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LAND RESOURCES OF THE MAIN DRAINAGE BASINS IN THE NORTH WESTERN COAST OF EGYPT : AN ASSESSMENT BY USING REMOTE SENSING AND GIS

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Abstract

The main objective of this study is to evaluate the land resources of catchment basins in the north western coast of Egypt by using remote sensing and GIS. The study area is bounded by longitudes 27° 03' and 27° 52' east and latitudes 31° 00' and 31° 22' north. Landsat ETM+ data and Shuttle Radar Topography Mission (SRTM) were used with the field observations to delineate the catchment basins over the area. The Tropical Rainfall Measuring Mission (TRMM) data were used to calculate water quantity stored in the different basins. A total of 25 soil profiles represent the different basins were morphologically described and sampled for the laboratory analyses. The results indicated that the soil texture differed from sandy to sandy clay loam and EC values changed from 1.0 to 67.7 dS/m. The percentage of organic matter (OM) ranged from 0.10 to 1.30 %, while $CaCO_3$ % ranged between 11.40 and 71.50 %. The area contains five great groups of soil i.e. *Typic Torripasamments, Typic Torriorthents, Typic Torrifluvents* and *Typic Haplocalcids*. The study show that the area was grouped into four land capability grades i.e. high capable (I) represent 3.56%, moderately capable i.e. 57.28 %, marginally capable (III) attain about 30.83 % and non-capable (8.23%). Also the obtained data showed that the annual quantity of water available in the different basins is 306368063 m^3 that sufficient to irrigate an area of 76592 feddans (1 feddan= 4200 m^2).

Keywords: Catchment basin, land resources, rainfall, GIS, remote sensing.

Introduction

There is no doubt that the ratio between land resources and human resources is one of the most critical problems in Egypt. The scarcity of fertile soils and water resources in Egypt imposes considerable attention in the assessment of land resources (Ali and Shalaby 2012). The policy of the horizontal expansion represents a very great importance for Egypt, since the rates of overpopulation increase annually with more than 2.1%, which is considered to be one of the sustainable development impediments (CAPMAS 2019). Horizontal extension in the new areas in the western desert is necessary to meet the demand of food due to the nature of Egypt population growth. The north western coast is considered one of the proposed areas for horizontal expansion policy. The cost of reclamation of such regions is rather high (IFAD 2016); therefore, the evaluation of land resources is an essential action in order to maintain the sustainable development of investment as well as the sustainable usage of the soils. Likewise, the water shortage in such areas drive the researchers to investigate the capability of using the water stored in the dominant basins. It is considered as the main limiting factor faces the agriculture sustainability (Velmurugan *et al.,* 2016). Water harvesting in the catchment basins is a must to realize the agriculture sustainability. Also the evaluation of land resources is a vital link in the chain leading to optimum management of land resources. It is allocated the indispensable task of translating the data on land resources into terms and categories, which can be assumed and used by all those concerned with land use planning (FAO, 1991, 2007 and Anaya-Romero *et al.* 2015). In this context, the use of remote sensing and Geographic Information System (GIS) allows producing multi thematic layers of soil properties, which offer a great source of data for the land use planners. The use of Digital Elevation Model (DEM) permits to delineate the catchment areas and hence the estimation of water quantity inside the basin is available (Chang 2006, Zhang *et al.,* 2005 and Zhou and Liu 2002). The Tropical Rainfall Measuring Mission (TRMM) remotely sensing data assess in calculating the annual rainfall over the study area. This data give records on the area every 3 days, which is rather suitable for water budget estimations (Kummerow *et al.,* 2000 and Gu *et al.,* 2010). Land capability assessment is very important to drive the limited water to the areas of high capability classes in the catchment areas. Finally, it is worthy to define the most suitable crops for the area. In this regard, land suitability for crops is essential to select the optimum land use for each catchment basin (Safa Mazahreh *et al.,* 2019).

The present study aims at evaluating the land resources of catchment basins in the north western coast of Egypt that could be achieved through (1) delineation of the catchment basins over the area by using spatial analysis and DEM data, (2) assessment of land capability by using the digital thematic maps of the soil properties and (3) Estimate the available annual water storied in the drainage catchments over the area using Shuttle Radar Topography Mission data and Rainfall averages.

Materials and Methods

Study area

The study area is located in the Northwestern coast of Egypt (Figure 1), it is bounded by longitude 27° 03' 00" E & 27° 52' 00" E and latitude 31° 00' 00" E & 31° 22' 00" E with a total area of 1257.34 km^2. The maximum temperature (29.7 ºC) is recorded in August while the minimum value (8.4 °C) is recorded in January. The mean annual rate maximum temperature is 25 °C. According to the climatological normal of Egypt (2000) the average rainfall is just about 137 mm/year. It comes in short periods between October and March and the rest of the year from April to September is almost dry. The maximum monthly rainfall reaches 33.2 mm in January. On the other hand, the maximum value of relative humidity is recorded in July and August (73.0%). The minimum relative humidity is recorded in April (61.0%).

