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Net Irrigation Water Requirements for Wheat in Egypt Under Climate Change Conditions

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ABSTRACT

Egypt appears to be particularly vulnerable to climate change especially with water scarcity problem. Climate change not only affects the temporal and spatial distribution of water resources, but also will increase the crop water consumption (ETc). The aim of this study is to estimate the effects of climate change on irrigation requirement (IR) for "Wheat" at different geographic regions in Egypt: El-Dakahlia, El-Fayoum and Assuit governorates were selected as Lower, Middle and Upper Egypt regions. The climate change data has been obtained from "MIROC-ESM" climate model with "RCP 8.5" climate scenario during 2018, 2040 and 2080 as a current, short and long term periods respectively. The results showed that the ETc would increase by 5 %, 8 % and 13 % in 2040 but, in 2080 would decrease by 8.5 % in Assuit. Whereas, in El-Dakahlia and El-Fayoum would increase by 8 % and 13 % respectively. The IR values would increase by 12 %, 21 % and 14 % to become (636.61 mm/season),(572.3mm/season) and (331.25 mm/season) in 2040 for Assuit, El-Fayoum and El-Dakahlia, respectively. But, expected to decrease in Assuit by 15 % to reach (478.4 mm/season) and increase by 23 % and 17 % to be (584.01 mm/season) and (339.85 mm/season) in 2080 for El-Fayoum and El-Dakahlia, respectively. These results indicated that, climate change would increase the water consumption for wheat in all examined regions in Egypt, and the highest impact would be in Middle and Lower Egypt followed by Upper Egypt during 2040 and 2080.

Keywords: Irrigation water requirement; Wheat Crop; General circulation Models (GCMs); Climate change models and scenarios

INTRODUCTION

Egypt is a country that is especially at risk to many of the sustainability defies and climate change impacts to which all countries around the world are struggling to respond MFA (2018). Because of aridity, limited and misuse of natural water resources, increased demand for industrial, domestic and agricultural sectors, ineffective irrigation methods, in addition to that rising populations and fast economic evolution in the countries of the Nile Basin, Egypt has been suffering from cruel water shortage in recent years Abdel Meguid (2017) and Ayyad *et al.* (2019).

The river Nile is the main source for water supply in Egypt. It provides 55.5 billion m3 year-1 that accounts for quite 90 % of the water budget, while the remaining 10 % comes from renewable and fossil groundwater beside a couple of showers of rainfall Abdel-Hafez (2011). Since rainfall contribution to Egypt's freshwater is low, the changes in the Ethiopian highlands are of great significance for water supply in Egypt because of their impact on the Nile flow which is of high sensitivity to rainfall variations and is clearly observed in the inflow change into Lake Nasser between 1993 to 2000. While an increase by only 10 % of total rainfall over the basin, raise the river stream by 40 % (Kwadijk *et al.* 2010). The agriculture sector is that the main consumer of water, which consumes 80-85 % of water resources, only but 30 % is effectively utilized by the crop, and therefore rest is consumed by poor management practices and deep percolation Mahmoud and El-Bably (2017).The unconventional wastewater resources provide an alternate supply to satisfy the increased demand Fawaz and Soliman (2016), which helps to diminish the gap between supply and demand and provide a solution to water shortage and global climate change (Loutfy 2010 and Ali *et al.* 2012).

Appraisal of potential evapotranspiration (ETo) is an important factor for assessing the agrarian water demand in various development stages and grasp hydrological processes. The climatic parameters considered the only factors affecting (ETo). Also, considered as a key factor of the hydrologic cycle because it estimates moisture transfer to the atmosphere and influences fundamental properties of the universal ecosystems like soil moisture content, run-off, and plant growth, which are important for providing water McVicar (2012). (ETo) is a type of potential evapotranspiration and does not consider the crop features and soil factors into a ccounts. Also, the clear understanding of historical trends and future changes in evapotranspiration are essential for the efficient use of water resources in vegetation management under conditions of global climate change (Shan *et al.* 2015). It is recognized that the values of evapotranspiration will affected by temperature increase and variations in wind and humidity. Eid (2001) reported that a

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temperature rise of 1°C result in the crop evapotranspiration increase by about 4-5 %, while increase in the crop evapotranspiration by about 15 % result from temperature rise of 3 °C. This indicates that, if the agricultural sector in Egypt is consuming 41 Billion cubic meters of water, and to maintain same level of productivity with a temperature rise of 1 °C would require additional 2.0 billion cubic meters. Also, it was reported that there is 6 % decline in groundwater recharge as the annual evapotranspiration rate increased by 10 % Eid *et al.* (2006).

Furthermore, the projected climatic variations will raise evapotranspiration (ETo) that would increase the potential irrigation demands in 2100 (Attaher *et al.* 2006 and Khalil 2013).

