative profile for this SMU. Soil surface is almost leveled, well drained, and deep, with sandy and sandy clay loam textures. Real density ranged between 2.49 to 2.72 g cm^{-3} with an average of 2.63 g cm^{-3} and bulk density varied from 1.35 to 1.94 g cm^{-3} with an average of 1.71 g cm^{-3} and both have relation with sand and clay contents. Soils in this unit are moderately to extremely saline where the EC values varied from 7.20 to 19.60 dS m^{-1} with an average value of 11.02 dS m^{-1}. Sodium was the predominant cation in all horizons followed by calcium and magnesium (69.32, 32.37, and 20.32 meq/100 g soil in average, respectively. On the other hand, sulphates were the dominant anions followed by chloride and bicarbonate (60.75, 57.75, and 3.55 meq/100 g soil in average, respectively. These soils ranged between slightly and moderately alkaline (soil pH ranged from 7.42 to 8.04, 7.76 in average) and ESP ranged between 11.91 to 14.43 % (12.70% in average).

Soils in this map unit are calcareous, where their total carbonate content ranged between 3.95 to 11.75 %, with an average of 6.99%). They are low in their content of soil organic matter (0.34 to 1.03 %, with an average of 0.64%). Gypsum content ranged between 2.14 to 5.51 % (3.81% in average). Cation exchange capacity ranged between 5.25 to 14.41 meq/100 g soil (about 9.06 meq/100 g in average) due to their coarse texture. This map unit is low to moderate in available nitrogen, phosphorus, and potassium, where their values ranged between 23.50 to 48.30 ppm, 7.16 to 15.12 ppm and 112.00 to 212.70 ppm, respectively.

According to Soil Survey Staff (2010), this map unit could be classified as *Sandy, siliceous, Thermic, Typic Torripsamments* and it covers 167.64 km^2 (about 7.99 % of the total area).

Table 19: Physical and some chemical properties for one of the representative profiles of SMU9.

Prof. No.	Depth cm	Horizon	Particle size distribution (%)				Texture	$CaCO_3$ %	Gypsum %	O.M %	ρs g cm^{-3}	ρb g cm^{-3}
			Coarse sand	Fine sand	Silt	Clay						
24	0-7	A	2.0	84.0	7.9	6.1	Sandy	6.0	2.1	0.6	2.6	1.7
	7-100	C	1.6	83.3	8.5	6.5	Sandy	4.8	2.8	0.6	2.5	1.8

Table 20: Chemical Properties for one of the representative profiles of SMU9.

Prof. No.	Depth cm	Soluble cations (meq. L^{-1})				Soluble anions (meq. L^{-1})				EC dSm^{-1}	pH	CEC meq/ 100 g soil	ESP (%)
		Ca^{2+}	Mg^{2+}	Na^{+}	K^{+}	$CO_3^{=}$	HCO_3^{-}	Cl^{-}	$SO_4^{=}$				
24	0-7	26.1	15.1	49.7	0.1	-	1.9	41.2	47.9	7.9	7.4	8.1	12.1
	7-100	18.5	9.2	36.2	0.1	-	1.4	25.2	37.4	5.7	7.5	8.5	12.1

- **Soil characteristics of soil map unit 10 (SMU10):**

Soil map unit 10 is represented by profile number 12. . Physical and chemical properties of profile number 12 are represented in tables 21 and 22 as a representative profile for this SMU. Soils in this map unit are nearly leveled, well drained, and deep, with a sandy clay loam texture. Real density was 2.49 g cm^{-3} and bulk density value was 1.31 g cm^{-3} and both have relation with particle size distribution.Soils in this unit are slightly saline where the EC value was 3.20 dS m^{-1}. Sodium was the predominant cation in this profile followed by calcium and magnesium (28.20, 7.30, and 4.50 meq/100 g soil, respectively). On the other hand, chloride was the dominant anions followed by sulphates and bicarbonate (30.60, 6.61, and 2.80 meq/100 g soil, respectively). Soils are moderately alkaline (soil pH was 8.22), and ESP was about 13.75 %.

Soils in this map unit are calcareous (total carbonate content was 18.41%) and have low content of soil organic matter (1.13 %). Gypsum content was nil in in this profile. Cation exchange capacity of this soil map unit was 16.12 meq/100 g soil due to their coarse texture. This map unit was moderate in available nitrogen and potassium; where their contents were about 53.10 ppm and 225.40 ppm, respectively. On the other hand, available phosphorus content was low (5.32 ppm).