Prevailing wind direction is mainly northwest during most of the year. Surface wind velocity varies from 8.1 to 11.9 km/h. Evaporation data indicate that the lowest value is 2.7 mm/day recorded in January, while the highest value is noticed in July and June (5.9 mm/day). As mentioned by Abbas *et al.*, 2008, El-Bayomi, 2009 and Yousif and Bubenzer, 2012, the area was classified into beaches, coastal dunes, coastal ridge, coastal depressions, lagoons, salt marshes and lakes, inland dunes, inland depressions, inland ridges, piedmont plain and structural plateau landforms

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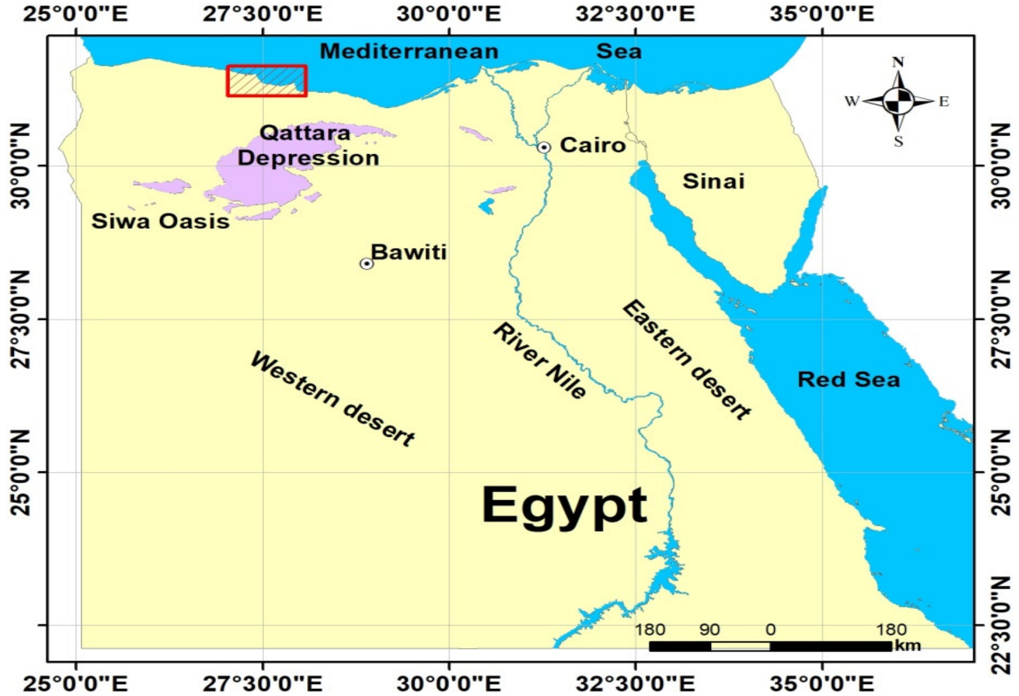

Fig. 1: Location of the study area (red box)

Shuttle Radar Topography Mission (SRTM)

Digital Elevation Model is a 3D electronic model of the land surfaces that offers a better implementation than the topographic maps (Brough, 1986). The Shuttle Radar Topography Mission (SRTM) is one of the most significant space surveys of earth ever assumed that it could be used to provide improved image of the terrain (Lee *et al.*, 1988). The Digital Elevation Model (DEM) of the study areas were produced from the SRTM image using Arc-GIS 10.4 software. A DEM can be employed to offer varieties of data that can assist in investigating the soils and water in dry enclosed basins. The DEM of SRTM was processed to automatically extract the drainage networks and sub-catchment boundary of the study area. The used method requires that all the sinks (i.e. local depressions) of the DEM to be filled and raised in elevation to their neighbouring cells in order to ensure the flow continuity within the catchment to an outlet. The filling step of the DEM does not distinguish between naturally occurring sinks (i.e. playas), which is the case in the study areas. The main playas dotting the area were delineated by visual interpretation of satellite images and their relative low elevations to surrounding were assessed using the available SRTM DEM. Some low surface areas (i.e. playas) are covered in parts by sand sheets and also cultivated patches. Consequently, the causal drainage network and catchment areas to the different terminal playas have been determined following the subsequent D-8 algorithm routine in Arc-GIS. Figures 2 represents the surface elevation of the study area as derived from SRTM data.