The agriculture sector is anticipated of being tremendously suffering from a decrease in crop water availability plus maximize of extreme weather incidents caused by the influence of enhanced CO2 concentrations and increase in surface temperatures. Attaher *et al.* (2006) concluded that by a range of 6-16 % the potential irrigation demands in all Egypt will increase due to future climate change and the raise in ETo. Also, Ouda *et al.* (2011) concluded that in Egypt, it is expected that water required for irrigation will increase by 33 % in 2025 as a result of temperature increase by 2 °C and population growth. Thus, quantifying how climatic variations in Egypt would influence the water requirements for strategically important crops, like wheat as cultivated under surface irrigation method with minimal use efficiency, i.e. 60 %. Tan and Shibasaki (2003) used four GCMs to demonstrate influence of climate change on future irrigation water requirement under different emission scenarios such as A1, A1F1 and B21 and their results show expected increase in water need by 7 % to 11 % in 2020 while, in 2050s by 12 % to 17 %, and by 13 % to 18 % in 2080. Also, Ashofteh *et al.* (2014) declared that, there are increases in crop water needs in future period. Moreover, wheat and barley of high tolerance and low sensitivity to climate change.

In Egypt Ouda *et al.* (2016) studied the use of ECHAM5 climate model with A1B climate scenario which included in the 4th assessment report of IPCC 2007 to predict the water requirements in 2020, 2030 and 2040 for major crops such as wheat and rice. The results revealed that the requirements for wheat will increase by 2–19 % and the applied irrigation water for rice would increase by 10–14 %.

Diaz *et al.* (2007) concluded that the irrigation requirements for 14 selected regions in Spain will varying under the baseline and different climate change scenario. Whereas, the average increase in irrigation requirement were (19.3 % in 2050_A2 and 16.3 % in 2050_B2). This is due to the reduction in rainfall and its changed distribution over the year. For example, in Los Dolores region the predicted increase in ETc is 8 %, while the irrigation requirements increase by around 23 %. Also, the irrigation requirements in the Genil Cabra region increased by 17 % in the 2050_A2 scenario. So, the existing irrigation systems, which are designed for much lower water demands, could have problems meeting these higher peak flows.

IPCC (2007) defined adaptation to climate change as “the adjustment in natural or human systems in response to actual or expected climatic stimuli or their effects, which moderates harm or exploits beneficial opportunities”. Vulnerability to climate change defined as “the degree to which a system is susceptible to, and unable to cope with adverse impacts of climate change, including climate variability and extremes”. Nour El-Din (2013) mentioned that adaptation of water management to climatic changes under an uncertain and changing situation implies balancing water demands and resources. Depending on policy choices models and scenarios deal with this waif by providing information on probable futures. Scenarios are a convenient device for analysis of how the drive forces impacting future emissions and for assessment of how the future might unfold. In a country like Egypt the adaptation strategies of climatic changes are vital, especially in the water sector that impacts other sectors in any way.

The main objectives of this research is to estimate the potential effects of short and long-term climate changes on irrigation water requirements for wheat crop at different geographic regions in Egypt using the MS excel sheet. Also, the outputs of this study will be used as a visualization for designing new model used for many objectives as; the on farm irrigation management under future climate changes to expect how much gross irrigation water to be applied and to predict the most suitable irrigation scheduling for different crops in different soil types plus developing adaptation strategies that would improve the agrarian practices to reduce the adverse impacts of climate change on the productivity of crops.

MATERIALS AND METHODS

Study areas

The study was carried out in three Governorates (El-Dakahlia, El-Fayoum and Assuit) which have the largest cultivated area distributed in different geographic regions in Egypt (Lower, Middle, and Upper Egypt) for wheat crop based on the BAS (2015) records. The common irrigation method in these study areas was the surface irrigation of 55 %.

Climate data

Current data

The current daily and monthly meteorological data in the studied areas for year 2018 were: maximum and minimum air temperature (T_{max} , T_{min} ,℃), wind speed at 2 m above the ground surface ($u_2, m/s$), maximum and minimum relative humidity (RH_{max} , RH_{min}, %) and rainfall (mm). This data were extracted from the daily and monthly meteorological reports of the world weather website: https :// www .worldweatheronline.com.

Climate change model and scenarios.

In this study, the future climate data such as maximum and minimum air temperature (T_{max} , T_{min} ,℃), solar radiation R_a (MJ m^{-2} day^{-1}), and rainfall (mm) has been obtained from the downscaling process for one of the global climate models "MIROC-ESM" and the "RCP8.5" climate scenario which considered the emissions of Co2 exceeds 1370 ppm in 2100 also assume an increase in the global temperature from 1.4 ℃ to 4.8°C.. The climate change parameters have been exported from http:// gismap. ciat.cgiar.org/ MarksimGCM for 2040 as (a short term) and 2080 as (along term) for the determined Governorates to calculate ET_o and irrigation water requirements. The obtained current and predicted monthly "Maximum temperature and rainfall" for wheat crop during its growth period from the weather stations were illustrated in the following Tables (1 and 2).

Table 1. Monthly and mean amount of maximum temperature for El-Dakahlia, El- Fayoum and Assuit governorate in 2018, 2040 and 2080 using MIROC-ESM climate model with RCP8.5.

Month	El-Dakahlia			El-Fayoum			Assuit		
	T-max [ºc]			T-max [ºc]			T-max [ºc]		
	Current	Predicted using RCP8.5		Current 2018	Predicted using RCP8.5		Current 2018	Predicted using RCP8.5	
	2018	2040	2080		2040	2080		2040	2080
Nov.	24	26.8	28	26	28.1	29.2	26	29.6	30.8
Dec.	20	22.6	24.1	20	22.5	24.4	20	24.3	26.5
Jan.	18	20.5	22	19	20.8	22.5	19	22.4	24.3
Feb.	21	21.6	23.1	21.8	22.6	24.6	25	24.5	26.5
Mar.	22.5	24.1	25.9	23.6	26.3	28.3	30	28.9	31.1
Apr.	26.3	28.5	30.3	29	31.4	33.3	32	34.1	36.1
Mean	21.9	24	25.6	19.9	25.3	27.1	25.3	27.3	25.9

Table 2. Monthly and mean amount of rainfall for El-Dakahlia, El- Fayoum and Assuit governorate in 2018, 2040 and 2080 using MIROC-ESM climate model with RCP8.5.

