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CROP WATER REQUIREMENTS OVER THE NILE VALLEY AND DESERT FRINGES AS A BASE OF THE OPTIMUM LAND USE

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Abstract

The scarceness of water resources in dry regions imposes considerable attention in both land use and crop water requirements. The main objective of this study is to calculate the water requirements over the Nile Valley and desert fringes considering the Agro-ecological Zones as a base for setting up the optimum land use. To fulfil this objective the thematic maps of land use, soils and reference crop evapotranspiration (ETo) were used for mapping the Agro-ecological zones of the area. The CROPWAT 8.0 software has been used to determine the water requirements of the main crops in the investigated area. Consequently, the spatial analyst function of the Arc-map 9.2 software was used to extract the crop water requirements of each Agro-ecological Zone. Results indicated that the estimated ETo in the Lower Egypt differs from 3.14 to 4.78 (mm) while it ranges between 6.38 and 7.12 (mm) in Upper Egypt. The average of crop water requirements in the Lower Egypt ranges between 2.39 and 3.51 mm /day. In Upper Egypt the average of crop water requirements was increased to be 5.87 mm/day. These changes are mostly related to the climatic condition and cropping pattern of each zone.

Keywords: crop water requirements, land use, Agro-ecological Zones, GIS, Nile Valley, Egypt

Introduction

Increasing water use efficiency is a major challenge that many countries trying to achieve. The rapid growth of the world population exerts a direct pressure on agriculture production, which will involve consumption of a huge volume of water (Stephen, 2008). It is anticipated that for the world to meet the growing demand of water in 2025, about 17% of the water being used for more irrigation will be required (Molden *et al*., 2000). In arid and semi-arid regions, surface and ground water resources are naturally limited, and the challenge to produce more food under increasing water scarcity is real (Bouman, 2007). Crop water management requires accurate estimations of proper water consumption using detailed methods relating applied water, crop production, and irrigation efficiency (Bausch, 1995). Traditional methods of water management are based on the crop coefficient (Kc) approach that requires the determination of reference evapotranspiration (ETo) and Kc. Potential evapotranspiration is then determined as a product of the ETo and Kc (Allen, 2000). Values of ETo differ widely according to the Agro-ecological Zones (FAO 1981) and the changes of crop water requirements is expected. In Egypt the Nile River is the main source for irrigation, with an annual allocated flow of 55.5 km^3/ year. The total actual renewable surface water resources estimated at 56 km^3/ year. Internal renewable groundwater resources are estimated at 1.3 km^3/ year. The total actual renewable water resources of the country are estimated to be 57.3 km^3/ year (FAO, 2000). The agricultural area in Egypt is composed of two parts: Nile Delta and Valley, which is the main contributor to food production, trading activities and national economy. Through the last four decades vast areas at the desert fringes of the Nile Valley and Delta were reclaimed using mostly Nile water (El-Bagouri, 2008); this imposes considerable attention in irrigation water management. In the view of the above-mentioned limitations, new techniques for estimating actual evaporation and transpiration are developed using spatial and temporal information needed for crop water management. These techniques have been categorized under hydrological models, remote sensing and field-based methods (Kite and Droogers, 2000). In this context GIS technology is very useful for automated logical integration of bio-climate, terrain and soil resource inventory information (Patel *et al*., 2000). This work aims to estimate the crop water requirements under the different Agro-ecological Zones in Egypt for setting the suitable land use in each zone by using GIS techniques.

Materials and Methods

The Investigated Area

The area under investigation incorporates the Nile Delta, Valley and their relevant desert fringes (Figure 1). It is extended between longitudes 29° 30´ & 32° 30´E and latitudes 22° 00& 31° 30N. The area includes both old cultivations in the Nile Delta and Valley and newly reclaimed areas in the desert fringes. It is considered as an arid region where, the mean annual rainfall, evaporation and temperature are 41.4 mm, 114.3 mm and 21ºC, respectively (Egyptian Meteorological Authority, 1996). The Pleistocene deposits which are composed of Nile silt in the Nile valley region and sand and gravel of assorted sizes in the desert fringes (CONOCO, 1989).

