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IMPACT OF CLIMATE CHANGE ON IRRIGATION WATER DEMAND FOR RICE CROP IN KAFR EL-SHEIKH GOVERNORATE, EGYPT.

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Abstract

This study investigates the projected changes in evapotranspiration and irrigation water demand for rice crop in Kafr El-Sheikh Governorate, Egypy. The mean air temperature were statistically downscaled and compared with the current climate, defined as the period 1971–2000. FAO-56 Penman-Monteith equation was implemented to estimate ETo by using current climatic data. Evapotranspiration is estimated based on the predicted maximum and minimum air temperature using the RCPs scenarios (RCP2.6 – RCP4.5 – RCP6.0 and RCP8.5) during three time series (2011-2040, 2041-2070 and 2071-2100). The obtained results revealed that the mean air temperatures were increased under all RCPs scenarios compared to current data. Moreover, the RCP8.5 had the highest mean air temperature compared to the other RCPs scenarios. ETo significant increased in different tested time series compared to the current ETo values. The values of irrigation water demands in long term time series (2071-2100) were higher than short term (2011-2040) or mid-term (2041-2070) with respect to the current situation. Total water budget in Kafr El-Sheikh for rice crop will increase under all scenarios compared with the current conditions and ranged from 92 to 345 Million cubic meters. This paper suggested a package of different adaptation options for better water management for rice crop in Kafr El-Sheikh Governorate.

Keywords: RCP scenarios –water budget –rice crop – adaptation options-Kafr El-Sheikh Governorate.

1. INTRODUCTION

Rice is the second priority cereal crop after wheat in Egypt. It occupies about 22% of the cultivated area during the summer season. Approximately 95% of all rice is grown in the six governorates that constitute the northern part of the Nile delta. The cultivated area of rice is about 1.409 million feddans in year 2011 that produced about 5.67 million ton paddy rice with a production per feddan of about 4.02 tons (**Economic Affairs Sector, EAS 2011)**.

Climate change is likely to have an impact on water use and water use efficiency in rice. Temperature increases due to global warming are likely to cause an increase in evapotranspiration losses. However, there is new evidence that

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CO_2 enrichment can increase water use efficiency due to a combination of reduced transpiration and increased biomass production resulting from reduced stomata conductance and increased shading from larger leaves (**Yoshimoto *et al.*, 2005**). **Fischer *et al.* (2006)** investigated the potential changes in global and regional agricultural water demand for irrigation within a new socio-economic scenario (A2r) and suggested that globally the impacts of climate change on increasing irrigation water requirements could be nearly as large as the changes projected from socioeconomic development. **Rodriguez Diaz *et al.* (2007)** studied the climate change impacts on irrigation water requirements in the Guadalquivir river basin in Spain and estimated a typical increase of demand between 15% and 20% in seasonal irrigation need by 2050. **De Silva *et al.* (2007)** studied the impacts of climate change on irrigation water requirements in the paddy field of Sri Lanka and predicted an increase of 13% to 23% of irrigation water demand depending on climate change scenarios. **Shrestha *et al.* (2013)** showed a remarkable increase in the irrigation water requirement (IWR) in the future as compared to the present climate.

The RCPs are called ‘Representative Concentration Pathways’ because they were developed to be ‘representative’ of possible future emissions and concentration scenarios published in the existing literature. They focus on the ‘concentrations’ of greenhouse gases that lead directly to a changed climate, and include a ‘pathway’ for the trajectory of greenhouse gas concentrations over time to reach a particular radiative forcing at 2100. There are four pathways: RCP8.5, RCP6, RCP4.5 and RCP2.6. The last is also referred to as RCP3-PD, where PD stands for Peak and Decline. The numbers in each RCP refer to the amount of radiative forcing produced by greenhouse gases in 2100. For example, in RCP8.5 the radiative forcing is 8.5 Watts per square-meter (W/m²) in 2100 (**IPCC, 2013**). RCP8.5, is representing a high-emission, non-mitigation future, and yields a range of temperature outcomes of 4.0 to 6.1 ^oC by 2100 (66% range). The lowest RCP2.6 assuming significant climate action, limits global temperature increase to below 2 ^oC with a `likely' chance greater than 66% probability (**Knutti and Hegerl, 2008**).

The main target of this work is to estimate the trend of temperature, reference evapotranspiration and water irrigation demands for rice crop under climate change conditions according to ICCP fifth assessment report (RCP scenarios) in Kafr El-Sheikh Governorate, Egypt.

