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WATER REQUIREMENTS FOR POTATO PRODUCTION UNDER CLIMATE CHANGE

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ABSTRACT

In support of research to predict the impact of climate change on reference evapotranspiration (ETo) in Egypt, this study investigates the projected changes in evapotranspiration in Egypt, with a focus on the Delta, Middle and Upper Egypt. The maximum and minimum temperature were statistically downscaled and compared with a current climate, defined as the period 1971–2000. FAO-56 Penman-Monteith equation was used to estimate ETo by using the climatic data. Evapotranspiration is estimated based on the predicted maximum and minimum using the RCPs scenarios (RCP3.0 – RCP4.5 – RCP6.0 and RCP8.5) during three time series (2011-2040, 2041-2070 and 2071-2100). The obtained results revealed that the maximum and minimum air temperatures were increased under all RCPs scenarios compared to current data. Moreover, the RCP8.5 had the highest maximum and minimum air temperature compared to the other RCPs scenarios. It was found that for all future periods the annual evapotranspiration will increase for the all agro-meteorological zones by uneven values. The main results in this study revealed that ETo significant increase in different tested time series compared to current ETo values. The values of ETo in long term (2071-2100) were higher than short (2011-2040) or mid-term (2041-2070) with respect to the current situation. The highest ETo values was predicted in this study by RCP8.5 during the 2071 – 2100 time series in the Upper Egypt region. The estimation of water requirements for potato crops in different agro-climatic zone show that winter season had the highest cultivated area with potato followed by summer season. Upper Egypt region has the lowest cultivated area of potato during different cultivation season. Total water requirements (WR) for potato during the different cultivating seasons revealed that WR will increase under all scenarios in comparison with the current conditions. The highest water use efficiency was recorded in the Upper Egypt climatic zone during the winter season at 2012. Winter season gave the highest water use efficiency under (WUE) current and future conditions. Moreover, all RCPs scenarios had lower WUE than the current conditions during different time series. Regardless of the seasons, the RCP8.5 gave the lowest WUE in comparison with the other RCPs scenarios.

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Keywords: *Downscale climatic data- Maximum and minimum temperature - Penman-Montheith equation- RCPs scenarios.*

1 Introduction

Egypt is a country with a large population with large consequent food demands but limited water resources. Climate change poses major issues for the Egyptian agricultural sector. The Egyptian Environmental Affairs Agency **EEAA,(2002)** reported that "Egypt is highly vulnerable to climate change impacts, mainly due to the large and tightly packed population, and if climate change makes Egypt's climate drier or warmer; pressures on agriculture would intensify".

Egypt currently faces a tight water future **Sanchez and Swaminathan (2005)** Stated that the water gap in Egypt will reach 21.0 billion m^3 by the year 2025 even in the absence of climate change with competition increasing **El-Raey (1999).**

Agriculture the major water consumer **AbouZeid (2002)**. Climate change will alter agricultural water use potentially increasing demand. Effects on crop water use, have been studied, under Egyptian conditions in scattered and limited studies (**El-Marsafawy *et al* (1999), Eid *et al*(2001),Medany(2001) , Abdrabbo *et al* (2013) and Farag *et al* (2014)**). This study investigates the projected changes in water usefor a major Egyptian crop, potatoes using the latest **IPCC (2013)** climate change projections.

1.1 Background on climate change and crop water use

Crop yields are affected by water stress in general especially if it happens at key stages of growth **Salter and Good (1967**). Insufficient water supply inhibits plant growth in terms of leaf area and plant height **(Porro and Cassel (1986), Thompson and Chase (1992) and Abdrabbo *et al* (2007)**.

Climate change as projected by atmospheric scientists **IPPC (2013)** in turn is projected to adversely affect Egyptian crop production **IPPC (2014)**.The projected climate changes in Egypt as of 2100 would cause an increase in crop water use. The increase in the Delta region is projected to be between 2.4% to 16.2 %, while Middle Egypt use increased by 5.9% to 21.1% and Upper Egypt region by5.8% to 22.5% up to the year 2100as compared to current situation **Farag *et al* (2014)**.