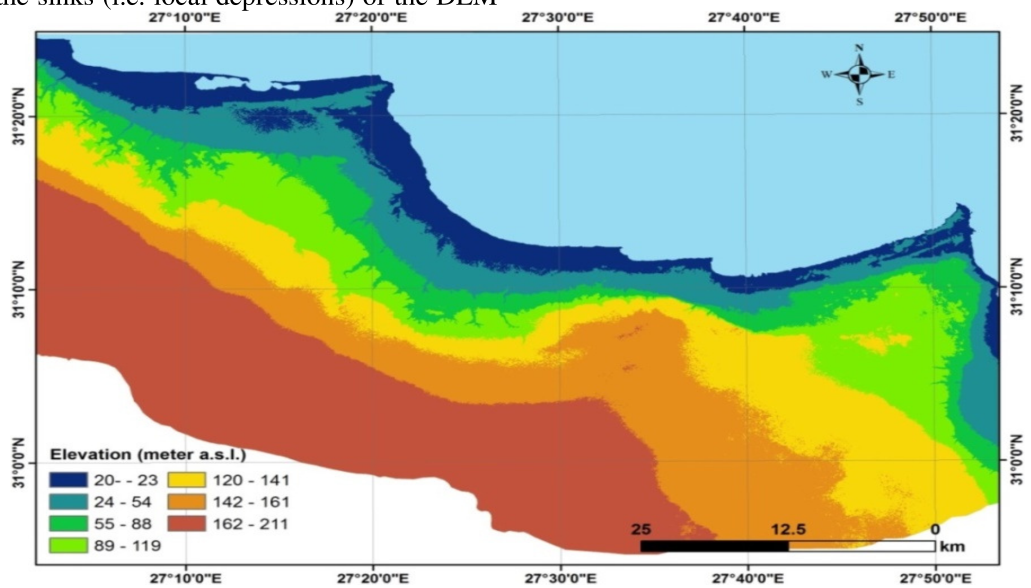

Fig. 2: Digital elevation model of the study area derived from SRTM data

Tropical Rainfall Measuring Mission (TRMM)

The Tropical Rainfall Measuring Mission (TRMM) data were used in this study to estimate the annual rainfall over the study area. The data were used to calculate the water hidden in the different basins in the area. The water quantity stored annually in the basin was estimated in view of the basin area and rainfall (mm) per year.

Field work, Laboratory analyses and Soil taxonomy

A semi detailed survey was carried out on the whole investigated area in order to gain an appreciation on soil patterns, land forms and the landscape characteristics. A total of 25 soil profiles were investigated in the field as shown in Figure 3. The morphological description of the profiles was carried out using the guidelines outlined by FAO (2006). Representative soil samples (85 samples) from different soil layers were collected for laboratorial analyses. The collected soil samples were air-dried, ground and sieved through a 2 mm stainless steel sieve then the laboratory analyses were executed using the procedure described by USDA (2004). The different soils were classified according to the American soil taxonomy (USDA 2010) using field work, laboratory analyses and climatic data

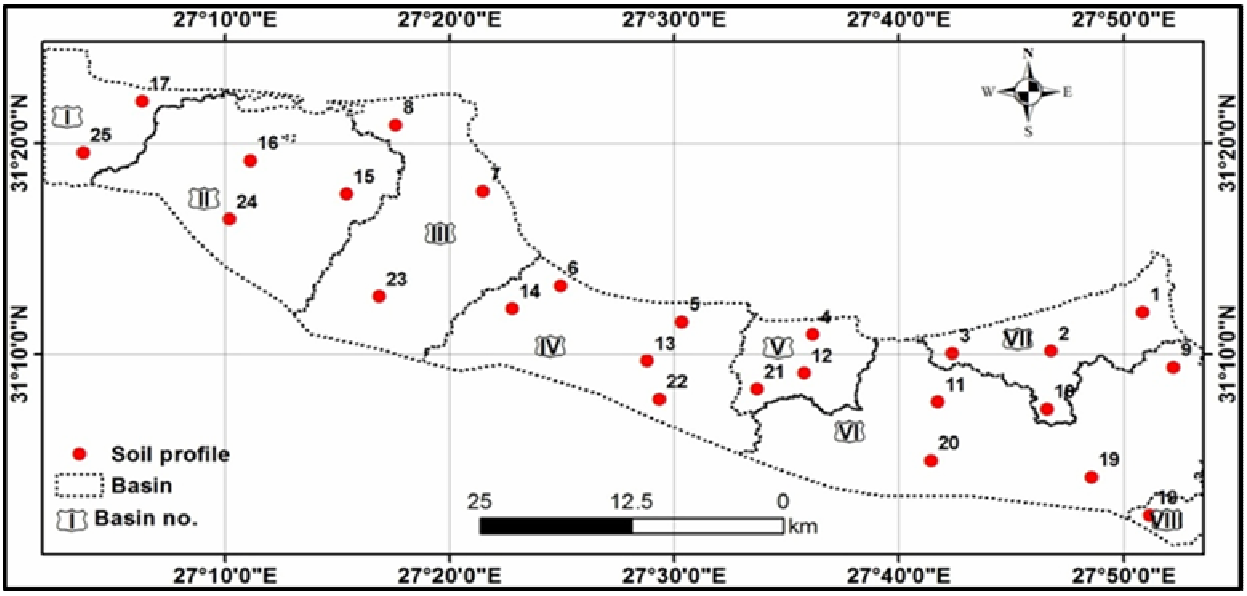

Fig. 3: Representative soil profiles plotted over the drainage basins

GIS applications

Arc GIS version 10.3 was used to delineate the catchment basins and drainage network; the spatial analyst technique was performed for this purpose using the SRTM data.

Land capability classification

Land capability classification was completed using the method detailed by Sys, *et al.* (1991); this method depends on the land characteristics of the different drainage basins in the study area.

Results and Discussion

Catchment areas and drainage orders

The surface topography in the study area controls the water movement and drives it towards the Mediterranean Sea. The investigated area was divided into 8 drainage basins or catchment areas (Figure 4). All these catchment areas are limited by the coastal line of Mediterranean Sea. The area of each basin widely varied from 17.68 sq km for the basin VIII to 336.44sq km for the basin VI as illustrated in Table 1. Drainage basins are placed in 5 orders that slightly directed to the sea, and so, the flash flood hazard is not expected in this area.