2. MATERIAL AND METHODS

Climate change scenarios

The IPCC released a set of climate change scenarios based on representative concentration pathways (RCPs). The RCP scenarios involved widely differing emissions pathways, reflecting differing levels of effectiveness in tackling emissions and climate change. The lowest, RCP2.6 is a very strong mitigation scenario, with CO_2 levels peaking by 2050 at ~443ppmv. RCP4.5 has a continuing rise in CO_2 concentrations to the end of the century, when they reach ~538ppmv. In RCP6.0, CO_2 concentrations rise more rapidly, reaching ~670ppmv by 2100. RCP8.5 continues current rapid increase of CO_2 emission trends with CO_2 concentration reaching 936ppmv by 2100 **IPCC (2013)**. Overall characteristics of these scenarios are given in Table (1).

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Table (1): Description of IPCC Representative Concentration Pathways (RCP) until 2100 compared with the average data from 1971 to 2000 year.

Scenario	Radioactive forcing	Atmospheric CO_2 Ppm in 2100	Global Temperature Increase	Pathway
RCP 2.6	3 Wm^2 before 2100 declining to 2.6 Wm^2 by 2100	490 ppm	1.5 °C	Peak and decline
RCP 4.5	4.5 Wm^2 post 2100	650 ppm	2.4 °C	Stabilization without overshoot
RCP 6	6.0 Wm^2 post 2100	850 ppm	3.0 °C	Stabilization without overshoot
RCP 8.5	8.5 Wm^2 in 2100	1370 ppm	4.9 °C	Rising

Data and Projections

The date projection was customize to the Delta region, Kafr El-shiekh Governorate. Downscaled climate data for this governorate was drawn from ClimaScope. Data on maximum and minimum historic temperature (1971 to 2010) plus projections for different years (2011-2040, 2041-2070 and 2071 - 2100) were assembled. Daily historical data on relative humidity, wind speed, precipitation and solar radiation were drawn from automated weather stations of the Central Laboratory for Agricultural Climate (CLAC) and data sources in the concerned governorate.

Evapotranspiration calculation

Evapotranspiration is a measure of crop water use and will be calculated, for both current and future conditions, using the Food and Agricultural Organization (FAO) Penman- Monteith (PM) procedure presented by **Smith and Pereira (1996)**. In this method, ETo is expressed as follows:

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

where ETo is the daily reference evapotranspiration (mm day^{-1}), Rn is the net radiation at the crop surface (MJ m^{-2} day^{-1}), G is the soil heat flux density (MJ m^{-2} day^{-1}), T is the mean daily air temperature at 2 m height (°C), U_2 is the wind speed at 2 m height (m s^{-1}), e_s is the saturation vapor pressure (kPa), e_a is the actual vapor pressure (kPa), Δ is the slope of vapor pressure curve (kPa $°C^{-1}$) and γ is the psychometric constant (kPa $°C^{-1}$). In application having 24-h calculation time steps, G is presumed to be 0 and e_s is computed as

$$e_s = \frac{e^0(T_{\max}) + e^0(T_{\min})}{2}$$

Where $e^0(\ )$ is the saturation vapor function and T_{max} and T_{min} are the daily maximum and minimum air temperature. The FAO Penman-Monteith equation predicts the evapotranspiration from a hypothetical grass reference surface that is 0.12 m in height having a surface resistance of 70 s m^{-1} and albedo of 0.23. The equation provides a standard to which evapotranspiration in different periods of the year or in other regions can be computed and to which the evapotranspiration from other crops can be related. Standardized equations for computing all parameters in Eq. (1) are given by **Allen *et al* (1998).**

Rice cultivated area in Egypt

The cultivation of rice in the Kafr El-Sheikh governorate is as follows: nursery starts at the second half of May; seedling transplanting in the soil after two to three weeks from cultivation the nursery; yield harvesting starts during the second half of August till the first week of October. In this study, the estimation of water requirements for rice began from mid of June, and harvesting date was at mid of September. These dates consider the average between long period and short period rice duration. Table (2) shows total rice cultivation from 2008 till 2012 by feddan (4200 square meter). Total water budget requirement for rice crop were resulted from multiplying total irrigation water demands (m^3/feddan /season) by total area cultivated (264062 feddans) with rice crop in Kafr El-Sheikh Governorate.