Thematic Maps

Land use : A total of 8 Lands at ETM+ acquired in 2010 have been used to extract the land use of the Nile Delta and Valley and their relevant desert fringes. The images were enhanced by using ENVI 4.7 software; to recover the SLC-off data, improve the contrast and enhancing the edges. The SLC-off data is exchanged with calculated values, then the image was stretched using linear 2%, smoothly filtered, and their histograms were matched according to Lilles and and Kiefer (2007). The atmospheric correction was done to reduce the noise effect. Images were radiometrically and geometrically corrected to accurate the irregular sensor response over the image and to correct the geometric distortion due to Earth's rotation (ITT, 2009). Land use/ cover classes are typically mapped from digital remotely sensed data through the process of a supervised digital image classification. The maximum likelihood classifier quantitatively evaluates both the variance and covariance of the category spectral response patterns when classifying an unknown pixel so that it is considered to be one of the most accurate classifiers, as it is based on statistical parameters. Supervised classification was done using ENVI 4.7 software depending on the ground checkpoints and the digital topographic maps of the study area. Then accuracy assessment was carried out using 150 points from field data and existing land cover maps.

Fig. 1 : Location of the investigated area on Egypt map

Soils : Soils map of Egypt produced by the Academy of Scientific Research and Technology (ASRT, 1982) was used in this study. The original nomenclature of soil order, suborders and great groups have been updated using the latest American Soil Taxonomy (USDA, 2010). The study area was covered by 31 map sheets of scale 1:100000. The maps was geometrically corrected and converted into digital format, and then the soil units were linked with the attribute table of the land use map using Arc-GIS9.2 software.

Reference Crop Evapotranspiration (ETo) : The reference crop evapotranspiration (ETo) have been estimated over the investigated area from the data of 31 climatological station distributed in the study area using the CROPWAT 8.0 software. The resulted values of ETo were exported to the Arc-GIS 9.2 software, then the geostatistical analysis technique was used to produce the ETo map.

Agro-ecological Zones : Arc- GIS 9.2 software was used to map the Agro-Ecological Zones and produce an attribute table described each zone over the investigated area. The thematic layers of land use, soils and ETo have been used.

Extracting the Optimum Land Use

Spatial analyst function in Arc-GIS 9.2 software was used to extract the optimum land use for each Agro-Ecological Zone on bases of crop water requirements, soils and climatic data.

Results and Discussion

Current Land Use

Figure (2) represents the main land use /cover of the investigated area. The data show that the area is dominated by 12 main land use type. Cultivation is the major type of land use as it covers 75.1% of the area (i.e. 272993.9 km^2). The main cultivations are Maize, Cotton, Clover, Wheat, Feba bean, Rice, Sugar cane, Citrus, Vegetables, Soya, olive, mango, banana and apple. The main land uses of the rest are areas in the early stages of reclamation, bare soils, fish ponds, wetlands, sabkhas, inland water, airport, harbour, industrial zones, urban areas, parks, and water bodies. These types of land use represent 24.9 % of the investigated area (i.e. 90303.6 km^2). It is clear that the Maize, Cotton, Clover, Wheat, Feba bean, Rice, Citrus, Vegetables and Soya are the main cultivations in the Nile Delta (Lower Egypt). The main crops in the Middle Egypt include Maize, Cotton, Clover, Wheat, Feba bean, and Sugar cane while sugar cane is the main land use type in Upper Egypt.