Month	El-Dakahlia			El-Fayoum			Assuit		
	Rainfall [mm /month]			Rainfall [mm /month]			Rainfall [mm /month]		
	Current	Predicted using RCP8.5		Current	Predicted using RCP8.5		Current	Predicted using RCP8.5	
	2018	2040	2080	2018	2040	2080	2018	2040	2080
Nov.	0	3.3	0.1	0	0.1	0.1	0	0	0.6
Dec.	0	6.2	0.9	0	1.1	0	0	0.3	0.1
Jan.	1	8.9	3.8	0	0.2	0.1	0	0.1	0
Feb.	0	7.9	2.1	0	0.7	0	0	0	0
Mar.	0	3	1	0	1.4	0.9	0	0.4	0.5
Apr.	0	1.7	1.1	0	0.2	0.2	0	0.9	0.4
Mean	0.17	5.2	1.5	0	0.62	0.21	0	0.28	0.27

Crop data

The required crop data for this study under the current and predicted management were crop categories, crop name , crop height (h,m), and management allowable depletion (MAD, %), yield response factor (K_y), planting date, harvest date, irrigation method, growth stages (in days), crop coefficient (K_c), lower threshold temperature (T_{base} , °C), the upper threshold temperature (T_{upper} , °C) and the effective rooting depth (Z_r, m). The date of planting varied according to the region in which the study was carried out based on the following website: http://www.fao.org/agriculture/seed/cropcalendar/welcome.do.

As for the wheat crop, it is planted in the Delta and Middle Egypt from "15-Nov", but in Upper Egypt it is planted from "1-Nov". The harvest time also varied according to the area of study and the climatic conditions to which the crop was exposed.

Soil data

The soil parameters that were determined for this study included soil texture, soil type and available water content (AWC, mm/m). These parameters varied according to the selected soil type for the governorate on which the study will be conducted, as shown in a Table (3).

Table 3. Available Water holding Capacity (AWC) for different soils.

Governorates	Studied texture	Available water capacity (AWC) (mm/m)
El-Dakahlia	Clay	192
Fayoum	Sandy clay loam	183
Assuit	Sandy loam	125

Calculation of ET_o, ET_c and Effective Rainfall (Pe)

All data of climate, crop and soil in current and future were used as an inputs for calculating the following parameters by using the MS Excel sheet capability, with the help of CROPWAT model.

Calculation of ET_o under the current climate

"FAO Penman–Monteith method" is recommended as the principle method for definition and calculation of reference crop evapotranspiration using weather data such as air temperature, radiation, air humidity and wind speed, in addition to the data related to the site (latitude and elevation above sea level), using daily, ten days, or monthly data. The reference crop evapotranspiration was calculated by Allen *et al.* (1998) as shown:

$$ET_0 = \frac{0.408\Delta(R_n - G) + \gamma\frac{900}{T+273}u_2(e_s - e_a)}{\Delta + \gamma(1 + 0.34u_2)} \qquad (1)$$

Where; ET_0 = Reference evapotranspiration (mm/day); R_n = Net radiation at the crop surface (MJ m^{-2} day^{-1}); G = Soil heat flux density (MJ m^{-2}day^{-1}); u_2 = Wind speed at 2 m height (m/s); e_s = Saturation vapour pressure (kPa); e_a = Actual vapour pressure (kPa); $e_s - e_a$ = Saturation vapour pressure deficit (kPa); Δ= Slope vapour pressure curve (kPa /°C); and γ= Psychrometric constant (kPa /°C)

Calculation of ET_o under the climate change

Since only predicted maximum and minimum temperature, rainfall and solar radiation are available from the output of GCMs, the Penman- Monteith (P-M) equation could not be used for ET_0 calculation in the future due to insufficient data expected. In order to solve this problem, the Hargreaves-Samani equation (H-S); is adopted according to (Hargreaves and Samani, 1985; modified later by Hargreaves 1994). The ET_0 has been calculated under the predicted climate change as follow:

$$ET_{0(H-S)} = 0.0023(T_{mean} + 17.8)(T_{max} - T_{min})^{0.5} R_a \quad (2)$$

Where; ET_0 **= Reference evapotranspiration (mm/day);** T_{mean} **= mean of the daily maximum and minimum temperature (°C);** T_{max}**= the daily maximum temperature (°C);** T_{min}**= the daily minimum temperature (°C); and** R_a **= Extraterrestrial solar radiation in the previous equation (mm/day).**

To increase the accuracy of estimation $ET_{0(H-S)}$ under predicted climate change, a linear regression equation (3) was used to calculate the daily, monthly and annually values of ET_0 in (P-M) by using the values of $ET_{0(H-S)}$. The intercept *a* and calibration slope *b* of the most effective fit regression line, were then used as regional calibration coefficients for every governorate (Shahidian *et al*. 2012):

$$ET_{0(P-M)} = a + b\,[ET_{0(H-S)}] \quad (3)$$

Calculation of $AGGDs$ and ET_c under current and predicted climate

Growing Degree Days ($GDDs$) is one widely used method for determination of the crop development stages in response to temperature. Growing degree days are calculated for every day using the daily (T_{max}), (T_{min}), and (T_{base}). The values are added together to determine the number of heat units which the crop needs to complete its growth cycle by the following equations according to (MCMastter and Wilhelm 1997).