Table (2). The total rice cultivation area in Kafr El-Sheikh Governorate from 2008 till 2012 season.

	Rice Area (Feddans)				
Year	2008	2009	2010	2011	2012
Area	264062	322052	274245	294164	165788
Average	264062				

Economic Affairs Sector, 2012

Estimation of irrigation requirements for Rice

Most of the effects of the various weather conditions are incorporated into the ET_o estimate. Therefore, as ET_o represents an index of climatic demand, K_c varies predominately with the specific crop characteristics and only to a limited extent with climate. This enables the transfer of standard values for K_c between locations and between climates. This has been a primary reason for the global acceptance and usefulness of the crop coefficient approach and the K_c factors developed in past studies. ET_c is determined by the crop coefficient approach whereby the effect of various weather conditions are incorporated into ET_o and crop characteristics into the K_c coefficient. In the crop coefficient approach the crop evapotranspiration, ETc, is calculated by multiplying the reference evapotranspiration, ET_o, by a crop coefficient K_c, according to FAO paper No. 33, the same methodology adopted by many studies (**Doorenbos and Kassam, 1986 and Gafar, 2009**).

$$IR = K_c * ET_o * LF * IE * R * \text{Area (Feddan)}/1000$$

Where:
IR = Irrigation requirement (m^3/feddan).

K_c = Crop coefficient (1.05-1.2-0.85).

ET_o = Reference crop evapotranspiration (mm/day).

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LF = Leaching fraction (assumed 20% of irrigation water).

IE = Irrigation efficiency of the flood irrigation in the field, (assumed 50% of the total applied).

R = Reduction factor (100% cover in rice)

Area = the irrigated area (one feddan = 4200 m^2).

1000 = To convert from liter to cubic meter.

Statistical analysis

Statistical analysis was used to establish whether there exist significant differences in the current ETo for the1971 to 2000 period versus the estimated ETo for the RCP climate change scenarios for the periods 2011-2040, 2041-2070 and 2071-2100. This was done with a paired t test at 0.05 significant level (**SAS, 2000)**. The hypotheses tested was:

H_0: $\mu_{i1} = \mu_{i2}$

H_A: $\mu_{i1} \neq \mu_{i2}$ (i.e. $\mu_{i2} > \mu_{i1}$)

Data were tested for differences in calculated ETo across Kafr El-shiekh Governorate.

3. RESULTS AND DISCUSSION

Average monthly mean air temperature:

1-Trend of temperature under future conditions (2011-2040).

Fig. (1) show the average monthly mean air temperature from June to September in Kafr El-sheikh Governorate under current (1971- 2000) and future (2011-2040) conditions for different RCPs scenarios. The average air temperature in Kafr El-sheikh increased from 1.70 to 2.00 ^{o}C for all RCPs scenarios than the current. There were no differences in air temperate between the four RCP scenarios during the time series 2011-2014.

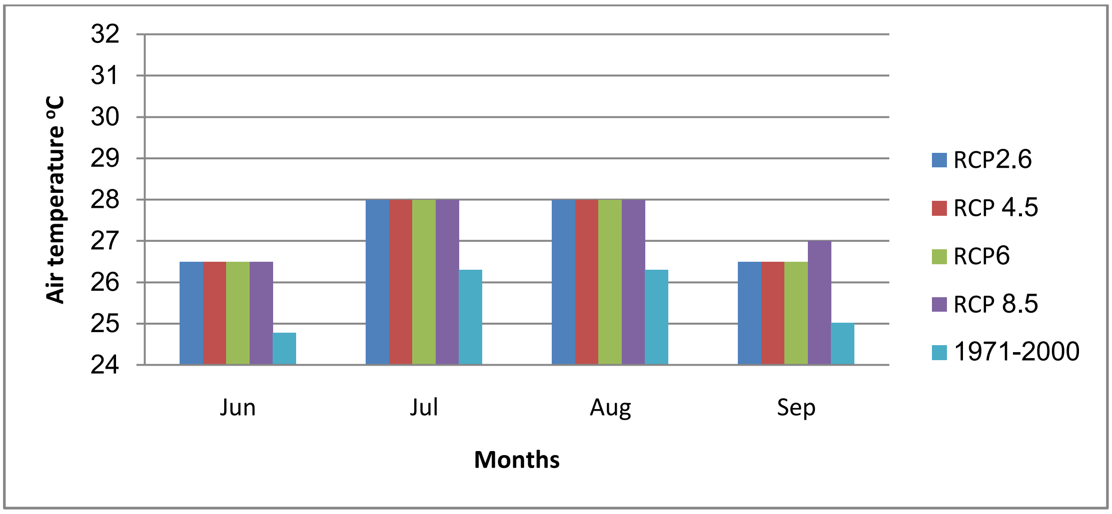

Fig 1.The average monthly air temperature in Kafr El-shiekh Governorate under current (1971-2000) and future conditions (2011-2040) for different RCPS scenarios.