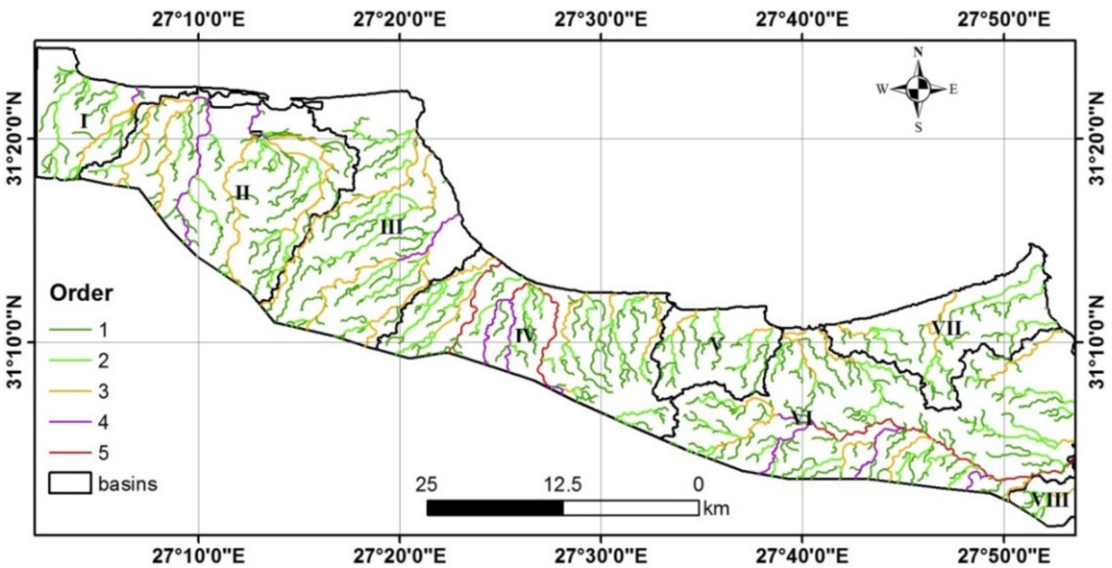

Fig. 4: The catchment areas and drainage orders in the studied area

Table 1: Numbers and areas of the derived drainage basins

Basin no.	Area (km2)	Area (Feddans)	Area (%)
I	77.37	18453.26	6.15
II	227.31	54214.22	18.08
III	219.51	52352.05	17.46
IV	202.01	48179.05	16.07
V	67.40	16074.90	5.36
VI	336.44	80241.74	26.76
VII	109.62	26144.29	8.72
VIII	17.68	4216.78	1.41
Total	1257.34	299876.29	100.00

Note: 1 feddan= 4200 m^2

The soils of catchment areas

Basin I : This basin is extended to cover an area of 77.37 sq km representing 6.15% which is mainly located in the coastal plain and Pediment landforms. The morphological description indicates that the soil depth in this basin differs from 110 to 120 cm. The soil color varied from very pale brown; light yellowish to yellowish brown in the successive layers of the investigated profiles. The soil texture is sandy loam while the structure is weak to medium sub-angular blocky. The lab analyses of these soils indicate that the organic matter content is low in all layers of the soil profiles as it ranges from 0.1-1.3 %. The soil pH values differ from 7.7 to 8. The calcium carbonate content (CaCO3 %) in the basin is in general high as it ranges from 15.2 % to 36.8%. Cation exchange capacity (CEC) widely varies in the studied profiles as it changed from 3.8 to 14.40 cmol/kg. The Electrical Conductivity (EC) ranges from 1.6 to 8.4 dS/m. The soils of basin I are classified as *Typic Torripsamments*.

Basin II : With an area of 227.31sq km representing 18.08% of the total investigated area. It is mainly located in the landforms of coastal and pediment. The soil color differs from light brown to very pale brown, strong brown, reddish brown and brown. The texture of basin II soils is sandy loam to sandy clay loam. The soil depth varies from 80 to120 cm while the soil structure in general is massive and changes in few cases to be weak sub-angular blocky. Organic matter ranges from 0.2% to 1.3%. The values of soil pH differ from 7.6 to 8. Calcium carbonate percent ($CaCO_3$ %) varies from 14.6% to 31.2 %.Cation exchange capacity (CEC) is located in the range (3.10 to 8.10) cmol/kg. The electrical conductivity (EC) ranges from 1.4 to 5.4 dS/m. The soils of basin II are classified as *Typic Torripsamments*.

Basin III : This basin inhabits an area of 219.51 km^2; it is mainly located in the coastal plain and partially in the Pediment plain. The soil color differs from brownish yellow, brownish yellow, to light yellowish brown. The texture of the soils is sandy loam to sandy clay loam. The soil depth varies from30 to100 cm. The soil structure is massive in all successive layers of the investigated soils of this basin.The organic matter values are differing from 0.2% to 0.9%. The values of soil pH range from 7.8 to 8.2. Calcium carbonate percent ($CaCO_3$ %) ranges from 15.4% to 35.4%. Cation exchange capacity (CEC) values are low as it not exceeds 4.6 cmol/kg; the electrical conductivity (EC) values range from 1.6 to 4.4dS/m. The soils of basin III are classified as *Typic Torripsamments*.