$$GDD = T_{avg} - T_{base} \quad (4)$$

$$T_{avg} = \frac{T_{max} + T_{min}}{2} \quad (5)$$

Where; GDD **= Growing degree days (ºC /day),** T_{avg} **= average air temperature (°C),** T_{min} **= minimum air temperature (°C),** T_{max} **= maximum air temperature (°C),** T_{base} **= Lower threshold temperature (°C),** T_{upper} **= Upper threshold temperature (°C).**

ET_c is generally associated with ET_o by a group of coefficients or factors that depend upon the sort of crop and growth stages as in the following equation:

$$ET_c = ET_o \times K_c \quad (6)$$

Where; ET_c **= crop evapotranspiration (mm/day);** k_c**= (Crop coefficient) is the ratio of the potential** ET_c **to reference** ET_o**.**

According to Jensen *et al.* (1990) values of K_c for generality agrarian crops increase from a low value at sowing until upper K_c is reached at about whole canopy cover. The empirical equation of calculating K_c for any period of the growing season can be calculated by equation (7) except K_c values of the initial stage which is constant and equal the K_c value of the growth stage under consideration according to (FAO 1998) as shown:

$$K_c = kc_{prev} + \left[\left(\frac{i - \Sigma L_{prev}}{L_{stage}}\right)\right](kc_{next} - kc_{prev}) \quad (7)$$

Where; K_C **= adjusted crop coefficient on day i for the develop, mid and late stage,** kc_{prev}**= crop coefficient at the end of previous stage,** i **= day number within the growing season,** ΣL_{prev} **= sum of the lengths of all previous stages (days),** L_{stage}**= length of the stage under consideration (days) and** kc_{next}**= crop coefficient at the beginning of next stage.**

Calculation of Effective Rainfall (P_e)

Estimating P_e is extremely difficult to determine and it is necessary to assess the irrigation requirement of crop. A simple approximation for calculating the P_e following the USDA Conservation Method, as cited in (Doll, 2002) is:

$$P_e = P(4.17 - 0.2\,P)/4.17 \qquad \text{for } P < 8.3 \text{ mm/day} \quad (8)$$

$$P_e = (4.17 + 0.1\,P) \qquad \text{for } P \geq 8.3 \text{ mm/day} \quad (9)$$

Where; P_e**= Effective rainfall (mm/day); and** P**= Total current and predicted rainfall on the day (mm/day).**

Calculation of net irrigation water requirements (NIR) under current and changing climate.

The IR estimated according to Allen *et al.* (1998) by the following equation:

$$\text{The } IR = zero \quad if\ ETc < P_e \quad \text{or} \quad ETa < P_e \quad (10)$$

$$\text{In case of standard condition } IR = ETc - P_e \quad if\ ETc > P_e \quad (11)$$

$$\text{In case of non-standard condition } IR = ETa - P_e \quad if\ ETa > P_e \quad (12)$$

Where; IR**= irrigation water requirement (mm/day); and** ET_a**= actual evapotranspiration (mm/day).**

RESULTS AND DISCUSSION

ET_o values under current and predicted climate.

Table (4) showed the variations and percentage of increase (PI %) in the value of (ET_o) during the growing season of wheat crop through the current (2018) and predicted periods (2040 and 2080), respectively under the RCP 8.5 climate scenario and the MIROC- ESM climate change model in the three selected governorate. According to the results, the highest PI % in ET_o during 2040 were 16 % in El-Dakahlia governorate followed by 13 % in El-Fayoum while the lowest were 11 % in Assuit. The result of ET_o for 2080 revealed that the PI % were 16 %, 15 % and 4 % for El-Fayoum, El-Dakahlia and Assuit, respectively. Also, Fig. (1) Showed that the total ET_o along the growth season of wheat is expected to increase in 2040 and 2080 compared to 2018 in El-Dakahlia and El-Fayoum, meanwhile, it is expected to be higher in Assuit in 2040 than that of 2018 and 2080.

Table 4. Total, mean seasonal values of ET_o and percentage of increase in ET_o (PI %) for wheat crop in the three selected governorate under 2018, 2040 and 2080 climate.

Variables	ETo (mm/season) of wheat crop							
	Current climate		Predicted climate using MIROC-ESM model with RCP8.5 scenario					
	2018		2040			2080		
	Total	Mean (mm/day)	Total	Mean (mm/day)	PI	Total	Mean (mm/day)	PI
El-Dakahlia	446	2.91	546	3.37	16	507	3.34	15
El-Fayoum	634	4.56	858	5.14	13	807	5.27	16
Assuit	740	4.87	806	5.38	11	686	5.04	4

PI = percentage of increase.