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2- Trend of temperature under future conditions (2041-2070).

Data in fig. (2) show the results of average monthly mean air temperature from Jun to September in Kafr El-Sheikh Governorate under current (1971- 2000) and future (2041-2070) conditions for the four RCP scenarios. The difference between RCP2.6 and current conditions ranged from 1.70 to 1.98 ^{o}C, while this difference increased under RCP 4.5 ranged from 2.70 to 2.73 ^{o}C. The highest difference was found in RCP8.5 ranged from 2.98 to 4.20 ^{o}C compared to current climatic conditions.

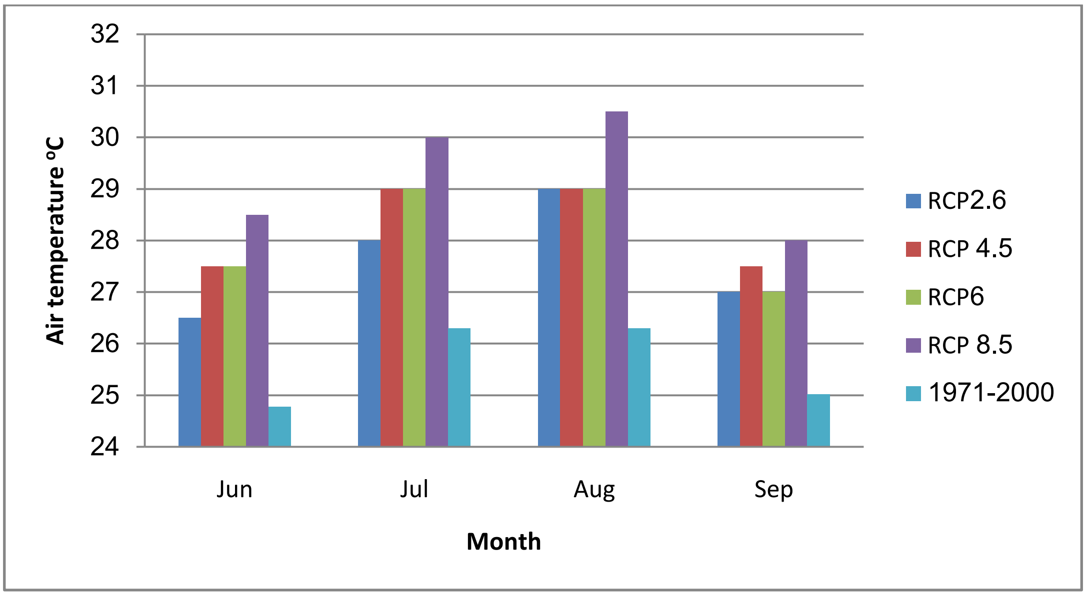

Fig 2.The average monthly air temperature in Kafr El-Shiekh Governorate under current (1971-2000) and future conditions (2041-2070) for different RCPS scenarios.

3- Trend of temperature under future conditions (2071-2100).

Fig. (3) illustrate the results of average monthly mean air temperature from Jun to September in Kafr El-Sheikh Governorate under current (1971- 2000) and future (2071-2100) conditions for the four RCP scenarios. The highest difference between (1971-2000) and RCP scenarios found in August; the difference between current and future conditions was about 2.70 under RCP2.6; but, the difference between current and future conditions during August was 6.7 under RCP8.5. The time series (2071-2100) has the highest mean air temperature compared to the other time series (2011-2040 and 2041-2070).there were no significant differences among the average monthly mean air temperature for RCP2.6 under time series 2041-2070 and 2071-2100 during Jun to September. These projections are in line with several previous studies **(Van Vuuren *et al.*, 2011**; **Moss *et al.*, 2008** and **Rogelj *et al.*, 2012**). In addition, recent studies found that RCP8.5 always produces the greatest increase in air temperature, with the difference between the RCPs increasing through the 21st century. For the near surface air temperature, all assessed models agree on a substantial warming towards the end of the century in all seasons of the year regardless of the underlying scenario. On an annual basis a warming in the range of +1.5 and +3°C for the low and in the range between +3.5 and +6 °C for the high emission scenario can be considered to be likely towards the end of the 21st century.