Soils

The data extracted from the digital format of the soil map of Egypt indicated that the Vertic Torrifluvents is the major sub great group in the alluvial Nile Delta, covering 12940.3 km^2. Patches of sub-great groups Typic Torrifluvents are included in the alluvial soils. The sub-great group Typic Quartizpsamments dominates the eastern and western desert fringes, covering an area of 4082 km^2 in addition to an area of 375.2 km^2 interfered with the Typic Torriorthents sub-great group. The Typic Torripsamments/Typic Torriorthents sub-great groups association exists in an area of 399.1 km^2. The sub-great groups Typic Torrifluvents, Typic Torriorthents and Typic Torripsamments exhibit significant coverage in delta borders, as their areas are 2514.9, 2390.9 km^2 and 1385.0 km^2. The sub-great groups of Typic Aquisalids, Typic Haplosalids and Aquic Torrifluvents occur in the northern Delta region influenced by the northern Delta lakes. They cover areas of 1928.8, 166.9 and 437.9km^2 of the total Nile Delta area respectively. Minor areas of Typic Haplocalcids, Typic Haplogypsids, Typic Petrogypsids and Typic Calcigypsids are distributed in the eastern and western Delta regions covering areas of 1012.6, 10007.5, 145.9 and 4.1 km^2 respectively. Limited Hill and Rockland areas exist in the southern Delta region, covering areas of 1223.2 and 1426.9 km^2 respectively. The Typic Torriorthents is the major sub great group in the Nile Valley region, covering an area of 14303.7 km^2. The origin of such soil is mostly related to the colluvial deposits in wadi mouths and plains. They are distributed in areas located in both western and eastern desert fringes, characterized by a gently sloping landscape. The sub-great group of Vertic Torrifluvents is dominating the Nile flood plain. These soils exhibit 8313.6 km^2 of the mapped area. The Typic Torrifluvents sub-great group also exists in the Nile flood plain associated with the Vertic Torrifluvents covering an area of 2026.4 km^2. The sub-great group Typic Quartizpsamments exists in the desert fringes and the interference zone between the desert area and flood plain covering an area of 1279.3 km^2. The given data show a minor existence of the sub-great groups Typic Haplocalcids, Typic Petrogypsids, Typic Haplogypsids, Typic Torripsamments and Typic Haplosalids.

Reference Crop Evapotranspiration (ETo)

The values of ETo over the study area have been divided from the climatic data of 31 stations distributed in the area. The obtained ETo means of the 31 values of ETo was separated and ranked in ascending order using least significant difference test (LSD0.05). The spatial analyst function was used to create a raster layer of ETo over the area (Figure 3). The results indicate that the estimated ETo differ from 3.14 to 7.12 (mm). It is found that the values of ETo in the Lower Egypt changes from 3.14 to 4.78 (mm) where the small values are associated with the coastal zone. In the Middle Egypt the values of ETo rages between 5.39 and 5.87 (mm), while in the Upper Egypt it located in the range 6.38 – 7.12 (mm).

Agro-ecological Zones

According to the above-mentioned data the area was divided into 7 agro-ecological zones, the classification of these zones implies that water requirement is similar within each zone while it widely differed between zones. The main land uses, and soil types have been extracted and used with the crop Kc and ETo values for estimating the crop water requirements in each zone. Table 1 represents the soils and land uses of each agro-ecological zone in the study area.