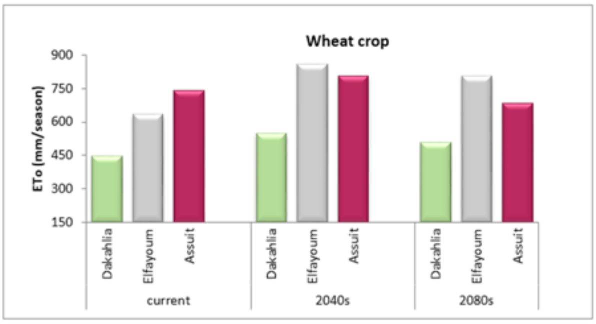

Fig. 1. Seasonal evapotranspiration (ET_o, mm/season) for wheat crop at the three selected governorate under the current, 2040 and 2080.

Variations in length of growing season and crop coefficient K_c based on the $AGGDs$ under current and predicted periods.

The impact of maximum temperature on length of wheat growing season and K_c factor in the three selected governorates is illustrated in Tables (5, 6 and 7).

In El-Dakahlia governorate the length of growing season for wheat crop were 153 days and expected to be 162 days and 152 days, while the accumulated growing degree days ($AGGDs$) were 1984.5, 1985.1 and 1989.9 ºC /season in 2018, 2040 and 2080, respectively as shown in Table (5). Also, the values of K_c factor through develop, mid and late stages are expected to be 0.79, 1.04 and 0.39 in 2040. The corresponding values, in 2080 are expected to be 0.79, 1.02 and 0.36 compared with the current period. The prolonged growth period in 2040 could be explained because of the temperature degrees are expected to be higher than 2018 and 2080 in the first stages of wheat growth where the plants are not in need for high $AGGDs$, whereas, in mid and late stages of growth the temperature degrees are low, even though the plant need high amount of $AGGDs$, so the period of growth is prolonged to reach the required $AGGDs$ when compared to 2018 and 2080.

The results of El-Fayoum governorate in Table (6) indicated that the longest growth season recorded for 2040 and expected to be 167 days, followed by 2080 with 153 days, while the shortest growth season is presented by 2018 with 139 days. This variation in the length of growth season is owed to fulfill the required $AGGDs$. In the mid and late stages of plant growth in 2018 and 2080, the temperatures were higher through the mid and late stages than 2040, so their periods of growth were decreased compared to 2040. Also, the values of K_c factor through the develop, mid and late stages for wheat in El-Fayoum are expected to be 0.8, 1.06 and 0.42 in 2040 while, in 2080 they are expected to be 0.79, 1.01 and 0.35, respectively for the current period, they were 0.93, 1.15 and 0.33. Meanwhile, in Assuit governorate the planting date for wheat crop is different from El-Dakahlia and El-Fayoum. The shortest growth season was predicted to be 136 days followed by 150 days and 152 days with $AGGDs$ 1999.9, 1990.6 and 1993.2 ºC /season in 2080, 2040 and 2018, respectively as shown in Table (7). The values of K_c factor over the develop, mid and late stages are expected to be 0.79, 1.02 and 0.37 in 2040, while in 2080 the corresponding values are expected to be 0.78, 0.98 and 0.37, respectively while for the current period it was 0.93, 1.15 and 0.33.

Table 5. Predicted length of growing season (days) and Kc for wheat crop in El- Dakahli governorate based on the $AGGDs$ through 2018, 2040 and 2080 climate.

Governorates	Wheat crop						
	Planting date	Harvesting Date	AGGDs (ºC /season)	length of growing season (days) Total	Stage length		Kc
				Current climate 2018			
El-Dakahlia	15/11/2017	16/04/2018	1984.5	153	Initial	19	0.7
					Develop	50	0.93
					Mid	60	1.15
					Late	24	0.33
				Predicted climate 2040 as a short term			
	15/11/2039	24/04/2040	1985.1	162	Initial	14	0.7
					Develop	46	0.79
					Mid	77	1.04
					Late	25	0.39
				Predicted climate 2080 as a long term			
	15/11/2079	14/4/2080	1989.9	152	Initial	16	0.7
					Develop	44	0.79
					Mid	70	1.02
					Late	22	0.36

Table 6. Predicted length of growing season (days) and Kc for wheat crop in El- Fayoum governorate based on the $AGGDs$ through 2018, 2040 and 2080 climate.

Governorates	Wheat crop						
	Planting date	Harvesting Date	AGGDs (ºC /season)	length of growing season (days) Total	Stage length		Kc
				Current climate 2018			
El-Fayoum	15/11/2017	02/04/2018	1995	139	Initial	17	0.7
					Develop	48	0.93
					Mid	52	1.15
					Late	22	0.33
				Predicted climate 2040 as a short term			
	15/11/2039	29/04/2040	1989.6	167	Initial	13	0.7
					Develop	50	0.8
					Mid	80	1.06
					Late	24	0.42
				Predicted climate 2080 as a long term			
	15/11/2079	15/04/2080	1992	153	Initial	22	0.7
					Develop	46	0.79
					Mid	65	1.01
					Late	20	0.35

Table 7. Predicted length of growing season (days) and Kc for wheat crop in Assuit governorate based on the $AGGDs$ through 2018, 2040 and 2080 climate.

Governorates	Wheat crop						
	Planting date	Harvesting Date	AGGDs (ºC /season)	length of growing season (days)			Kc
				Total	Length Stage		
	Current climate 2018						
Assuit	01/11/2017	01/04/2018	1993.2	152	Initial	19	0.7
					Develop	50	0.93
					Mid	60	1.15
					Late	23	0.33
	Predicted climate 2040 as a short term						
	01/11/2039	29/03/2040	1990.6	150	Initial	12	0.7
					Develop	45	0.79
					Mid	71	1.02
					Late	22	0.37
	Predicted climate 2080 as a long term						
	01/11/2079	15/03/2080	1999.9	136	Initial	13	0.7
					Develop	38	0.78
					Mid	61	0.98
					Late	24	0.37

ET_c values under current and predicted climates.