Bazzaz and Sombroek (1996) Indicate that projected future temperature rises are likely to reduce the productivity of major crops, and increase its water requirements thereby directly decreasing crop water use efficiency and increasing irrigation demands.

1.2 Background on potatoes

Potatoes are a major crop in Egypt and contributes immensely to human nutrition and food security **Karim *et al* (2010)**. The total cultivated area of potatoes is 89 thousand hectares, which produce about two million Tons. About 85% of the production is consumed domestically with total potato exports in 2005 of296 thousand tons. There are three major cultivation season for Potato in Egypt: Summer season cultivated during December and January; Nili season cultivated during late September and early October and winter season cultivated during late October and early November. The weather conditions during growing season and farm management are considered one of the most important constrains on the ability to increase production **Amadi *et al* (2009)**.

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2 Material and methods

2.1 Climate change scenarios

The IPCC **IPCC (2013)** released a set of climate change scenariosbased onrepresentative concentration pathways (RCPs).The RCP scenarios involve 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 rapidly increasing CO2 emission trends with CO_2 concentration reaching 936ppmv by 2100 **IPCC (2013)**. Overall characteristics of these scenarios are given in table 1.

Table (1): Description of IPCC Representative Concentration Pathway (RCP) until 2100 compared to 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

2.2 Evapotranspiration calculation

Evapotranspiration is a measure of crop water use and will becalculated, 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:

Eq (1)

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

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

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

In turn the crop water requirement (WR), is calculated by multiplying the reference crop evapotranspiration, ET_o, by a crop coefficient, $K_c$following **Allen *et al* (1998).**

$WR = (ET_o * K_c) + LR * 4.2$ ……… (m^3 / Feddan/ day)

Where: -

WR = irrigation requirement for crop m^3/ Feddan/ day

K_c = Crop coefficient [dimensionless].

ET_o = Reference crop evapotranspiration [mm/day].

LR = Leaching requirement LR (%) (Assumed 20% of the total applied water)

4.2 is a conversion factor transforming the estimate from millimeters per day to cubic meters per Fadden per day (Fadden = 4200 m^2)

Finally water use efficiency (WUEwas calculated according to **Attaher and Medany (2008)** as the ratio of crop yield (y) to the total amount of irrigation water use in the field for the growth season (WR),

WUE (Kg/m3) = Y (kg)/WR (m^3)

2.3 Potato cultivation seasons

There are three major cultivation season for Potato in Egypt: Summer season cultivated during December and January; nili season cultivate during late September and early October and winter season cultivate during late October and early November.

2.4 Data and Projections

Egypt can be divided into several agro-climatic regions. The most important agro-climatic regions are: the Delta region, represented in this study by seven governorates (Kafr El-shiekh, Dakahlia, Sharqia, Ismailia, Portsaid, Suez and Cairo));the Middle Egypt regionrepresented by four governorates (Giza, Fayoum, Beni Suif and Menya) and the Upper Egypt regionrepresented by five governorates (Asyut, Sohag, Qena, Luxor and Aswan).

Downscaled climate data for these regions were drawn from ClimaScope(http://climascope.tyndall.ac.uk/) for the concerned governorates and average data for each agro-climatic zone were computed.Data on maximum and minimum historic temperature (1971 to 2010) plusprojections for diffferent eras (2011-2040, 2041-2070 and 2071 - 2100)were assembled.Daily

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historical data onrelative humidity, wind speed, preciptation and solar radiationweredrawn fromfrom automated weather stations ofthe Central Laboratory for Agriculture Climate (CLAC)and data sources in the concerned governorates.

2.5 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 periods2011-2040, 2041-2070 and 2071-2100, This was done with a paired t test at significant level 0.05 **SAS (2000)**. The hypotheses tested are:

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

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

The data were tested for differences in calculated ETo across the seven governorates in the Delta region, plus the four governorates in Middle Egypt and the five governorates in Upper Egypt.