Basin IV : This basin has gently undulating to undulating topography. This landform occupies an area of 202.01 km^2 (48179.05 Feddans) representing 16.07 % of the total investigated area. It is mainly located in the coastal plain and landforms. The color of these soils differs from yellow and very pale brown, strong brown, light yellowish to reddish yellow. The texture of the soils varies from sandy loam and sandy clay loam. The soil depth varies from 75 to100 cm; the soil structure in general is massive in the different layers; in few cases it changes to be weak medium sub-angular blocky. The organic matter content ranges from 0.3% to 1.2%. The values of soil pH range from 7.7 to 8.1. Calcium carbonate content ($CaCO_3$ %) values range from 11.9% to 71.5 %. Cation exchange capacity (CEC) values range from 4.40 to 23.04 Cmol/kg. The electrical conductivity (EC) values range from 1.2 to 7.1dS/m. The soils of basin IV are classified as *Typic Torripsamments* and *Typic Haplocalcids*.

Basin V : This basin has almost flatto undulating topography. It occupies 67.40km^2 (16074.90 Feddans) representing 5.36% of the total area. It is mainly located in the coastal plain and Pediment plain landforms. These soils are characterized by yellow, reddish yellow, brownish yellow and strong brown colors. The texture of the basin soils is sandy loam to sandy clay loam. The soil depth varies from 90 cm to 140 cm. Generally, these soils are considered as massive structure in all successive layers of the studied soil profiles. Organic matter content ranges from 0.2 to 1.1%. The values of soil pH range from 7.8 to 8.3. The calcium carbonate ($CaCO_3$ %) values range from 10.8 % to 44.3 %. Values of Cation exchange capacity (CEC) values are low as it not exceed13.82 Cmol/kg. The electrical conductivity (EC) values range from (1.5 to 9.6dS/m). The soils of basin V are classified as *Typic Torriorthents*.

Basin VI : This basin is extended to cover an area of 336.44sq km (i.e. 80241.74Feddans). It is mainly located in the coastal plain and Pediment plain landforms. The morphological description indicates that the soil depth in this basin differs from 50 to 130 cm. The soil color varies from reddish and strong brown to light yellow in the successive layers of the investigated profiles. The soil texture is sandy loam to sandy clay loam, while the structure is weak to medium sub-angular blocky. The detailed soil morphology of the soils in basin VI is represented in appendix no. I. The lab analyses of these soils indicate that the organic matter content is low in all layers of the soil profiles as it ranges from 0.3 to1.1 %. The soil pH values are differing from 7.6 to 8.2 the calcium carbonate content (CaCO3 %) in the basin VI is in general high as it ranges from 11.9 %to44.6%. Cation exchange capacity (CEC) is widely differing in the studied profiles as it changed from 4.70 to 12.60 Cmol/kg. The Electrical Conductivity (EC) values range from 1.5to 7.1dS/m. The soils of basin VI are classified as *Typic Torrifluvents.*

Basin VII : The basin VII landscape occupies the eastern parts of the investigated area; the basin is rather almost flat topography. It occupies 109.62km^2 (i.e. 26144.29Feddans) representing 8.72% of the total area. It is mainly located in the coastal plain landforms. The soil color differs from very pale brown to yellow. The soil texture is sandy loam; the soil depth varies from 60 cm to 90 cm. Generally, these soils are considered as massive structure in all successive layers of the studied soil profiles. The organic matter content is low in all layers of the soil profiles as it ranges from 0.3 to 0.8 %. The soil pH values are differing from 7.9 to 8.3. The calcium carbonate content ($CaCO_3$ %) content ranges from 11.4 % to 52.3 %. Cation exchange capacity (CEC) is widely differing in the studied profiles as it changed from 3.78 to 13.46 Cmol/kg. The Electrical Conductivity (EC) values range from 1.0 to 67.7 dS/m. The soils of basin VII are classified as *Typic Torrifluvents*.

Basin VIII : With an area of 17.68sq km (i.e. 4216.78Feddans) representing 1.41% of the total investigated area. It is mainly located in the coastal plain landforms. The basin VIII landscape occupies the eastern parts of the investigated area. The soil color differs from light yellowish to brownish yellow. The texture of basin VIII soils is sandy loam. The soil depth 110 cm the soil structure is massive in the different layers. The soil structure is massive in the surface layers, while it changed to single grains in the subsurface layers. Organic matter ranges from 0.3 % to 1.1%. The values of soil pH range from 7.9 to 8.0 Calcium carbonate ($CaCO_3$ %) content ranges from 20.4% to 28.3 %. Cation exchange capacity (CEC) values are located between 12.10 and 13.20 Cmol/kg. The electrical conductivity (EC) values range from 1.4 to 5.4 dS/m. The soils of basin VIII are classified as *Typic Torripsamments*.