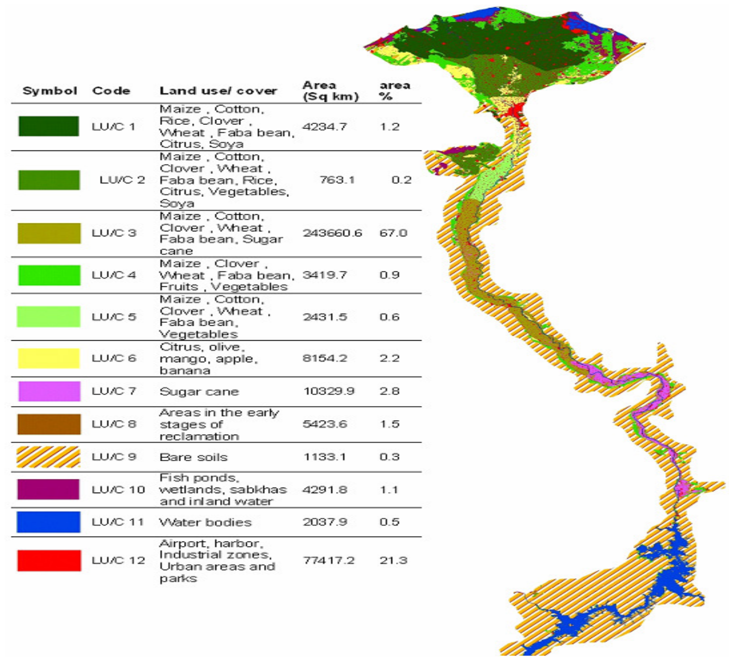

Fig. 2 : The main land uses of the investigated area

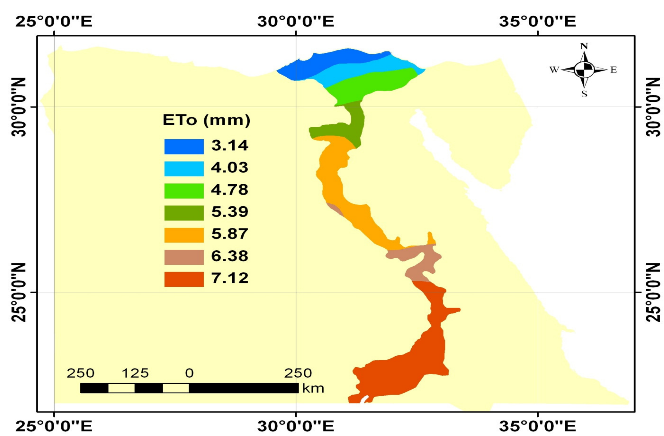

Fig. 3 : Thematic layer of the estimated daily ETo (mm) over the investigated area

Table 1 : Soils and main land uses in the different Agro-ecological Zones

Zone	ETo (mm)	Dominant Soils	Cultivated Crops
1	3.14	VT; TT	Rice, Cotton, Maize, Wheat, Clover, Sugar Beat,Vegetables
2	4.03	VT; TT; TQ	Maize, Cotton, Wheat, Clover, Faba bean, Vegetables.
3	4.78	VT; TT; TQ, TTo	Maize, Cotton, Wheat, Clover, Faba bean, Vegetables.
4	5.39	VT; TT; TQ; TC	Maize, Cotton, Wheat, Clover, Faba bean, Fruits, Vegetables.
5	5.87	VT; TT; TQ, TTo	Maize, Cotton, Wheat, Clover, Faba bean, Fruits, Sugar cane, Vegetables
6	6.38	VT; TT; TQ, TTo	Maize, Cotton, Wheat, Clover, Faba bean, Fruits, Sugar cane, Vegetables
7	7.12	VT; TT; TQ; TTo	Maize, Cotton, Wheat, Clover, Faba bean, Fruits, Sugar cane, Vegetables

Note: VT= Vertic Torrivluvents; TT= Typic Torrifluvents; TQ= Typic Quortzisanments; TC= Typic Calciorthids; TTo= Typic Torriorthens

Crop Water Requirements

Table (2) represents the averages of ETo, crop Kc and crop water requirements of the main land uses in the different Agro-ecological Zones. Regardless the growing season it is noticed that the averages of daily crop water requirements differ widely from zone to another. The lowest values are corresponding to the Lower Egypt, where it ranges between 2.39 and 3.51 mm /day. Averages of crop water requirements in Upper Egypt region were increased to be 5.87 mm/day. These changes are mostly related to the climatic condition and cropping pattern of each zone.