The life cycle of any crop can be divided into four growth stages each stage has its own duration and its own ET_c which differ among tested periods along the growing season according to the selected governorates. For the Dakahlia Governorate, Fig. (2) pointed that the values of ET_c for wheat over the period from 15/11 to 8/02 were somewhat similar through 2018, 2040 and 2080, as 2040 had the highest curve among them. In the period from 14/01 to 30/03, the highest ET_cvalues were in 2080 followed by 2040. The peak values of wheat ET_c were from 28/02 to 30/03 and the lowest values were from 31/03 to 24/04 through the three years 2018, 2040 and 2080. The steep fluctuation in the ET_c values through the mid and late stages owed to the sudden increase in the K_c values at the start of mid stage and the sudden decrement at the end of this stage until the late stage.

In El-Fayoum governorate as shown in Fig. (3), the ET_cvalues between the dates from 15/11 to 15/03 were somewhat close to each other in years 2018, 2040 and 2080s, while the peak values of ET_c were from 28/02 to 30/03 during 2040 and 2080. In the period after 15/03, the values of ET_c were dissimilar for all curves and fluctuated diversely. However, 2040 has recorded the highest values over other seasons. The differences among curves were clearer in the mid stage because of the differences in the ET_o and K_c values. The sudden decrease in the ET_c values through the latest stage due to the sudden decrease in the K_c values through this stage.

Fig. (4), shows the ET_c values in Assuit. Through the period from 1/11 to 9/02 ET_c values were close to each other in 2018, 2040 and 2080 where, 2080 was the highest. Between dates 19/02 to 1/04 the values of ET_c were similar in 2018 and 2040 until the end of the crop growth period unlike 2080, this difference appeared because the wheat crop completed its life-cycle quickly in 2080 before 2040 and 2018 due to the increase of temperatures along the growing season, ET_o and K_c values. The sudden decrease in the ET_c values through the late stage is attributed to the sudden decrease in the K_c values through this stage.

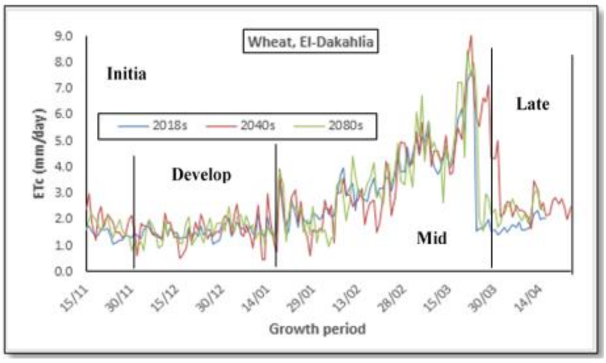

Fig. 2. Predicted daily ET_c values for wheat crop through 2018, 2040 and 2080 in El- Dakahlia governorate.

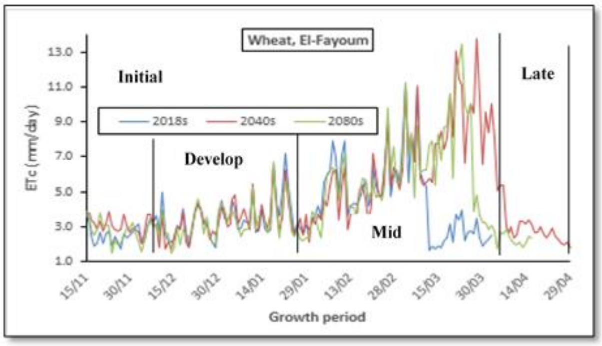

Fig. 3. Predicted daily ET_c values for wheat crop through 2018, 2040 and 2080 in El- Fayoum governorate.

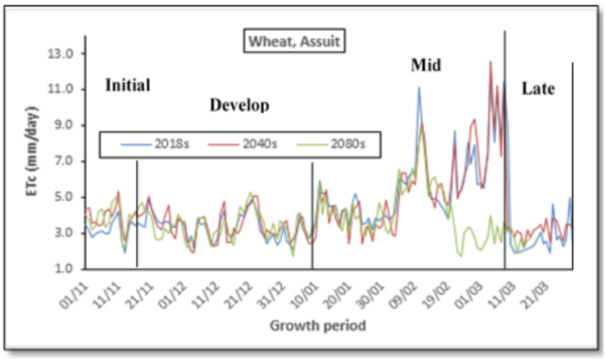

Fig. 4. Predicted daily ET_c values for wheat crop through 2018, 2040 and 2080 in Assuit governorate.