Water resources in the catchment basins

Water shortage is the main constrain facing the agriculture sector in Egypt, especially in the northwestern coast, where the rain-fall is the main source of water. The mean daily rain-fall over the area is represented in Figure 5. Tis data were extracted from the Tropical Rain-fall Measuring Mission (RMM) data (NASA, 2019). The obtained data indicated that the daily rain-fall in the area ranges between 0.1 to 0.9 mm/day. The high amount of rain-fall is found to the south of Mersa Matrouh area. It is noticed that the front of the plateau areas are characterized by high rain-fall rate. The accumulated rain-fall during 1999 to 2017 is illustrated in Figure 6. The data indicated that the high values of rain-fall (5500.4 mm/ 18 years) are associated with the western parts of the investigated area, while low values (3287.36 mm / 18 years) characterize the rest of the study area. Considering the catchment areas and the annual rain-fall rate, the water volume and cultivated areas in each basin were calculated (Table 2). The obtained data revealed that the area is characterized by rain-fall rate of 236.34 mm / year. This indicated that the total water volume received over the investigated area is 306368063 m^3, thus the areas that could be cultivated is almost equal 76592.02 feddans i.e. 25.6% of the total area.

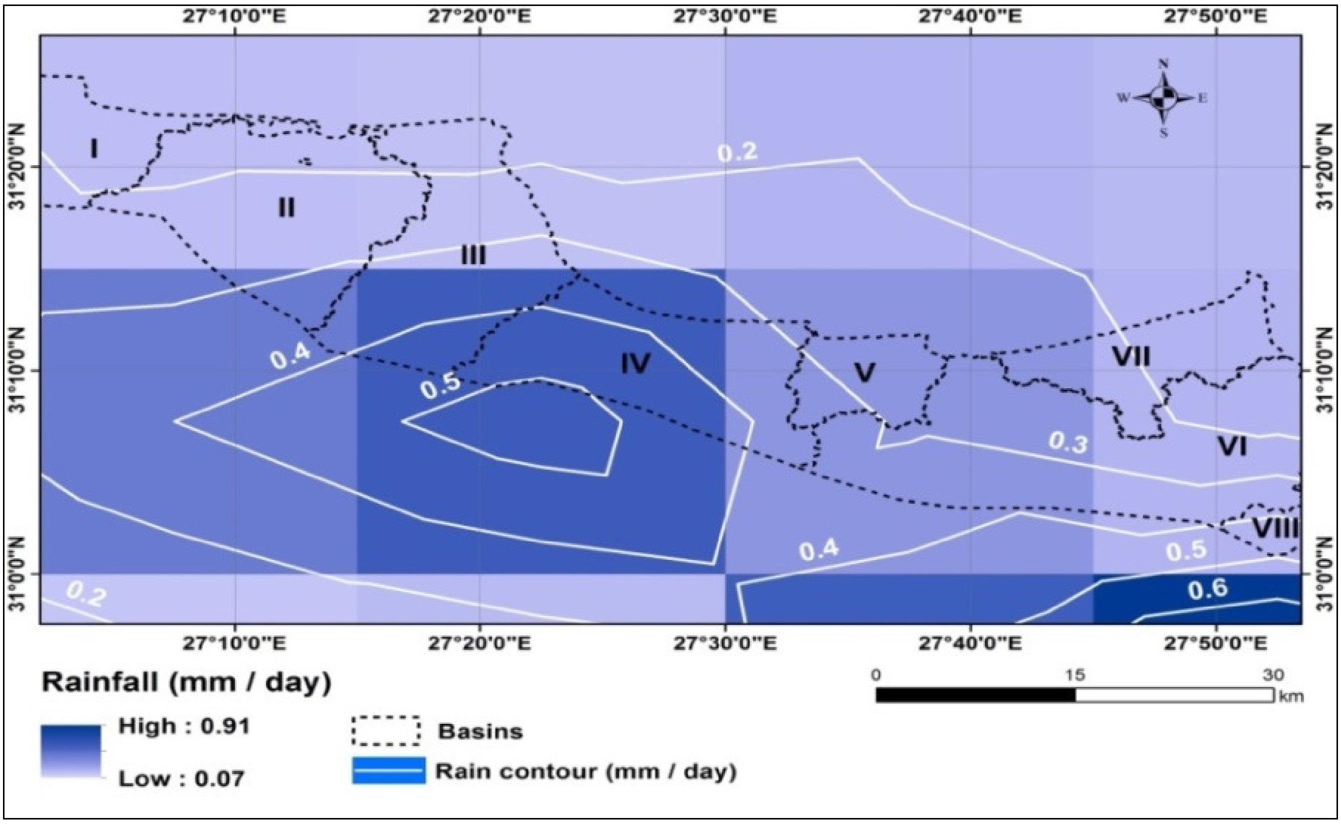

Fig. 5: Mean daily rain-fall over the investigated area (Source: NASA, 2019).