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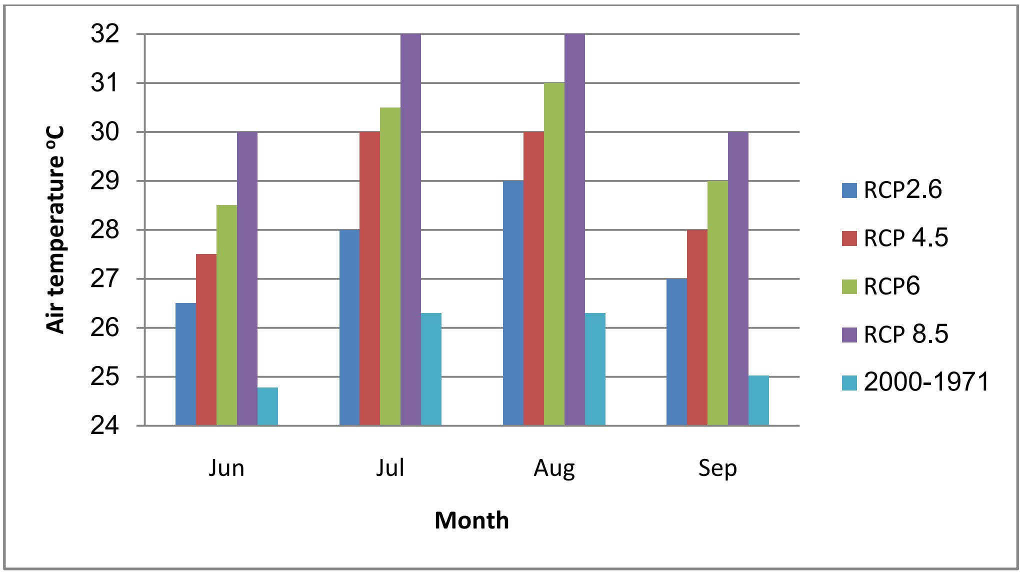

Fig 3.The average monthly air temperature in Kafr El-Shiekh Governorate under current (1971-2000) and future conditions (2071-2100) for different RCPS scenarios.

Trend of reference evapotranspiration (ETo) under the current (1971-200) and RCP scenarios

Data in Table (3) showed that the highest monthly ETo values in the Kafr El-Sheikh under the current situation (1971-2000) occured during August (5.27 mm/day), while the lowest ETo occured in September (5.05 mm/day). The climate change scenarios increased ETo significantly during the three studied time series. The highest increasing percentage of ETo values occured under RCP8.5; while the lowest increasing percentage of ETo values projected under RCP2.6 for the different time series. Regarding the ETo under short term time series (2011-2040) there were significant difference between current (2011-2040) ETo values and RCP scenarios. The increasing percentage between current and RCP scenarios at time series (2071-2100) were different depending on the scenario. The lowest increasing percentage was recorded in RCP2.6 (7.8%); while the highest increasing percentage was recorded in RCP8.5 (22.9%). These results agreed with **Allen *et al.* (2005)** who reported that there are a host of other variables that are related to temperatures which affect crop growth and yield, for example evaporation, transpiration, and vapor pressure deficit. Even solar radiation has been shown to be related to the diurnal air temperature difference. **Farag *et al*. (2014)** reported that the increasing percentage of the ETo values in Delta region under 2050s and 2100s were higher than current conditions by 10 to 18% depending on the climate change scenario. All ETo values under climate change scenarios increased significantly compared to current condition.