3 RESULTS AND DISCUSSION

3.1 Trend of annual maximum air temperature

Fig. (1) Shows the projections for annual maximum air temperature for Delta region under current (1971- 2000) and future (2011-2040, 2041-2070 and 2071 - 2100)conditions. The annual maximum temperature in the Delta is projected to increase for all RCPs scenarios. The highest annual maximum air temperature values arise under RCP8.5, while the lowest arise under RCP2.6.

Similar results were found for Middle and Upper Egypt (Figures 2 and 3). The average annual maximum air temperature in middle Egypt is about 2°C hotter than in the Delta region.

These projections are in line with several previous studies **(Abdrabbo *et al* (2013),Smith *et al* (1996); AbouZeid (2002))**. In addition, recent studies have found that the warming over the last 50 years is about 0.13ºC per decade **(Smith *et al* (1996); SAS (2000); Attaher *et al* (2006)**

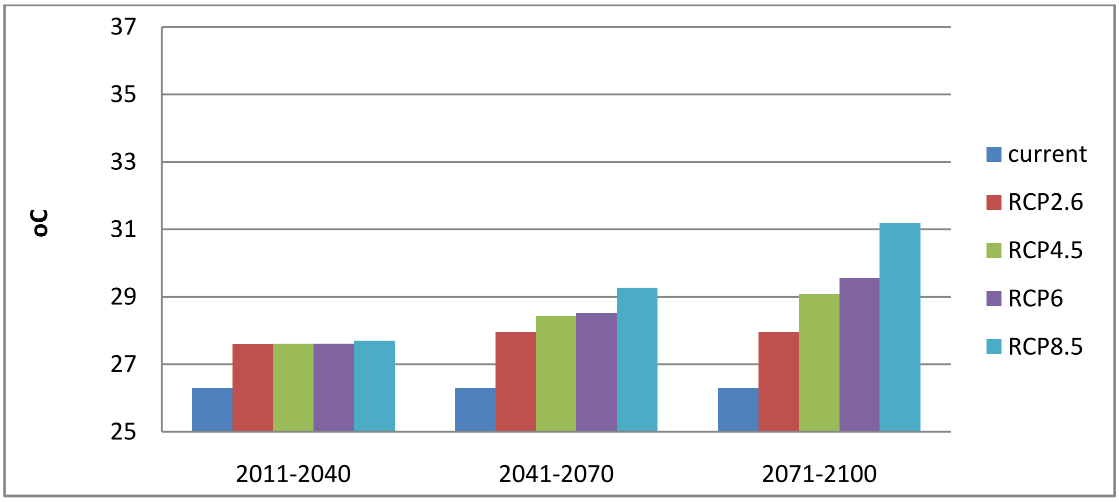

Fig 2. The average annual maximum air temperature in Delta region under current and future conditions for different RCPS scenarios.

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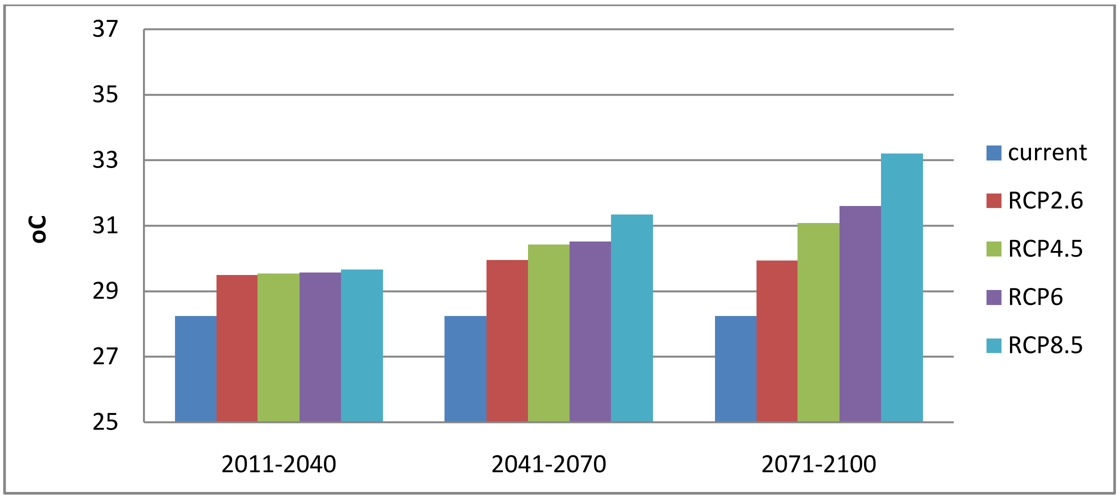