The seasonal ET_c values in the three selected governorates are shown in Table (8) and Fig. (5).The lowest seasonal ET_c values in current and predicted periods were presented by El-Dakahlia governorate. Whereas the highest ET_c values during 2018 were 627 mm and 532 mm are recorded for Assuit and El-Fayoum, respectively and the highest values during 2040s and 2080 were in El-Fayoum. Meanwhile, in Assuit it is expected to increase in 2040 (640 mm) then decrease in 2080 (510 mm). Also, Table (8) shows that the highest values of ET_c among different growth stages in the three selected governorates and through the three different study periods were connected with the mid- stage for example, the mid-stage (494 mm/stage) in 2040 at El-Fayoum governorate can be considered the longest and most important stage of crop growth, in which the crop consumed a large amount of water to form cereals. On the other hand, the lowest values were observed in the initial stages for instance in El-Dakahlia governorate recorded the ever lowest ET_c value (26.6 mm/stage) in 2040. It is well known that the initial stage represents the germination and early growth stage where the plant needs simple amounts of water. The percentage of increase of ET_c from 2018 to 2040 was predicted as 13 %, 8 % and 5 % for El-Dakahlia, El-Fayoum and Assuit, respectively, but in 2080 the PI % was expected to be 13 % in El-Fayoum and 8 % in El-Dakahlia. However, in 2080, there was a decrement by a percentage of 8.5 % when compared to 2018 ET_c values as in Table (8).

Table 8. Total, mean, stage value of ET_c, (PI %) and (PD %) for wheat crop in the three selected governorate under 2018, 2040 and 2080 climate.

Governorates	ETc (mm/season) for wheat crop														
	Current climate				Predicted climate using MIROC-ESM model with RCP8.5 scenario										
	2018				2040					2080					
	Total	Mean	Stage value		Total	Mean	Stage value		PI	Total	Mean	Stage value		PI	PD
Dakahlia	372	2.4	Ini.	26.7	438	2.7	Ini.	26.6	13	397	2.6	Ini.	26.9	8	-
			Dev.	80.8			Dev.	71				Dev.	67.9		
			Mid	222			Mid	279.4				Mid	250.5		
			Late	42.1			Late	61				Late	51.6		
Fayoum	532	3.8	Ini.	41.4	755	4.1	Ini.	41.2	8	653	4.3	Ini.	59	13	-
			Dev.	155			Dev.	156.5				Dev.	142.5		
			Mid	281			Mid	494				Mid	395		
			Late	54.3			Late	63				Late	56.5		
Assuit	627	4.1	Ini.	61.2	640	4.3	Ini.	48.4	5	510	3.75	Ini.	49	-	8.5
			Dev.	165.3			Dev.	159				Dev.	133		
			Mid	341.8			Mid	363				Mid	262		
			Late	58.7			Late	69.6				Late	66		

PD = percentage of decrease.

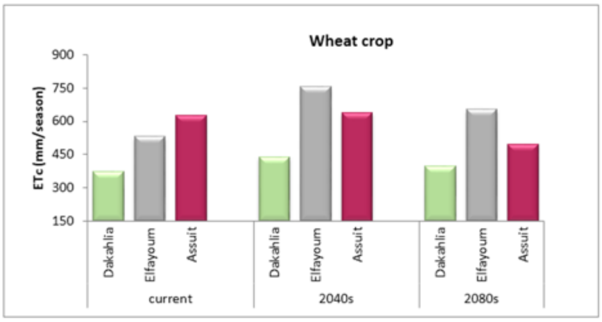

Fig. 5. Seasonal crop evapotranspiration (ET_c, mm/season) for wheat crop at the three selected governorate under the current, 2040 and 2080.

Net Irrigation water requirements under current and predicted climate.

The variation and percentage of increase and decrease in the net irrigation requirements for wheat crop under the current and future climate in the three selected governorates are shown in Table (9). The highest net irrigation requirement in 2018s were 568.29 mm in Assuit, whereas, the lowest were 290.14 mm recorded in El-Dakahlia. The net irrigation requirements in El- Fayoum are predicted to increase in 2040 by 21 % to reach 572.3 mm and by 23 % in 2080 to reach 584.01 mm as compared to 2018. Meanwhile, the corresponding values of net irrigation in Dakahlia were 331.25 mm, and 339.85 mm in 2040 and 2080, by a percentage of increment over 2018 by 14 and 17 %, respectively. In Assuit we had a different pattern, as there was a normal increase in 2040 by 12 % (636.61 mm), then a big contrast in 2080, as there was a decrement by 15 % (478.4 mm) compared to 2018 season. This contradiction may be due to the big variation in climates between 2040 and 2080 seasons in Assuit.

Table 9. Total net water requirements (mm/ season), (PI %) and (PD %) for wheat crop in the three selected governorate under 2018, 2040 and 2080 climate.

Variables	Net irrigation (mm/season) for wheat crop					
	Current climate	Predicted climate using MIROC-ESM model with RCP8.5 scenario				
	2018	2040		2080		
	Total	Total	PI	Total	PI	PD
El-Dakahlia	290.14	331.25	14	339.85	17	---
El-Fayoum	472.1	572.3	21	584.01	23	---
Assuit	568.29	636.61	12	478.4	---	15

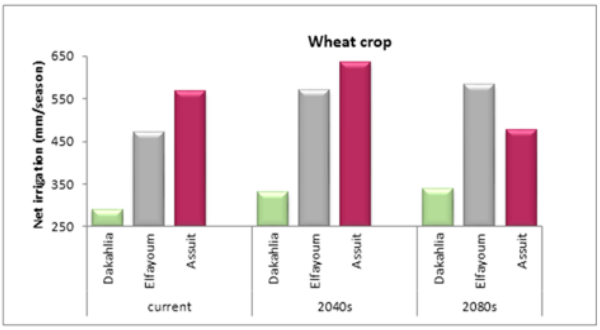

Fig. 6. Seasonal net irrigation water requirements (mm/season) for wheat crop at the three selected governorate under the current, 2040 and 2080.