Table (3) : Average reference evapotranspiration (mm/day) under current (1971-2000) and RCP scenarios at Kafr El-Sheikh governorate

Time series	Month	1971-2000	RCP3	RCP4.5	RCP6	RCP8
2011-2040	Jun	5.40	5.79	5.79	5.79	5.79
	Jul	5.26	5.60	5.60	5.60	5.60
	Aug	5.27	5.61	5.61	5.61	5.61
	Sep	5.05	5.31	5.31	5.31	5.41
P-Value			*	*	*	*
Average		5.24	5.58	5.58	5.58	5.60
%		**0**	**6.4%**	**6.4%**	**6.4%**	**6.9%**
Time series	**Month**	**1971-2000**	**RCP3**	**RCP4.5**	**RCP6**	**RCP8**
2041-2070	Jun	5.40	5.78	6.02	6.02	6.26
	Jul	5.26	5.61	5.80	5.82	6.03
	Aug	5.27	5.83	5.82	5.80	6.12
	Sep	5.05	5.38	5.49	5.38	5.55
P-Value			*	*	*	*
Average		5.24	5.65	5.78	5.75	5.99
%		**0**	**7.8%**	**10.3%**	**9.7%**	**14.2%**
Time series	**Month**	**1971-2000**	**RCP3**	**RCP4.5**	**RCP6**	**RCP8**
2071-2100	Jun	5.40	5.78	6.02	6.24	6.61
	Jul	5.26	5.61	6.00	6.15	6.61
	Aug	5.27	5.83	6.06	6.22	6.64
	Sep	5.05	5.38	5.56	5.75	5.91
P-Value			*	*	*	*
Average		5.24	5.65	5.91	6.09	6.44
%		**0**	**7.8%**	**12.7%**	**16.2%**	**22.9%**

*** Significant at P < 0.05**

Irrigation water demands for rice in Kafr El-Sheikh

Data in Table (4) show the irrigation requirements for rice in Kafr El-Sheikh. The average monthly irrigation requirements for rice crop resulted from multiplying the average monthly ETo by crop coefficient of rice. According to the current situation, one feddan of rice needs about 5401 m^3 of irrigation water in Kafr El-Sheik Governorate. It is clear that the highest irrigation requirements recorded under RCP 8.5 at time series (2071-2100) was about 6708 m^3/ feddan; while the lowest irrigation requirements recorded under RCP 2.6 at time series (2011-2040) was about 5748 m^3/ feddan. All RCP scenarios at time series (2011-2041) has the almost the same value, 5748 m^3/ feddans, without any difference between them.

Fig. (4) show the differences of irrigation water demands (m^3/feddan /season) in Kafr El-Sheikh governorate under current (1971-2000) and different RCPs scenarios. The highest difference between estimated irrigation requirements under current and future conditions which found at time series (2071-2100) under RCP 8.5 was about +1307 m^3/feddan /season; whereas the lowest which found at time series (2011-2070) under RCP2.6 was about +348 m^3/feddan /season.

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From the above mentioned results, it is clear that water requirement will increase significantly by difference values under climate change scenarios. Similar results were shown by **Gerten et al. (2011)** and **Olesen et al. (2007),** who predicted a reduction in IWR (irrigation water Requirement) of 4 to 82% by the end of the twenty-first century, depending on crop type and location. The projected decrease in IWR for the future climate scenarios indicated the need of a better management plan during the dry months. The water required for land preparation and the daily evapotranspiration in rice field will increase by an average of 31.3 mm and 0.33 mm/day, respectively, by the year 2100. Climate change will increase the daily use of water for irrigation by an amount of 0.8 mm/day at the end of this century (Shahid, 2011). The irrigation requirements for the important strategic crops in Egypt are expected to increase by a range of 6% to 16% by 2100. The high vulnerability of on-farm irrigation systems in Egypt is attributed to the low efficiency of irrigation management patterns (EEAA, 2010).

Table (4): Irrigation water demands (m3/feddan/season) for rice cultivated in the Kafr El-Sheikh Governorate under current and different RCP climate change scenarios.

time series	Month	1971-2000	RCP2.6	RCP4.5	RCP6	RCP8.5
	Jun	857	920	920	920	920
	Jul	1908	2035	2035	2035	2035
	Aug	1911	2031	2031	2031	2031
2011-204	Sep	725	762	762	762	762
P-Value			*	*	*	*
Total		**5401**	**5748**	**5748**	**5748**	**5748**
	Jun	857	918	955	955	994
	Jul	1908	2035	2111	2111	2187
	Aug	1911	2115	2104	2104	2221
2041-2070	Sep	725	773	789	773	797
P-Value			*	*	*	*
Total		**5401**	**5840**	**5958**	**5942**	**6199**
	Jun	857	918	955	991	1050
	Jul	1908	2035	2198	2233	2399
	Aug	1911	2115	2177	2257	2411
2071-2100	Sep	725	773	799	826	849
P-Value			*	*	*	*
Total		**5401**	**5840**	**6129**	**6308**	**6708**