Fig 3.The average annual maximum air temperature in Middle Egypt region under current and future conditions for different RCPS scenarios.

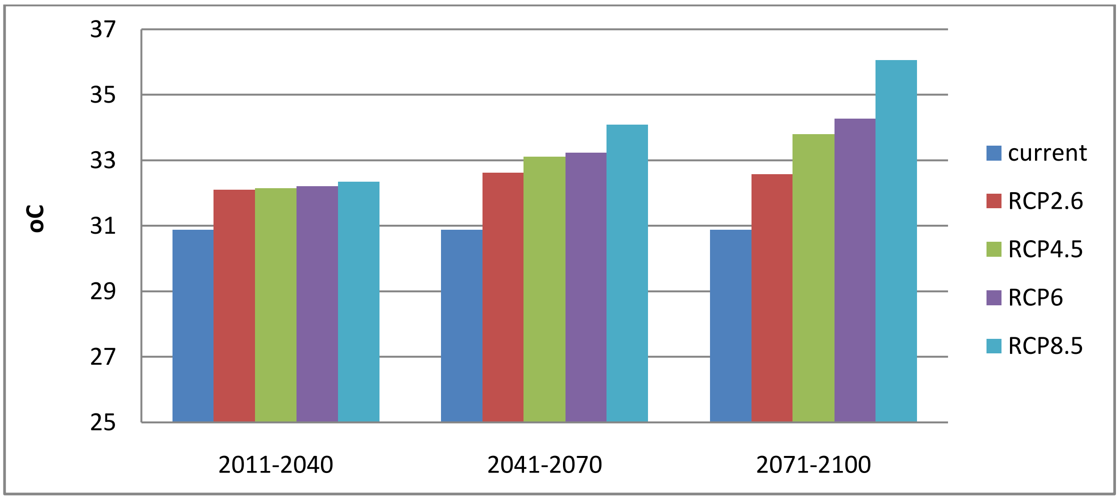

Fig 4. The average annual maximum air temperature in Upper Egypt region under current and future conditions for different RCPS scenarios.

3.2 Trend of annual minimum air temperature

Data in figures 4, 5 and 6 show results for average annualminimum air temperature. These also increased with generallythe same trends occurring in the Delta, Middle and Upper Egypt regions with Upper Egypt having the highest average annual minimum air temperature followed by Delta, while the Middle Egypt region had the lowest annual minimum air temperature. These results are in line with **Ayub and Miah (2011)** which mentioned that "temperature will increase by uneven values in different climatic regions under climate change conditions".

