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# INFLUENCE OF IRRIGATION WATER QUANTITY ON THE LAND CAPABILITY CLASSIFICATION

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## Abstract

The assessment of land capability is an important issue for adequate land use planning, especially under arid climate types. El-Fayoum depression (central Egypt) offers a great potential for irrigated agriculture, covering an area of 1776 km$^2$. A submodel of the MicroLEIS Decision Support System, Cervatana model has been used to evaluate the general land use capability or suitability for specific agricultural uses, including topography (t), soil properties (l), erosion risk (r) and bioclimatic deficiency (b) as input variables. For each specific soil and crop, results are grouped in four classes: S1-optimum, S2-good, S3-moderate and N-marginal. Graphical outputs were processes to present the biophysical information of the studied area using Geographic Information System (GIS) tools. Land capability has been analysed under four different management scenarios: irrigation conditions using [i] $2.6\times10^6$, [ii]$19.5\times10^6$ and [iii] $13.0\times10^6$ m$^3$ annual water inputs (respectively, 100, 75 and 50% of the total irrigation water volume entering El-Fyoum depression), and [iv] rainfed conditions, with 11.3 mm/year. In the hypothetical irrigation scenarios [i] and [ii], most of the study area, including Vertic Torrifluvents and Typic Haplogypsids, was classified as S2. Marginal class only includes a small area adjacent to Qarun lake (Typic Haplosalids). Decreasing irrigation water with 25% does not have a negative effect on land capability and, consequently, on crop production. This is important, taking into account that the amount of irrigation water inputs in the study area is considered excessive. Reduction of irrigation water to 50% leads to a decrease in land capability, decreasing yields to 27% (maize), 21% (cotton) and 15% (sunflower). Major changes after reduction of irrigation by 50% are expected in Typic Haplocalcids, Torripsamments and Typic Haplosalids. Finally, all soil units were classified as marginal under rainfed conditions. These results contribute to the assessment of land capability under different management scenarios and allow for better management planning and land use in El-Fayoum depression.

***Keywords***: Land evaluation; land use change; Irrigation, Nile River, USDA soil classification

## Introduction

World population has almost doubled in the last sixty years, particularly in the poorest countries (Bongaarts and Sinding, 2011), leading to a very high demand of food. Increasing food production and supporting civil and engineering structures have been the principal foci of soil science research during the 20th century and, at a global scale, the main challenge of current agriculture is to increase food supply for intensely growing world population (Davidson, 1992; Lal, 2008).Technical innovation has contributed to sharply increase agricultural production through the 20th century (Youngberg and DeMuth, 2013). To overcome this challenge, three general approaches are recommended: [i] to protect soil from degradation processes such as erosion and contamination; [ii] to improve land capability and the intensification of agricultural production; and [iii] the exploration of new productive areas to increase agricultural production (Branca *et al*., 2013; Lal, 2008; Lal 2013). In arid land, the use of modern techniques for water irrigation management is one of the most important ingredients to increase the productivity of agricultural crops in the present time, under diverse land use and different irrigation quantity (Mansour et al 2019a,b,c,d; Eldardiry *et al*., 2015; El-Hagarey *et al*., 2015, Goyal and Mansour 2015; Ibrahim *et al*., 2018; Mansour 2015). Using simulation models techniques aims to improve the management of water irrigation systems specially under the scarcity of water in the dry climate condition (Mansour *et al*., 2014, 2015a-e; Tayel *et al*., 2012a,b, 2015, 2016, 2018, 2019; Mansour and Aljughaiman 2012, 2015, Mansour and El-Melhem 2012, 2015 and Attia *et al*., 2019).

Land evaluation is a key tool for adequate and rational land use planning and the sustainable use of natural resources (Sonneveld *et al*., 2010). Land evaluation may be defined as “the process of assessment of land performance when used for specified purposes, involving the execution and interpretation of surveys and studies of land use, vegetation, landforms, soils, climate and other aspects of land in order to identify and make a comparison of promising kinds of land use in terms applicable to the objectives of the evaluation” (FAO, 1976), or “the selection of suitable land, and suitable cropping, irrigation and management alternatives that are physically and financially practicable and economically viable” (FAO, 1985). According to De la Rosa (2005), land evaluation tries to predict land behaviour for each specific use, in contrast to soil-quality assessment, as soil biological parameters are not considered by land evaluation. Land evaluation predicts land performance, both in terms of the expected benefits from and constrains to productive land use, as well as the expected environmental degradation due to these uses.