According to Soil Survey Staff (2010), this map unit could be classified as *Loamy, mixed, super active, thermic, Typic Torrifluvents* and it covers about 7.06 km^2 (about 0.34 % of the total area).

Table 21: Physical and some chemical properties for one of the representative profiles of SMU10.

Prof. No.	Depth cm	Horizon	Particle size distribution (%)				Texture	$CaCO_3$ %	Gypsum %	O.M %	ρs g cm^{-3}	ρb g cm^{-3}
			Coarse sand	Fine sand	Silt	Clay						
12	0-100	C	3.2	51.2	23.2	22.5	Sandy Clay Loam	18.4	N.D	1.1	2.5	1.3

Table 22: Chemical Properties for one of the representative profiles of SMU10.

Prof. No.	Depth cm	Soluble cations (meq. L^{-1})				Soluble anions (meq. L^{-1})				EC dSm^{-1}	pH	CEC meq/ 100 g soil	ESP (%)
		Ca^{2+}	Mg^{2+}	Na^{+}	K^{+}	$CO_3^{=}$	HCO_3^{-}	Cl^{-}	$SO_4^{=}$				
12	0-100	7.3	4.5	28.2	0.0	-	2.8	30.6	6.6	3.2	8.2	16.1	13.8

- **Soil characteristics of soil map unit 11 (SMU11):**

Soil map unit 11 is represented by profile number 21. Physical and chemical properties of profile number 21 are represented in tables 23 and 24 as a representative profile for this SMU. Soils in this map unit are almost leveled, well drained, and deep, with a very gravelly sandy texture. Real density ranged between 2.61 to 2.67 g cm^{-3} with an average value of 2.65 g cm^{-3} and bulk density values varied from 1.35 to 1.42 g cm^{-3} with an average value of 1.38 g cm^{-3}. Soils in this unit are slightly to moderately saline, where the EC values varied from 2.10 to 4.90 dS m^{-1}, with an average of 3.40 dS m^{-1}. Sodium was the prec ominant cation in all horizons followed by calcium and magnesium (22.27, 11.10, and 6.63 meq/100 g soil, respectively). On the other hand, sulphate was the dominant anions followed by chloride and bicarbonate (20.27, 17.17, and 2.60 meq/100 g soil, respectively). Soils in this map unit are slightly alkaline (soil pH ranged from 7.66 to 7.76, 7.71 in average) and the ESP ranged between 11.85 to 12.00 % (11.95% in average).

Soils are non-calcareous, where the total carbonate content ranged between 2.18 to 4.26 %, with an average of 3.00%). Soils also have lower content of soil organic matter (1.23 to 1.50 %, with an average of 1.35%). Gypsum content ranged between 2.19 to 4.72 % (3.34% in average). Cation exchange capacity of this soil map unit ranged between 14.35 to 19.43 meq/100 g soil (about 17.21 meq/100 g in average). This map unit is moderate in available nitrogen, phosphorus and potassium, where their values ranged between 57.80 to 64.90 ppm, 2.56 to 4.38 ppm, and 233 to 251 ppm, respectively.

According to Soil Survey Staff (2010), this map unit could be classified as *Sandy skeletal, Siliceous, Thermic, Typic Torriorthents* and it covers about 16.41 km^2 (about 0.78 % of the total area).

Table 23: Physical and some chemical properties for one of the representative profiles of SMU11.

Prof. No.	Depth cm	Horizon	Particle size distribution (%)				Texture	$CaCO_3$ %	Gypsum %	O.M %	ρs g cm^{-3}	ρb g cm^{-3}
			Coarse sand	Fine sand	Silt	Clay						
21	0-13	A	67.63	25.86	4.90	1.61	Very Gravelly Sandy	2.6	3.1	1.3	2.7	1.4
	13-40	AC	61.03	33.12	4.12	1.73	Very Gravelly Sandy	4.3	4.7	1.2	2.6	1.4
	> 40	C	37.95	50.05	9.03	2.97	Very Gravelly Sandy	2.2	2.2	1.5	2.7	1.4

Table 24: Chemical Properties for one of the representative profiles of SMU11.