CONCLUSION

The study revealed the inverse impact of climate change on wheat crop grown in different geographic regions in Egypt according to the obtained results. An increase of the ET values is expected for all the three studied governorates due to the future increase of temperature, and consequently a high increment percentage in Middle and Lower Egypt followed by a mild increment rate in Upper Egypt during 2040 and 2080.

Values of ETo are expected to raise in Egypt between 11-16 % in 2040 season and between 4-16 % in 2080 season according to the region. A lower increment in ETc values is expected to increase in the range of 5-13 % in 2040 and 2080 years in all regions, except for Assuit in 2080 a decrement for 8.5 % was expected. Also, the IR increased in arrange between 12 – 23 % according to the region and year of prediction. The only exception was for Assuit in 2080 where a decrement percentage of 15 % was predicted.

Finally, undoubtedly the irrigation water requirements will further aggravate under predicted climate change since surface irrigation is prevailing in Egypt with low application efficiency. The percentage of water requirements vigorously increased in lower, middle and to some extent in Upper Egypt. Thus, the decision makers should think about some future strategies to be able to adapt. These strategies may include crop replacements, improving irrigation systems and farm practices.

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عمق ماء الرى الصافى لمحصول القمح في مصر تحت تأثير التغيرات المناخية

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التغيرات المناخية قضية عالمية ذات تأثيرات محلية، ومصر من أكثر الدول تأثرًا و تضررا منها، ومن أكبر المشاكل التى واجهت مصر هى مشكلة ندرة المياه مع وجود تغيرات مناخية. لا تؤثر التغيرات المناخية فقط على التوزيع الزماني والمكاني لموارد المياه فحسب ، بل سيزيد أيضًا من استهلاك المحاصيل للمياه (ETc).وكان الهدف من هذه الدراسة هو تقديرتأثيرالتغيرات المناخية على عمق ماء الرى الصافى (NIR) لمحصول "القمح" في ثلاث محافظات زراعية رئيسية في مصر: محافظة الدقهلية ؛ محافظة الفيوم ؛ محافظة أسيوط كدراسة حالة لأقاليم مصرالسفلى والوسطى والعليا. تم الحصول على البيانات المتوقعة للمناخ بإستخدام نموذج MIROC- ESM وسيناريو RCP 8.5 خلال عام 2040م و2080م كفترة قصيرة وطويلة الأجل مقارنة ب 2018م كفترة حالية على التوالي. وأظهرت النتائج أن المتوسط الموسمي لقيم البخر نتح الأساسى "ETo" لمحصول القمح سيزداد بنسبة 11٪ ، 13٪ ، 16٪ في عام 2040م و 4٪ ، 16٪ ، 15 ٪ عام 2080 م لمحافظة أسيوط والفيوم والدقهلية على الترتيب مقارنة بالفترة الحالية. وأيضا أوضحت النتائج أن عدد الوحدات الحرارية المتوقعة "$AGDDs$ " التى يحتاجها محصول القمح فى محافظة الدقهلية ليكمل دورة نموه خلال عامى 2040م و2080م هى (1985.1 وحدة حرارية)، و(1989.9 وحدة حرارية) مقارنة بالفترة الحالية والتى كانت (1984.5وحدة حرارية). بينما فى محافظة الفيوم كانت قيم الوحدات الحرارية المتوقعة فى عامى 2040م و2080م هى (1989.6 وحدة حرارية)، و(1992 وحدة حرارية) مقارنة بعام 2018م والتى كانت (1995 وحدة حرارية). أما بالنسبة للنتائج المتوقعة لمحافظة أسيوط هى (1990.6 وحدة حرارية)، و(1993.2 وحدة حرارية) لعامى 2040م 2080م على التوالى مقارنة بعام 2018م والتى كانت (1999.9 وحدة حرارية). ومن المتوقع أيضا أن تزداد قيم ETc بنسبة 5٪ ، 8٪ ، 13٪ لمحافظة أسيوط والفيوم والدقهلية فى عام 2040م ، ووجد أنه في عام 2080م ستنخفض قيمتها بنسبة 8.5٪ في أسيوط ، بينما فى الدقهلية والفيوم سترتفع بنسبة 8٪ ، 13 ٪ على التوالي. أيضا وجد أن قيم الاحتياجات المائية ستزداد بنسبة 12٪ ، 21٪ ، 14٪ لتصل إلى (636.61 مم/الموسم)، (572.3 مم/الموسم) و(331.25 مم/الموسم) فى عام 2040م لأسيوط والفيوم والدقهلية على التوالى و تنخفض بنسبة 15٪ وترتفع بنسبة 23٪ ، 17٪ لتصل إلى (478.4 مم/الموسم)، (584.01 مم/الموسم) و(339.85 مم/الموسم) عام 2080م لنفس المحافظات على التوالى. وأشارت النتائج السابقة إلى أن ظروف التغيرات المناخية ستزيد من استهلاك المياه لمحصول القمح في جميع المناطق التي تم اختيارها للدراسة في مصر ، وسيكون التأثير الأكبر في مصر الوسطى ثم الوجه البحري يليه صعيد مصر خلال عامى 2040م و2080م.