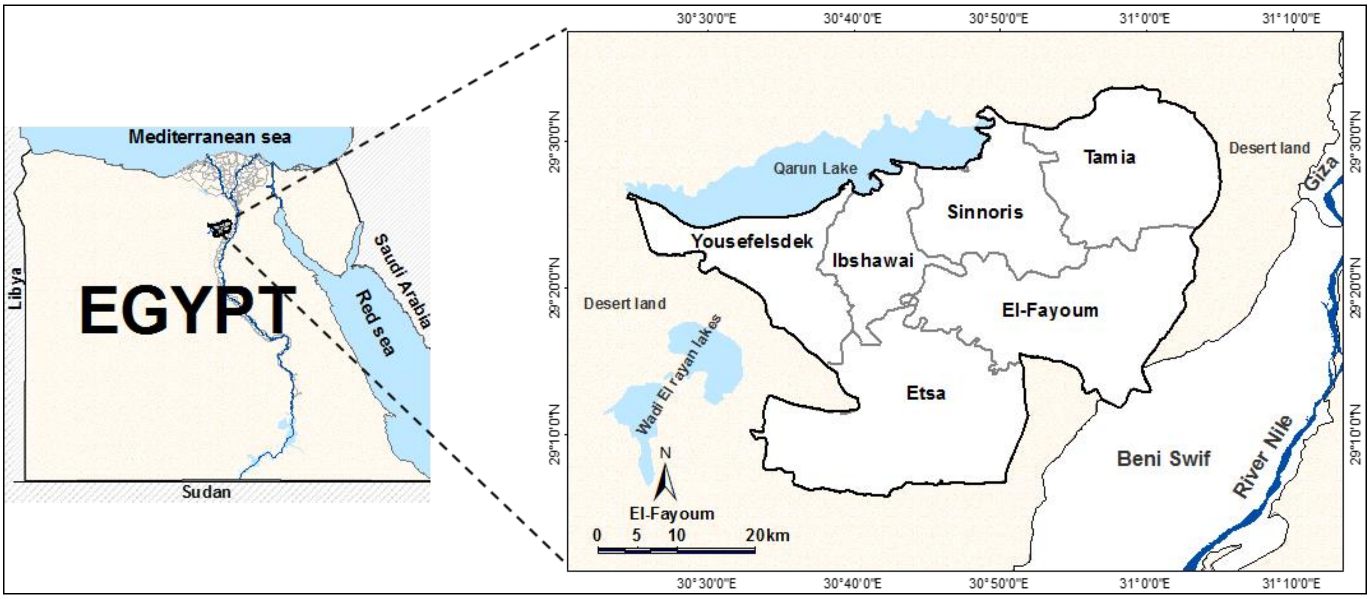

**Fig. 1 :** El-Fayoum depression is darkened on the map of Egypt, and its administrative boundaries are indicated in the enlarged image.

The assessment of land capability helps to foreknow if the choice of an area for a specific use contributes to success or failure. Consequently, the assessment of land capability is necessary in order to make the best use of land and to minimize potential negative impacts (Singer, 2002). This is especially important in the context of arid land and global change. Agricultural production under climate change scenarios is undergoing sustainability challenges due to degradation of soil fertility, water and biodiversity resources (Carsan *et al*., 2014).

The agro ecological MicroLEIS decision support system (DSS) was developed to help decision-makers to solve specific agro-ecological problems. It has been designed as a knowledge-based approach, which incorporates a set of inter-related tools and three databases (De la Rosa *et al*., 2002; Munoz-Rojas *et al*., 2012): soil (SDBm), climate (CDBm) and agricultural uses and management (MDBm). Thus, custom applications can be performed on a wide variety of problems related to land productivity and land degradation (Abd-Elmabod *et al*., 2012; Anaya-Romero *et al*., 2011; Muñoz-Rojas, 2011). The methodology proposed by MicroLEIS DSS aims to investigate the impact of new scenarios such as land use changes, soil management and global change on land potentialities and vulnerabilities (Muñoz-Rojas *et al*., 2013; Shahbazi *et al*., 2010; Anaya-Romero *et al*., 2015; Muñoz-Rojas *et al*., 2015; Abd-Elmabod *et al*., 2017; Abd-Elmabod *et al.* 2019a; Abd-Elmabod *et al*., 2019 b). The MicroLEIS DSS models are described in detail by De la Rosa (2004), De la Rosa et al. (1981, 1992, 1993, 1999), Farroni et al. (2002), Horn et al. (2002) and Sánchez *et al*. (1982).