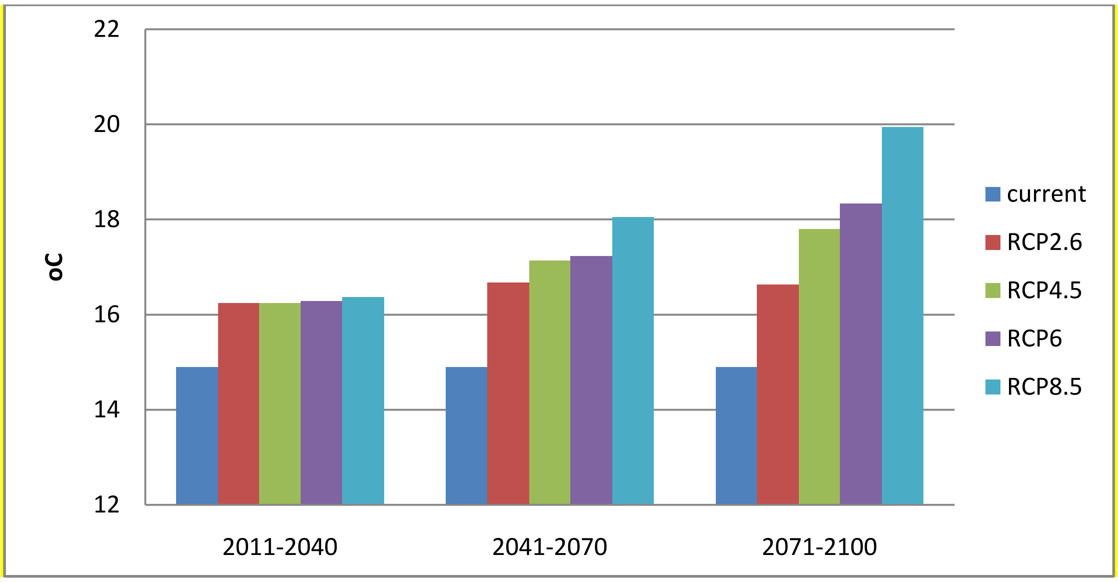

Fig 5. The average annual minimum air temperature in Delta region under current and future conditions for different RCPsscenarios.

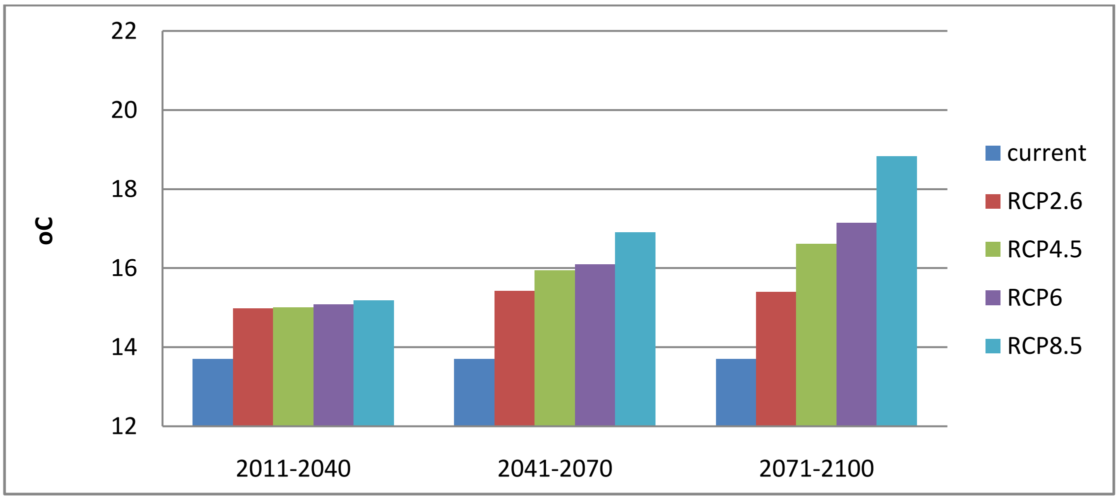

Fig 6. The average annual minimum air temperature in Middle Egypt region under current and future conditions for different RCPsscenarios.