*** Significant at P < 0.05**

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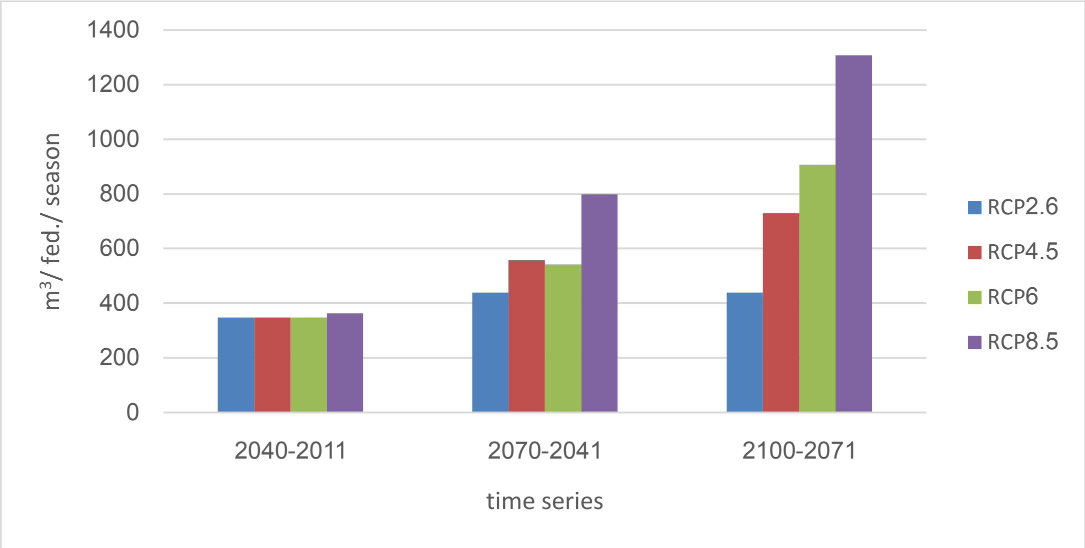

Fig. (4) Different Irrigation water demands (m^3/feddan /season) in Kafr El-shiekh governorate under current (1971-2000) and different RCPS scenarios.

Water budget for rice cultivated in the Kafr El-Sheikh Governorate under current and future condition.

Data in Table (5) show that total water budget for rice crop were resulted from multiplying total irrigation water demands (m^3/feddan /season) by total area cultivated (average area cultivated per feddan for five year) with rice in Kafr El-Sheikh Governorate.

According to current situation, water budget for rice crop in Kafr El-Sheikh need about 1426 million m^3 / season. It is clear that the highest water budge recorded under RCP 8.5 at time series (2071-2100) was about 1771 million m^3 / season; While, the lowest water budge recorded under RCP 2.6 at time series (2011-2040) was about 1518 million m^3 / season. All RCP scenarios at time series (2011-2041) had the almost same value 1518 million m^3 / season without any differences between them. The recorded water budge under RCP 2.6 at time series 2040-2070 and 2071-2100 had almost the same value 1542 million m^3 / season.

Fig. 5 show the differences of water budget, in million m^3 / season, in Kafr El-Sheikh Governorate under current (1971-2000) and different RCPs scenarios. The highest difference between water budgets found at time series (2071-2100) under RCP 8.5 was about +345 million m^3 / season; while the lowest difference of water budget found at time series (2011-2070) under RCP2.6 was about +92 million m^3 / season. Generally, the water budget will increase significantly by difference values under climate change scenarios.

Taking into account the demand for irrigation water in southern Europe and the Mediterranean area, under drier conditions more water will be required per unit area, and peak irrigation demands are expected to rise owing to droughts and high temperatures which put crops under severe stress. However, in some cases (Italy, Greece, Maghreb, central Spain, southern France and Germany) water demand is more than 150–200 m3/ha/year (**Lavalle et al., 2009**). The cultivated areas in Egypt have been increased over the past three decades. The government policy intends to increase reclaimed lands for agriculture. According to Abd El-Rahman **(2009),** the great challenge for the coming decades will therefore be the task of increasing food production, with the limited water resources, especially in arid and semi-arid regions (**Abouzeid, 2002 and FAO, 2003**). Moreover, **Abdrabbo, *et al*. (2013**). Furthermore, future temperature rise is

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likely to increase irrigation requirements, thereby directly decreasing crop irrigation water use efficiency. Irrigation requirements of the strategic crops in Egypt are projected to increase by a range of 6% to 16% by 2100. The high vulnerability of on-farm irrigation systems in Egypt is attributed to low efficacy of irrigation management patterns (**EEAA, 2010**).