Egypt faces a severe limitation of available agricultural land. This is further hindered by the scarcity and quality of irrigation water and suitable soils in semiarid and arid areas (Muñoz-Rojas *et al*., 2017; Abbas *et al*., 2019). Restriction of arable land due to soil salinity and expansion of urban areas over previously productive soils has led to expansion of agriculture to desert and coastal regions. In addition, although water availability and irrigation in the Blue Nile river basin are currently challenged by increasing population, economic development and water demands (Awulachew *et al*., 2012), it has been suggested that the construction of planned mega dams in the area may affect river regimes, livelihoods and human health (Ali *et al*., 2014). In order to shed light on the investigation about impacts of irrigation changes in El-Fayoum area, the main objective of this research is to evaluate the impact of different water supply rates: 2.6 × $10^6$ $m^3$ (100% of current irrigation rate), 19.5 × $10^6$ $m^3$ (75%), and 13.0 × $10^6$ $m^3$ (50%) in an arid area of El-Fayoum (Egypt).

## Material and Methods

### *Study area*

El-Fayoum depression (northern Egypt) is located a 90 km from Cairo and includes six districts with a total area of 1776 $km^2$, between $29^o02'$ – $29^o35'$ N and $30^o23'$ – $31^o05'$ E (Fig. 1 :). The area is a natural endorheic depression on a limestone plateau (Eocene). It offers a great potential for agriculture due to water supply from Bahr Yousef river, a tributary of Nile.

Soil temperature regime is Hyperthermic. Mean annual temperature is 22 $^oC$ and the difference between mean summer and mean winter temperature is above 5 $^oC$. Annual rainfall ranges from 8 to 11 mm, mostly concentrated between December and March. In contrast, potential evapotranspiration ranges from 3.1 to 10.3 mm/day, 6.8 mm/day on average (data by courtesy of the Climatological Survey Department of El- Fayoum Governorate).

El-Fayoum depression spreads over a marine sedimentary basin which has undergone alternating periods of erosion and deposition since the late Cretaceous period (Klitzsch et al., 1988). Most of the study area distributes through silt formations and small patches of limestone, gravels and sand dunes (Fig. 2 :). Elevation ranges from -53

(Qarum Lake, in the northern part of the study area) and 120 masl (eastern part).