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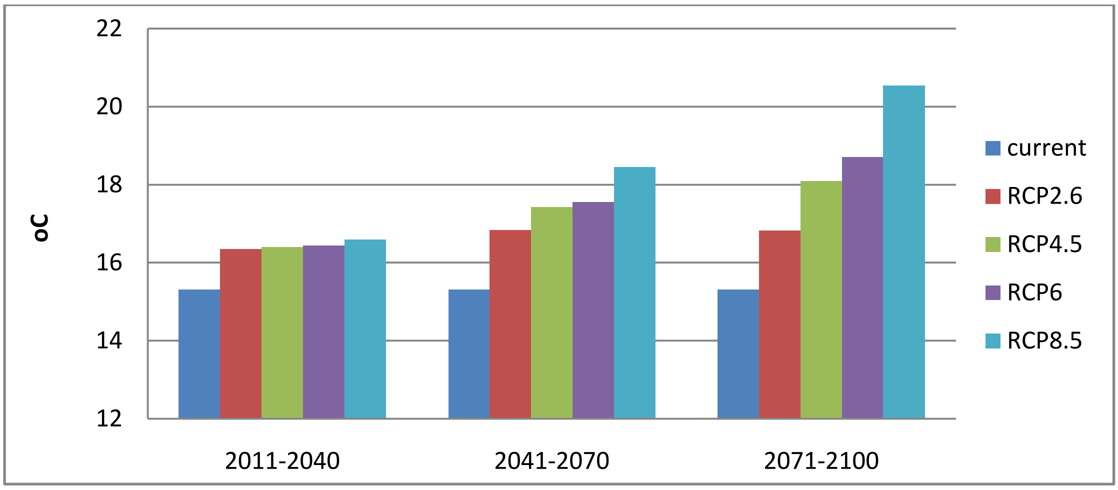

Fig 7. The average annual minimum air temperature in Upper Egypt region under current and future conditions for different RCPsscenarios.

3.3 Trendsinthe current and future ETo

Data in Table 2 illustrate the results of the ETo calculations for the Delta region under current and future conditions. The highest monthly ETo in the Delta under the current situation occurs during June (6.06 mm/day), while the lowest ET occurs inJanuary (2.26mm/day). Climate change uniformly increases ETo. The highest percentage increase occurs under RCP8.5.The lowest under RCP2.6.

Regarding Middle Egypt (Table 3), the ETo increases were greater. The highest average ETo value was recorded in July (7.59 mm/day); while the lowest value was recorded in January (2.62 mm/day). The percentage increase of ETo ranged between4.67(RCP6.0 at 2011-2040) to 19.55% (RCP8.5 at 2071-2010) compared to current conditions.

Table 4gives results for Upper Egypt region which also show higher average ETo values and in fact greater increases than in the Delta and the Middle Egypt regions.

Overall it is clear from Tables (2, 3 and 4) that there are uneven increases in monthly ETo under different tested RCPs scenarios. These results agree with those in **Ayub and Miah (2011); Haas (2002); Allen et al (2005); Attaher and Medany (2008);F.A.O. (1982).**

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Table 2. Average reference evapotranspiration (mm) under current and future conditions at Delta region.

month	Current	RCP2.6	RCP4.5	RCP6	RCP8.5	RCP2.6	RCP4.5	RCP6	RCP8.5	RCP2.6	RCP4.5	RCP6	RCP8.5
		2011-2040				2041-2070				2071-2100			
Jan	2.26	2.40	2.40	2.41	2.42	2.43	2.46	2.47	2.55	2.43	2.54	2.59	2.75
Feb	2.65	2.78	2.79	2.79	2.79	2.81	2.88	2.89	2.96	2.81	2.93	2.98	3.12
Mar	3.29	3.47	3.47	3.48	3.48	3.49	3.56	3.57	3.65	3.49	3.62	3.67	3.90
Apr	4.46	4.65	4.65	4.66	4.68	4.73	4.79	4.81	4.96	4.72	4.89	5.01	5.27
May	5.45	5.64	5.64	5.65	5.66	5.72	5.81	5.84	5.97	5.71	5.94	6.05	6.35
Jun	6.06	6.36	6.36	6.38	6.41	6.48	6.60	6.61	6.80	6.47	6.74	6.84	7.24
Jul	5.89	6.21	6.21	6.21	6.25	6.35	6.48	6.53	6.75	6.35	6.69	6.83	7.36
Aug	5.85	6.22	6.22	6.22	6.23	6.34	6.46	6.50	6.74	6.34	6.65	6.86	7.31
Sep	5.84	6.04	6.04	6.05	6.08	6.17	6.21	6.22	6.41	6.15	6.38	6.44	6.79
Oct	5.52	5.75	5.75	5.75	5.77	5.84	5.94	5.95	6.13	5.83	6.10	6.16	6.53
Nov	4.38	4.69	4.69	4.71	4.72	4.74	4.82	4.84	4.98	4.74	4.93	5.05	5.33
Dec	3.76	3.98	3.98	3.99	4.01	4.04	4.13	4.15	4.26	4.04	4.22	4.31	4.56
P-Value		*	*	*	*	*	*	*	*	*	*	*	*
%		5.06%	5.19%	5.02%	5.56%	6.73%	8.98%	8.55%	12.17%	6.61%	11.23%	13.33%	20.09%
Average %		5.21%				9.11%				12.81%			