Table (5): Average water budget (million cubic meter) for rice cultivated in the Kafr El-Sheikh Governorate under current and different RCP climate change scenarios.

	Month	1971-2000	RCP2.6	RCP4.5	RCP6	RCP8.5
2011-2040	Jun	226	243	243	243	243
	Jul	504	537	537	537	537
	Aug	505	536	536	536	536
	Sep	191	201	201	201	201
P-Value			*	*	*	*
Total		**1426**	**1518**	**1518**	**1518**	**1518**
2041-2070	Jun	226	242	252	252	262
	Jul	504	537	557	557	578
	Aug	505	558	555	555	587
	Sep	191	204	208	204	210
P-Value			*	*	*	*
Total		**1426**	**1542**	**1573**	**1569**	**1637**
2071-2100	Jun	226	242	252	262	277
	Jul	504	537	580	590	633
	Aug	505	558	575	596	637
	Sep	191	204	211	218	224
P-Value			*	*	*	*
Total		**1426**	**1542**	**1619**	**1666**	**1771**

*** Significant at P < 0.05**

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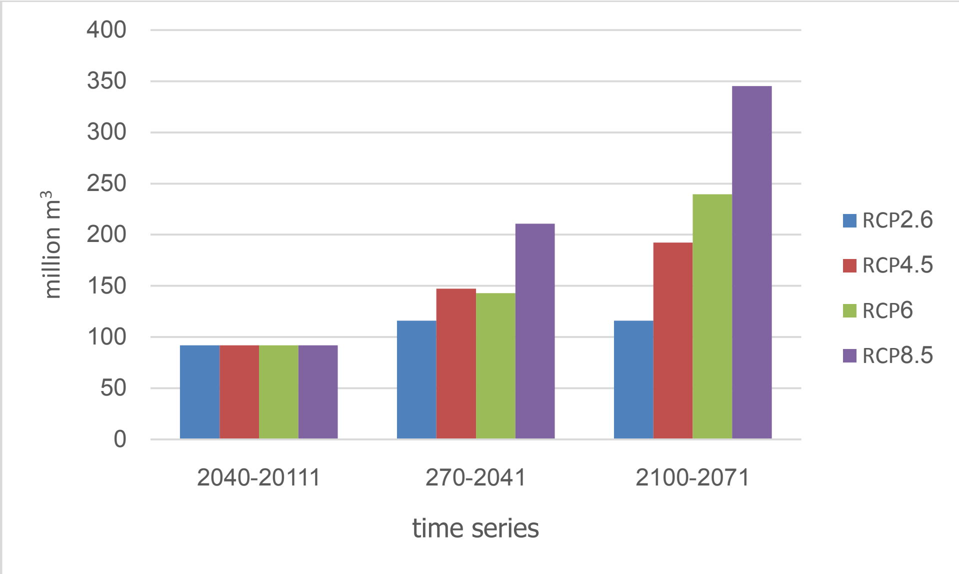

Fig. (5) The different water budget (million m^3/) in Kafr El-shiekh governorate under current (1971-2000) and different RCPS scenarios.

4. ADAPTATION

Given this situation, Egyptian agriculture is in great need for water budget adaption as increases in available water are not likely to happen. This adaptation would require actions such as:

- Improving irrigation system efficiency by reducing conveyance and application losses.
- Cultivation of dry rice varieties that need less water (by 33% of irrigation water).
- Improve different agricultural practices such as better use of fertilizers and pesticides.
- Breeding of short duration crops and improving water use efficiency.

5. CONCLUSION

Egypt is quite vulnerable to climate change and this study shows that irrigation water demands increases depending on climate change scenarios. The total amount of irrigation water demands increased per fedden per year ranging from 348 to 1370 m^3 in Kafr El-Shiekh Governorate under different climate change RCP scenarios. On the other hand, water budget under climate change scenarios in the same Governorate will increase, ranging from 92 to 354 million cubic meters. More adaptation options need to be studied under Egyptian condition.

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