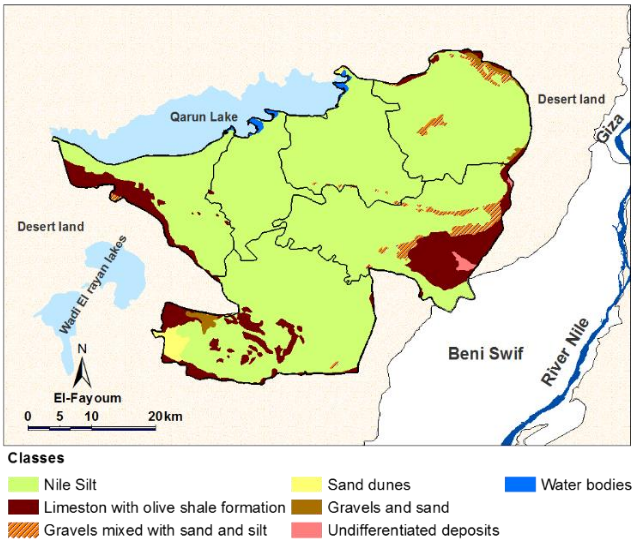

**Fig. 2 :** Lithological map of El-Fayoum.

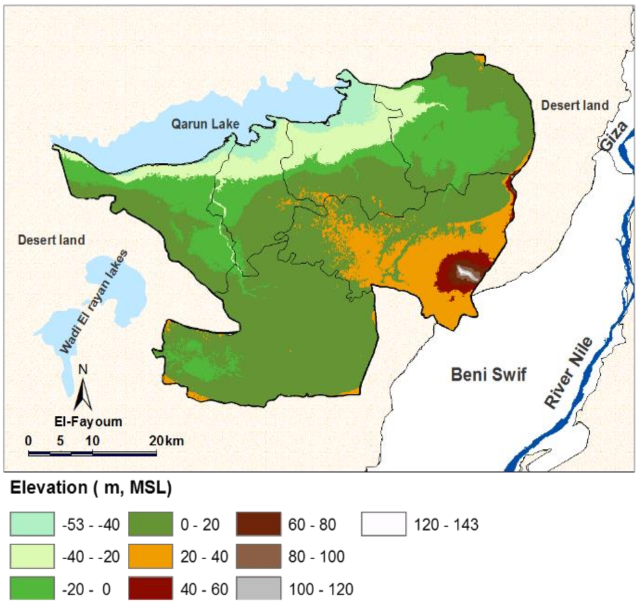

**Fig. 3 :** Elevation map of El-Fayoum.

### *Soil data*

Main soil types in El-Fayoum are shown in Fig. 5 :. Vertic Torrifluvent is the dominant soil subgroup, covering an area of 760 km$^2$ (42.79% of the study area). Other important subgroups are Typic Haplocalcids (421 km$^2$, 23.70%) and Typic Torrifluvents (141 km$^2$, 7.94%). The rest of soil subgroups (Typic Haplogypsids, Typic Haplosalids and Typic Torripsamments) are found in small marginal areas (11.45%). Six soil profiles, representative of the study area, were selected for this research (**Error! Reference source not found.**): Vertic Torrifluvents, Typic Haplocalcids, Typic Torrifluvents, Typic Haplogypsids, Typic Haplosalids, Typic Torripsamments, as described by Haroun (2004) and Ali (2005). Site information, morphological description and detailes physical and chemical data from selected soil profiles were included in the SDBm, processed and used as input variables in the model (Abd-Elmabod *et al*., 2010).

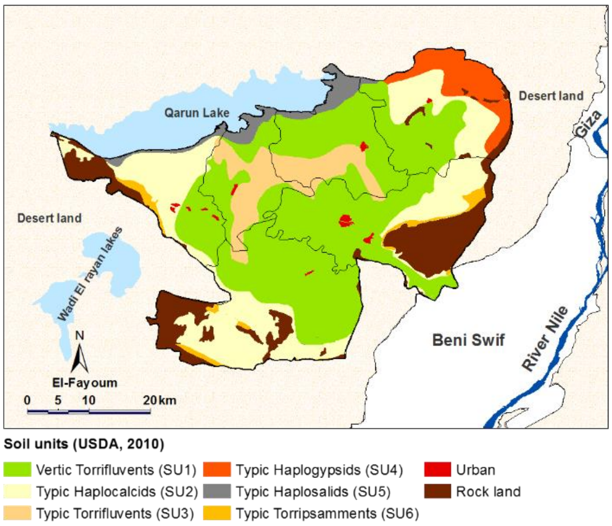

**Fig. 5 :** Soil map of El-Fayoum. (ASRT, 2009)

**Table 1 :** Classification of selected soil profiles (Soil Survey Staff, 2010) and corresponding area.

| Soil profile | Soil subgroup | Area (km$^2$) | Source |
|---|---|---|---|
| FA-H19 | Vertic Torrifluvents | 760 | Haroun (2004) |
| FA-H05 | Typic Haplocalcids | 421 | Haroun (2004) |
| FA-H07 | Typic Torrifluvents | 141 | Haroun (2004) |
| FA-A13 | Typic Haplogypsids | 87 | Ali (2005) |
| FA-H08 | Typic Haplosalids | 58 | Haroun (2004) |
| FA-H15 | Typic Torripsamments | 26 | Haroun (2004) |

### *Climate and irrigation data*

Climatic data (monthly mean temperature, maximum mean monthly temperature, minimum mean monthly temperature and monthly mean rainfall) between 1962 and 2006 are shown in Table 2 :. Data were collected from El-Fayoum weather station and integrated into the CDBm database for processing and computing. Irrigation data and water supply from the Nile River (via Elahoun and Hassan Wasef) were provided by the Directorate of Irrigation in El-Fayoum. On average, total water supply of the Nile River to El-Fayoum depression is 2.64 $\times 10^9$ m$^3$/year (1990-2006).