***** Significant at P < 0.05***

the P-values are less than 0.05.

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Table 3. Average reference evapotranspiration (mm) under current and future conditions at Middle Egypt region.

month	Current	RCP2.6	RCP4.5	RCP6	RCP8.5	RCP2.6	RCP4.5	RCP6	RCP8.5	RCP2.6	RCP4.5	RCP6	RCP8.5
		2011-2040				2041-2070				2071-2100			
Jan	2.62	2.77	2.77	2.79	2.80	2.82	2.88	2.89	2.99	2.82	2.96	3.02	3.20
Feb	3.25	3.45	3.45	3.45	3.47	3.49	3.57	3.57	3.67	3.49	3.62	3.69	3.88
Mar	4.08	4.29	4.30	4.30	4.31	4.34	4.42	4.44	4.53	4.34	4.51	4.59	4.82
Apr	5.76	6.00	6.00	6.01	6.03	6.10	6.20	6.20	6.40	6.09	6.36	6.44	6.84
May	7.00	7.24	7.24	7.24	7.24	7.35	7.43	7.46	7.65	7.34	7.60	7.72	8.09
Jun	7.59	7.94	7.94	7.96	8.00	8.06	8.21	8.23	8.46	8.06	8.35	8.50	8.98
Jul	7.48	7.82	7.83	7.87	7.90	7.97	8.15	8.19	8.47	7.96	8.38	8.57	9.15
Aug	7.37	7.78	7.80	7.80	7.83	7.96	8.08	8.17	8.46	7.95	8.33	8.54	9.12
Sep	7.03	7.24	7.25	7.26	7.29	7.33	7.48	7.49	7.68	7.32	7.64	7.72	8.13
Oct	6.44	6.71	6.71	6.74	6.79	6.82	6.93	6.96	7.14	6.82	7.10	7.24	7.62
Nov	4.83	5.14	5.14	5.16	5.16	5.22	5.33	5.35	5.51	5.22	5.44	5.56	5.90
Dec	4.15	4.40	4.40	4.41	4.42	4.48	4.55	4.58	4.74	4.47	4.68	4.79	5.09
P-Value		*	*	*	*	*	*	*	*	*	*	*	*
%		4.78%	5.00%	4.67%	5.38%	6.41%	8.79%	8.31%	11.97%	6.34%	10.91%	12.97%	19.55%
Average %		4.96%				8.87%				12.44%			

***** Significant at P < 0.05**
***the P-values are less than 0.05.**

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Table 4. Average reference evapotranspiration (mm) under current and future conditions at Upper Egypt region.