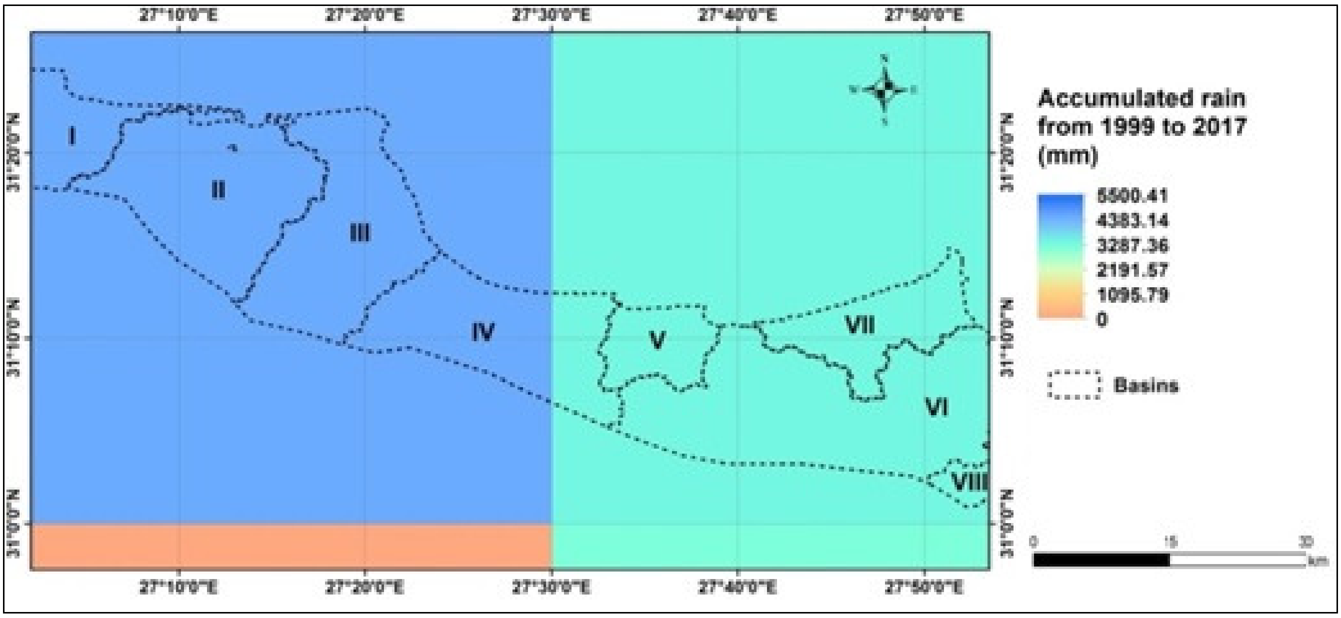

Fig. 6: Accumulated rain-fall over the investigated area from 1999 to 2017 (Source: NASA, 2017)

Table 2: Areas, annual rainfall, water volume and land to be cultivated in the different basins

Basin No.	Catchment area (km2)	Annual rainfall (mm)	Water volume (m^3)	Area to be cultivated	
				(Feddans)	(%)
I	77.37	305.6	23644272	5911.068	32.1
II	227.31	305.6	69465936	17366.48	32.1
III	219.51	305.6	67082256	16770.56	32.1
IV	202.01	243.5	49189435	12297.36	25.6
V	67.40	182.6	12307240	3076.81	19.2
VI	336.44	182.6	61433944	15358.49	19.2
VII	109.62	182.6	20016612	5004.153	19.2
VIII	17.68	182.6	3228368	807.092	19.2
	1257.34	236.34	306368063	76592.02	25.6

Water volume (m^3) = catchment area (m^2) × rainfall (m)**;** Area to be cultivated = water volume (m^3) / 4000, where 4000 is the average of water required to cultivate 1 feddan per year

Land capability classes

Evaluating of capability is an essential stage for future practical use. The land capability classes were assessed using the soil characteristics illustrated in Table 3. The data in Table 4 and Figure 7 represent the areas of each capability class in the different catchment basin. The data indicate that basin No. I include the soils of high (189.36 feddans) and moderate (18080.09 feddans) capability. As previously mentioned, the annual water quantity stored in this basin is 23644272 m^3 that is sufficient to cultivate a total of 5911.06 feddans, this means that 32.1 % of the basin area could be cultivated. These soils are located under class I and II. Regarding to basin No. II, the dominant capability classes are class I, II and III, while the water budget reaches to 69465936 m^3 that is adequate to cultivate only an area of 17366.48 feddans. In this respect, available water should be directed to cultivate the soils of high capability class. In basin No. III all capability classes are found including class I (1176.94 feddns), class II (26845.42 feddans), class III (20288.63 feddans) and class IV (52151.77 feddans). Water quantity in this basin is 67082256 m^3, which is typically enough to irrigate a total of 16770.56 feddans. The available water should be fixed to irrigate the soils of class I and II. The data obtained for basin No. IV indicates that the soils are prevailed by four capability classes (i.e. I, II, III and IV). Class I and II represent 29010.07 feddans i.e. 60.41 %. In view of water resources in this basin, the water quantity is 49189435 m^3 that is suitable to irrigate 12297.36 feddans; all of these areas include only class I and II. Results indicate that basin No. V includes all land capability classes, where class I and II represent more than 70% (11368.89 feddans) of the basin area. The annual water stored in this basin (12307240 m^3) is suitable for irrigating a total of 3076.81 feddans. Water in this basin is very limited therefore, it is recommended to cultivate only the soils of high and moderate capability clsses. In basin No. VI, the area is dominated by capability classes I (7.88 %), class II (41.08 %), class III (45.15 %) and class IV (5.89 %). Water quantity cached in this basin is adequate to cultivate a total of 15358.49 feddans. In basin No. VII, only class III (42.89 %) and IV (57.11 %) are found. Parts of the areas dominated by class III could be cultivated where the quantity of available water in this basin is sufficient to irrigate about 5004.15 feddans. In basin No. VIII only soil capability of class II is found (4099.03 feddans). The water quantity stored in this basin is satisfactory to cultivate a total of 807.09 feddans. The water in this basin could be used to irrigate only 19.2 % of basin No. VIII.