**Table 2 :** Monthly mean temperature (Tm, °C), maximum mean monthly temperature (Tmax, °C), minimum mean monthly temperature (Tmin, °C), monthly mean rainfall (Rm, mm) between 1962 and 2006 and monthly mean irrigation water (Im, $\times 10^3$ m$^3$) between 1990 and 2006.

| Month | Tm | Tmax | Tmin | Rm | Im |
|---|---|---|---|---|---|
| January | 12.8 | 20.3 | 6.2 | 1.7 | 79 |
| February | 14.3 | 22.1 | 7.1 | 2.0 | 177 |
| March | 17.1 | 25.1 | 9.7 | 4.0 | 215 |
| April | 21.4 | 30.1 | 13.3 | 0.3 | 212 |
| May | 25.3 | 33.7 | 17.0 | 0.1 | 230 |
| June | 28.5 | 37.0 | 20.2 | 0.0 | 274 |
| July | 29.0 | 39.0 | 21.5 | 0.0 | 298 |
| August | 28.9 | 37.0 | 21.7 | 0.0 | 291 |
| September | 26.9 | 34.8 | 20.1 | 0.0 | 249 |
| October | 23.9 | 31.4 | 17.3 | 0.4 | 226 |
| November | 18.9 | 26.4 | 12.6 | 1.2 | 210 |
| December | 14.2 | 21.7 | 7.9 | 1.6 | 182 |
| Mean | 21.8 | 29.9 | 14.6 | 0.9 | 220 |
| **Total** | | | | **11.3** | **2643** |

### *Assessment of land capability*

In order to study agro-ecological responses to restriction of water supply due to planned dams in the Nile catchment, land capability of El-Fayoum was analyzed under three possible scenarios: current scenario (with 100% of current irrigation rate, 2.6 × $10^6$ $m^3$), moderate restriction (75%, 19.5 × $10^6$ $m^3$), and strong restriction (50%, 13.0 × $10^6$ $m^3$, 50%). The fourth scenario represent the assessment of land capability under zero irrigation water from the Nile.

Agroecological assessment was carried out using the Cervatana module of MicroLEIS DSS. MicroLEIS DSS is a decision support system developed to assist decision-makers facing specific agro-ecological problems (De la Rosa *et al*., 2004; Mansour *et al*., 2019). Cervatana module forecasts the general land use capability or suitability for possible agricultural uses. Cervatana computes different groups of variables (bioclimatic deficiency, erosion risk, soil properties and topography; Fig. 6 :) and provides qualitative responses. The four broad classes subsequent from the land capability model are: 1- Optimum class (S1); 2- Good class (S2), 3- Moderate class (S3), 4-Marginal class (N). In the final evaluation outputs, each class (S1 to N) is followed by a letter that indicate the major limiting factors (Topography(t), and/or Soil (l), and/or Erosion risk (r), and/or Bioclimatic deficiency (b))

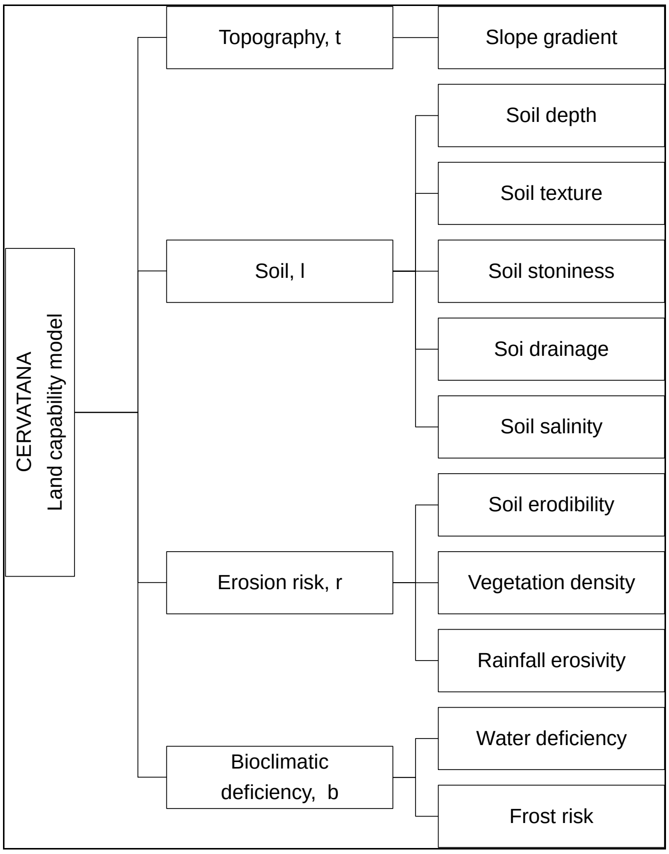

**Fig. 6 :** General scheme of the Cervatana model.

### *Spatial analysis*

Geographical Information System (GIS) was extensively used in evaluating spatial and temporal variation of soil properties (cf. Cemek *et al*., 2007; Mousavifard *et al*., 2013). ArcGIS 10.2 software was used for data manipulation and processing of the land resources database in order to acquire the spatial data output. Terraza and Cervatana models' results have been integrated in GIS software in order to achieve spatial analysis of land capability and yield reduction.