The crop water requirements of the single crops in the different zones were estimated as illustrated in Table 3. These crops include Maize, Cotton, Rice, Clover, Wheat, Faba bean, Soybean, Sugar cane, Vegetables, Citrus, Olive, Banana, Mango and Apple that represent the main crops in the study area. It has been noticed that the daily water requirements for crops have been doubled in zone 7 compared with zone 1.

The estimated water requirements of the Lower Egypt (Zones 1, 2 &3) for the main crops are differ from 1.88 mm/day for Wheat to 4.54 mm/day for Rice. In the Middle Egypt (Zones 4 & 5) the estimated requirements were changed from 3.23 mm /day for Wheat to 5.19 mm/ day in case of Cotton cultivation. For the Upper Egypt the estimated requirements are high as it differs from 3.83 mm/ day for Wheat cultivation to 6.3 mm/ day in cotton cultivation. The optimum land use in the area that minimizes the water requirement could be selected on bases of agro-ecological zones and crop water requirements.

Under the climatic condition of the study area the daily water requirement for Vegetables, Soybean and Faba bean are relatively high, so it is recommended to concentrate these crops in the Lower Egypt. In Upper Egypt sugar cane and maize are basic crops but the replacement of clover instead the vegetables and soybeans will decrease the evapotranspiration and accordingly the water requirements will be decreased from about 2.5 to 2 mm/day.

Table 2 : Averages of ETo, crop Kc and crop water requirements in the different Agro-ecological Zones

Zone	ETo average (mm)	Kc average (mm)	Crop water requirements average (mm/ day)
1	3.14	0.76	2.39
2	4.03	0.755	3.04
3	4.78	0.735	3.51
4	5.39	0.735	3.96
5	5.87	0.76	4.46
6	6.38	0.74	4.72
7	7.12	0.825	5.87

Note: the crop Kc average was was derived from the cropping pattern in each zone

Table 3 : The crop water requirements (mm/ day) of the single crops in the different zones

Crops	Agro-ecological Zones						
	1	2	3	4	5	6	7
Maize	2.59	3.32	3.94	4.45	4.84	5.26	5.87
Cotton	2.78	3.57	4.23	4.77	5.19	5.65	6.30
Rice	2.98	3.83	4.54	--	--	--	--
Clover	2.04	2.62	3.11	3.50	3.82	4.15	4.63
Wheat	1.88	2.42	2.87	3.23	3.52	3.83	4.27
Faba bean	2.59	3.32	3.94	4.45	4.84	5.26	5.87
Soya	2.62	3.37	3.99	4.50	4.90	5.33	5.95
Sugar cane	--	--	--	3.77	4.11	4.47	4.98
Vegetables	2.51	3.22	3.82	4.31	4.70	5.10	5.70
Citrus	2.12	2.72	3.23	3.64	3.96	4.31	4.81
Olive	2.12	2.72	3.23	3.64	3.96	4.31	4.81
Banana	2.51	3.22	3.82	4.31	4.70	5.10	5.70
Mango	2.46	3.16	3.75	4.23	4.61	5.01	5.59
Apple	2.43	3.12	3.70	4.18	4.55	4.94	5.52

Conclusion

This study confirms the importance of thematic layers of soils, climate and agro-ecological zones when calculating the crop water requirements. The spatial analyses of these layers reduce the errors especially in places of missing data. By using GIS, the area under investigation was divided into seven agro-ecological zones. Zones 1, 2 and 3 represent Lower Egypt, zones 4 and 5 represents the Middle Egypt and zones 6 and 7 covers the Upper Egypt. The main crops in these zones are Maize, Cotton, Rice, Clover, Wheat, Faba bean, Soybean, Sugar cane, Vegetables, Citrus, Olive, Banana, Mango and Apple that represent the main crops in the study area. The results indicate that the daily water requirements for crops have been doubled in zone 7 compared with zone 1. The optimum land use in the area that minimizes the water requirement could be selected on bases of agro-ecological zones and crop water requirements.

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