Table 3: Range of some soil chemical and physical characteristics of the studied basins

Basin No	pH 1:2.5	EC_e dS/m	$CaCO_3$ (%)	CEC Cmol/kg	O.M %	Soil depth	Texture*
I	7.7-8.0	1.6-8.4	15.2-36.8	3.8-14.20	0.1-1.3	110-120	SL
II	7.6-8.0	1.4-5.4	14.6-71.2	3.10-8.10	0.2-1.3	100-120	SL-SCL
III	7.8-8.1	1.4-4.4	15.4-35.7	3.45-6.6	0.2-0.9	30-100	SL-SCL
IV	7.7-8.1	1.2-7.1	11.9-71.5	4.40-23.04	0.2-1.1	75-100	S-SCL
V	7.8-8.7	1.5-9.6	11.4-44.3	3.87-13.82	0.2-1.1	90-140	SL-SCL
VI	7.6-8.2	1.5-7.1	11.9-46.3	5.03-12.60	0.3-1.1	75-130	SL-SCL
VII	7.9-8.3	1.0-67.7	11.4-52.3	3.75-13.46	0.3-0.8	60-90	S-SCL
VIII	7.9-8	1.2-3.2	20.4-28.3	12.10-13.20	0.3-1.1	110	SL

*S: sandy; SL: sandy loam; SCL= sandy clay loam

Table 4: Areas of each land capability class over the investigated catchment

Basin No.	Capability class							
	High(I)		Moderate (II)		Marginal (III)		Non-capable (IV)	
	Fadden	%	Fadden	%	Fadden	%	Fadden	%
I	189.36	1.04	18080.09	98.96	0.00	0.00	0.00	0.00
II	2642.70	4.89	49031.47	90.71	2377.87	4.40	0.00	0.00
III	1176.94	2.26	26845.42	51.48	20288.63	38.90	52151.77	7.36
IV	272.07	0.57	28738.02	59.84	17510.07	36.46	1504.03	3.13
V	93.55	0.58	11275.34	70.38	4652.13	29.04	0.00	0.00
VI	6294.12	7.88	32804.32	41.08	36051.54	45.15	4702.37	5.89
VII	0.00	0.00	0.00	0.00	11139.37	42.89	14834.11	57.11
VIII	0.00	0.00	4099.03	100	0.00	0.00	0.00	0.00

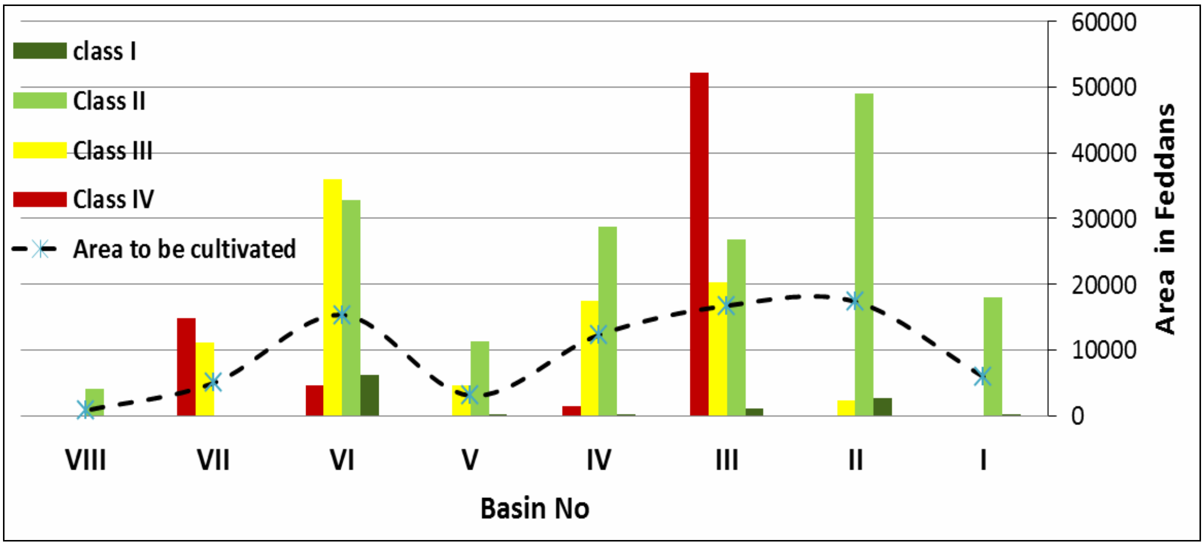

Fig. 7: Land capability classes and areas to be cultivated in the different catchment basins

Conclusion

The land resources in catchment basins of the northwestern coast of Egypt were investigated by using remote sensing data and GIS techniques. The area is dominated by 8 main basins. The soil and water resources were assessed in each basin. The highly capable soils occupy about 3.56% of the studied basins, while moderately capable soils exhibit 57.28% of the area. The marginally and non-suitable soils dominate 30.83 and 8.33% of the studied area respectively. The total water quantity annually stored in the catchment basins is close to 306,000000 m^3 which is sufficient to cultivate about 76,000 feddans (25.6 %) of the total area. In general, water in the different basins is very limited, so it is recommended to cultivate the soils of high and moderate capabilities.

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