Topography, soil, erosion risk and bioclimatic deficiency geo-data were processed and integrated in a digital model using ArcGIS 10.2 (ESRI, 2013).

## Results and Discussion

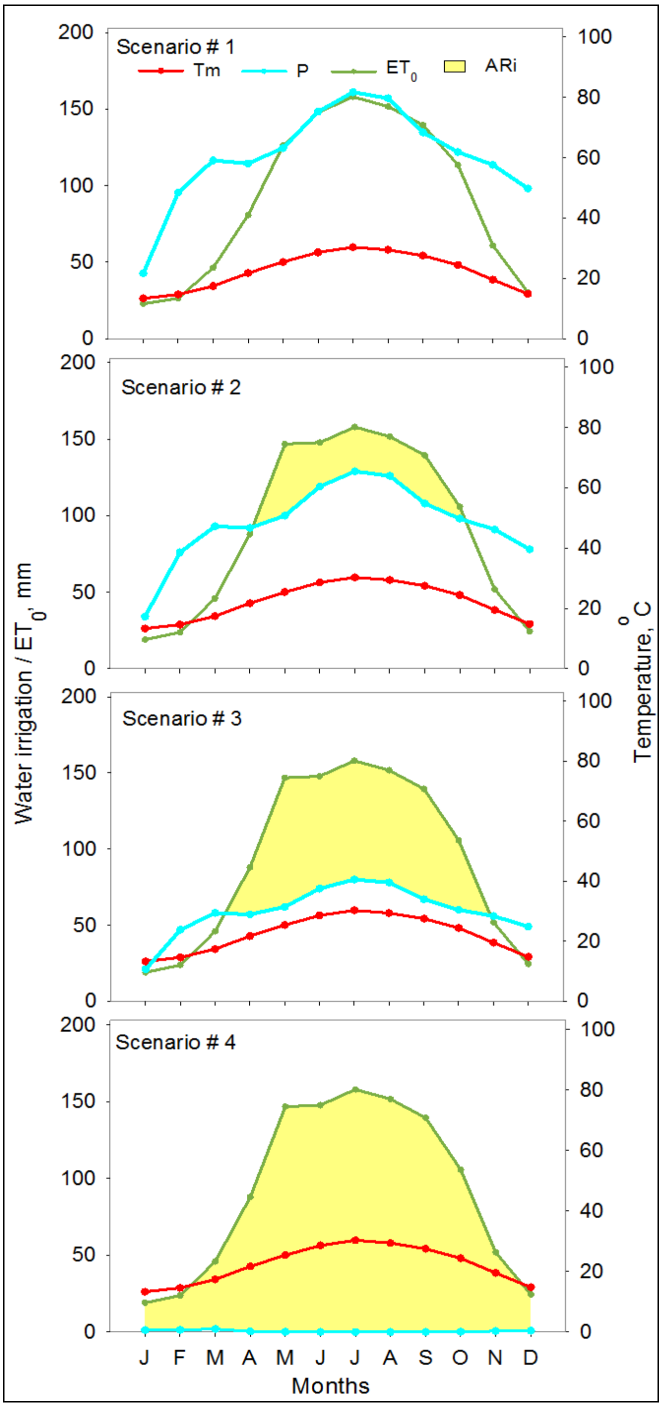

**Fig. 7 :** CDBm output under irrigation scenarios and rainfed scenario. Tm, mean temperature ($^{O}C$); P, irrigation water (mm); $ET_0$ potential evapotranspiration (mm); Ari, aridity index.

The bioclimatic classes are established by combining the classes of water deficiency and frost risk, following the criterion of maximum limitation. Frost risk, according to the criteria of Verheye (1986) adapted for the Mediterranean regions, frost risk is representing the number of months with minimum temperature average below 6 °C (as the complement of the frost-free period).