Prof. No.	Depth cm	Soluble cations (meq. L^{-1})				Soluble anions (meq. L^{-1})				EC dSm^{-1}	pH	CEC meq/ 100 g soil	ESP (%)
		Ca^{2+}	Mg^{2+}	Na^{+}	K^{+}	$CO_3^{=}$	HCO_3^{-}	Cl^{-}	$SO_4^{=}$				
21	0-13	14.8	8.1	30.1	0.1	-	2.3	22.1	28.7	4.9	7.7	17.8	12.0
	13-40	10.9	7.2	20.9	0.0	-	2.6	17.3	19.1	3.2	7.7	14.4	12.0
	> 40	7.6	4.6	15.8	0.0	-	2.9	12.1	13.0	2.1	7.8	19.4	11.9

CONCLUSION

It could be concluded that the integration of both remote sensing and GIS data and techniques could provide an effective and versatile tool to manipulate and produce the physiographic and soil maps of Bahariya Oasis. This is in combination with the field observations and laboratory analyses. Three main physiographic units were recognized in the studied area, which are: plains, depression floor with low, moderately high and high lands, and pediment. Also, eleven soil map units (SMUs) were identified in the oasis depending on the soil physical, chemical and morphological characteristics. These SMUNs include: 1. *Sandy, siliceous, calcareous, thermic, Lithic Calcigypsids*, 2. *Sandy, siliceous, thermic, Lithic Haplogypsids*, 3. *Sandy, siliceous, thermic, Typic Haplogypsids, 4. Sandy, siliceous, thermic, Typic Aquisalids*, 5. *Sandy, siliceous, thermic, Typic Haplosalids*, 6. *Loamy, mixed, active, thermic, Typic Gypsiargids*, 7. *Sandy, siliceous, thermic, Typic Quartzipsamments*, 8. *Sandy, siliceous, thermic, Lithic Torripsamments*, 9. *Sandy, siliceous, thermic, Typic Torripsamments*, 10. *Loamy, mixed, super active, thermic, Typic Torrifluvents*, and 11. *Sandy skeletal, siliceous, thermic, Typic Torriorthents*. Calcium, gypsum, and salt accumulations were very obvious in most of the studied soils. Silicate clay represented in the argillic horizon was observed in few areas of the depression.

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تصنيف أراضي الواحات البحرية بإستخدام تقنيات الإستشعار من البعد ونظم المعلومات الجغرافية

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****الهيئة القومية للإستشعار من البعد وعلوم الفضاء – القاهرة – مصر**

الواحات البحرية واحدة من أهم المناطق الجيولوجية في الصحراء الغربية ، وتعد منطقة واعدة لمشاريع التوسع الزراعي بسبب وفرة وجودة المياه الجوفية وملائمتها للأنشطة الزراعية. يهدف هذا البحث إلى إنتاج خريطة تصنيف التربة لهذه المنطقة باستخدام تقنيات الإستشعار من البعد ونظم المعلومات الجغرافية (GIS) . حيث استخدمت صور القمر الصناعى الفرنسى Spot 4 ، والتى تم الحصول عليها عام ٢٠١١ وكذلك نموذج الارتفاعات الرقمية (DEM) لتطوير الوحدات الفيزيوجرافية للمنطقة . وقد تم تحديد ثلاث وحدات فيزيوجرافية رئيسية في الواحة، وهي السهول Plains ، سطح المنخفض Depression floor بما يحتوية من أراضى منخفضة ومتوسطة وعالية الإرتفاع ثم Pediment . ولقد أجريت هذه الدراسة على عدد ٣١ قطاع أرضى تمثل هذه الوحدات الفيزيوجرافية. وتم توصيف هذه القطاعات وأخذ عينات تربة من الآفاق المختلفة ثم إجراء التحليلات الطبيعية والكيميائية على هذه العينات. وقد تم تصنيف التربة في منطقة الدراسة تحت ١١ وحدة أرضية (SMU) تبعا للتقسيم الأمريكى للأراضى ، وهي :

1. *Sandy, siliceous, calcareous, thermic, Lithic Calcigypsids*, 2. *Sandy, siliceous, thermic, Lithic Haplogypsids*, 3. *Sandy, siliceous, thermic, Typic Haplogypsids, 4. Sandy, siliceous, thermic, Typic Aquisalids*, 5. *Sandy, siliceous, thermic, Typic Haplosalids*, 6. *Loamy, mixed, active, thermic, Typic Gypsiargids*, 7. *Sandy, siliceous, thermic, Typic Quartzipsamments*, 8. *Sandy, siliceous, thermic, Lithic Torripsamments*, 9. *Sandy, siliceous, thermic, Typic Torripsamments*, 10. *Loamy, mixed, super active, thermic, Typic Torrifluvents*, and 11. *Sandy skeletal, siliceous, thermic, Typic Torriorthents*.

كما وجدت تراكمات واضحة جدا من الكالسيوم والجبس والأملاح في معظم الأراضى بمنطقة الدراسة. كما لوحظ وجود تراكمات قليلة من الطين السليكاتى في مناطق محدودة بالمنخفض.

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