**Table 3 :** Output results of Terraza model.

| Crops | Bioclimatic deficiency classes | | | |
|---|---|---|---|---|
| | **Scenario # 1** | **Scenario # 2** | **Scenario # 3** | **Scenario # 4** |
| **Wheat** | C1{h1-f1}, (0) | C1{h1-f1}, (0) | C1{h1-f1}, (0) | C4{h4-f1}, (100) |
| **Barley** | C1{h1-f1}, (0) | C1{h1-f1}, (0) | C1{h1-f1}, (0) | C4{h4-f1}, (100) |
| **Maize** | C1{h1-f1}, (0) | C1{h1-f1}, (0) | C2{h2-f1}, (27) | C4{h4-f1}, (100) |
| **Cotton** | C1{h1-f1}, (0) | C1{h1-f1}, (0) | C2{h2-f1}, (21) | C4{h4-f1}, (100) |
| **Sunflower** | C1{h1-f1}, (0) | C1{h1-f1}, (0) | C1{h1-f1}, (15) | C4{h4-f1}, (100) |

C, bioclimatic classes; f, frost risk; h, water deficiency; between parentheses, yield reduction

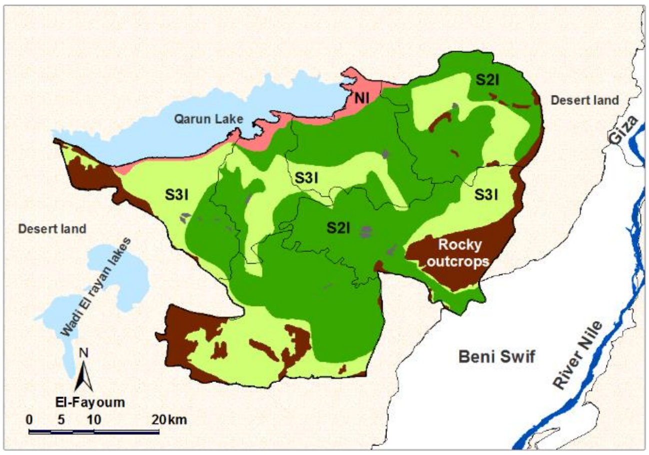

**Fig. 1 :** Land capability of El-Fayoum soil under irrigation scenarios (Scenario# 1,2).

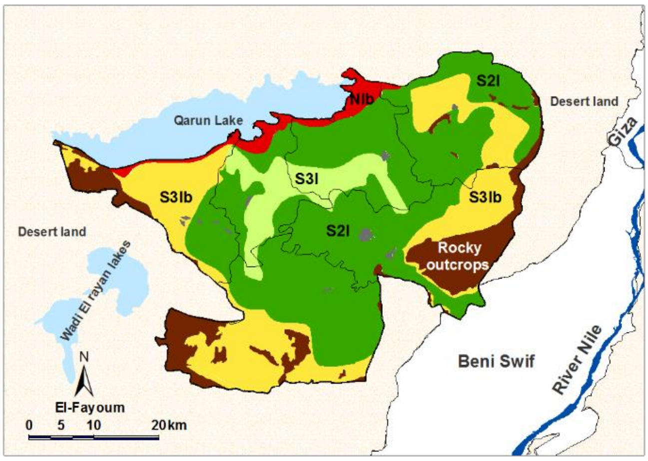

**Fig. 8 :** Land capability of El-Fayoum soil under irrigation scenarios (Scenario# 3).

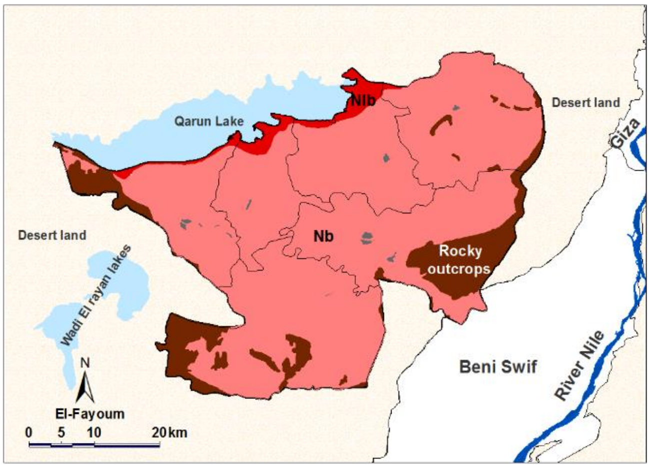

**Fig. 9 :** Land capability of El-Fayoum soil under rainfied conditions (Scenario# 4).

## Discussion

Based upon the four scenarios hypothetical water irrigation that were proposed:

**Scenario 1**: The quantity of water irrigation was considered as a precipitation 1427, mm/year (100%). The total cultivated land occupies an area of 1566 $km^2$ (ASRT, 2009) while the total amount of irrigation water for the depression is 2.3 x $10^3$ $hm^3$

**Scenario 2**: The irrigation water was decreased by 25% this hypothetical scenario represents the state of aridity under water shortage

**Scenario 3**: The irrigation water was decreased by 50%, this hypothetical scenario represents the state of aridity under water shortage (decreased by 50%). Under this condition a quantity of 31.5% of the total irrigation water is needed to mitigate the expected aridity.

**Scenario 4**: The current climatic condition (precipitation quantity 11 mm /year), under this scenario the whole area is characterized by a hyper-arid condition and truly drought will affect the cultivation.

De la Rosa et al (2009) stated that using soil type information in decision-making is at the heart for sustainable use and management of agricultural land. This agro-ecological approach can be especially useful when formulating soil-specific agricultural practices to reverse environmental degradation, based on the spatial variability of soils and related resources.

Under irrigation condition there is no difference between (Scenario# 1, 2), were the soil Vertic Torrifluvents has a good capability subclasses (S2l) the important soil limiting factor is the drainage. Land capability has a moderate subclass (S3l) in the soil types Typic Haplocalcids, Typic Haplogypsids, Typic Torrifluvents and Typic Torripsamments, with a limiting soil factors in the high content of calcium carbonate, drainage and soil texture. On the other hand, marginal land capability subclases (Nl) have been found in Typic Haplosalids with a limiting factor soil salinity.

In the Scenario# 3 irrigation scenario land capability classification ranged from S2l to Nlb, were the soil Vertic Torrifluvents has a good capability subclasses (S2l). The moderate land capability subclass with one of limiting soil factors (S3l) have been observed in the soil types Typic Haplogypsids, Typic Torrifluvents. Land capbilty sub classes with two limting factor, soil and water deficiency on the soil types Typic Haplocalcids and Torripsamments with a subclass (S3lb). otherwise Typic Haplosalids has a Nlb subclasses.

Under rainfied condition (Scenario# 4) the land capability subclasses classified as Nb in all soil unites as a result of lack of precipitation except on Typic Haplosalids categorized as Nlb as result of the value of electric conductivity and lack of rainfall.

According to the Terraza model calculations, maize, cotton, and sunflower with a yield reduction of 27, 21, 15 respectively.

Soil salinity and depth represent the most limiting factors prevailing in the studied area especially in the adjacent parts to Quarun lake that have a Typic Haplosalids soil type, therefore; it is recommended to execute leaching process for removing the excess soluble salts from the soils under an effective drainage system before establishing the agricultural utilization projects. Calcium carbonate ($CaCO_3$, %) affects the pH and thus has a significant impact on the availability of nutrients to the plant that have an impact on land capability especially on Typic *Haplocalcids* soil. Heavy texture and poor drainage on of the important soil limitations on Vertic Torrifluvents soil type.

## Conclusions

Land evaluation is a suitable tool to predict the agriculture capability for different soil types to determine the best and worst soil type in order to achieve suitable land use. According to the general agro-ecological quality (land suitability) of the soils the best soils type of El Fayoum depression is Vertic Torrifluvents (760 $km^2$) with a good (S2l) land capability classes under the three-irrigation scenario. The worst soil type is Typic Haplosalids with marginal land capability subclasses NI in Secnario1, 2 and Nlb in scenario 3. Water irrigation quantity perturbation effects in El-Fayoum depression are more serious than in the rainfed conditions, El-Fayoum depression without the irrigation water would become a barren dessert were the land capability classes has been classified as marginal soils under rainfied conditions. The most affect soil with the decreasing of irrigation water volume are Typic Haplocalcids and Torripsamments and Typic Haplosalids. Crops that need high quantity of irrigation water like maize, cotton and sunflower will have a high sensibility of water irrigation reduction and will be more influenced than the other crops in a third irrigated scenario.

Irrigation systems and agriculture drainage must be improved in order to improve the land capability, also special irrigation systems in this land must be apply where, the systematic irrigation work to improve and modify the properties of soil in addition to water save. Is likely to bring about severe water future stress; therefore, water management priorities can be felt more and more.

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