month	Current	RCP2.6	RCP4.5	RCP6	RCP8.5	RCP2.6	RCP4.5	RCP6	RCP8.5	RCP2.6	RCP4.5	RCP6	RCP8.5
		2011-2040				2041-2070				2071-2100			
Jan	3.03	3.41	3.43	3.43	3.44	3.50	3.57	3.59	3.72	3.49	3.67	3.75	4.02
Feb	3.73	4.19	4.20	4.22	4.24	4.26	4.35	4.35	4.48	4.26	4.42	4.50	4.72
Mar	4.79	5.52	5.51	5.52	5.53	5.57	5.66	5.67	5.83	5.57	5.77	5.86	6.19
Apr	6.74	7.55	7.57	7.57	7.59	7.69	7.82	7.84	8.06	7.68	8.00	8.13	8.59
May	8.23	8.93	8.94	8.94	8.98	9.03	9.22	9.25	9.48	9.01	9.41	9.54	10.06
Jun	8.81	9.75	9.76	9.81	9.83	9.93	10.04	10.14	10.39	9.92	10.28	10.48	11.03
Jul	8.85	9.84	9.91	9.90	9.96	10.06	10.27	10.31	10.64	10.04	10.53	10.74	11.45
Aug	8.95	9.92	9.91	9.93	10.03	10.12	10.33	10.41	10.71	10.11	10.57	10.82	11.59
Sep	8.33	9.17	9.19	9.19	9.20	9.23	9.42	9.45	9.67	9.23	9.59	9.74	10.20
Oct	7.64	8.33	8.33	8.35	8.43	8.53	8.60	8.65	8.88	8.50	8.82	8.93	9.44
Nov	5.74	6.41	6.42	6.42	6.46	6.50	6.63	6.67	6.87	6.50	6.79	6.92	7.37
Dec	4.66	5.26	5.26	5.27	5.32	5.38	5.47	5.50	5.69	5.37	5.62	5.73	6.12
P-Value		*	*	*	*	*	*	*	*	*	*	*	*
%		11.22%	11.40%	11.03%	11.97%	12.93%	15.49%	14.96%	18.78%	12.82%	17.55%	19.66%	26.76%
Average %		11.40%				15.54%				19.20%			

**** Significant at P < 0.05***

****the P-values are less than 0.05.***

3.4 Water requirements

Data in Tables 5, 6 and 7 show the regional estimates of potato water requirements values in the summer, nili and winter seasons. The nili season has the highest water requirements (cubic meter per feddan) under current and future conditions. These results agree with those in **El- Marsafawy and Eid (1999), Eid *et al* (2001), Hulme *et al* (2001),IPCC (2007) and Diodato and Bellocchic (2010**).Projected future temperature rise increases water requirements although it is small in the near term but then shows expansions as time and temperature change increases. In turn this ET rise would increase irrigation requirements, thereby directly decrease crop water use efficiency and increase irrigation needs. In turn this indicates irrigation requirements for potatoes would be 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 low efficacy of irrigation management patterns **Abdrabbo *et al* (2013) and Irmak *et al* (2012).**

3.5 Total National water use for Potatoes

Data in Table 7show the total cultivated area(feddan) with potatoes for 2012by cultivation seasons (summer, nili and winter).Data in Tables 8 show the consequent total national water requirements (WR) by cultivation season using 2012 land areas.

Nationally these total water requirements increase across all but the RCP2.6 scenarios with the 2100 increase being as much as 6% for the total crop. These results verify those of **Irmak *et al* (2012), Moratiel (2011) and Nour El-Din (2013)**. Who concluded that the crop-water requirements of the important strategic crops in Egypt would increase under all IPCC SRES scenarios of climate change, by a range of 5 to 13% during the 2100.Additionally while not considered here the consequence of these changes is expected to be reduced yields of several staple food crops **Lobell *et al* (2008)**.

3.6 Water use efficiency .

An estimate of WUE (kg tuber yield / cubic meter of water) for potato under current and future conditions was presented in Table9. The lowest water use efficiency occurs in the Nili season due to the highest water requirements and lowest productivity per feddan then. The highest water use efficiency is in Upper Egypt during the winter.

WUE falls under all RCPs with RCP8.5 giving the lowest WUE. In addition, the vulnerability of on-farm irrigation in the Egyptian agricultural regions and the acceptable adaptation measures vary according to the local conditions of each region.

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Table (5). Average water requirements (m^3/feddan/season) for potato in summer season under current and future conditions at Delta, Middle and Upper Egypt region.

Month		RCP2.6	RCP4.5	RCP6	RCP8.5	RCP2.6	RCP4.5	RCP6	RCP8.5	RCP2.6	RCP4.5	RCP6	RCP8.5
	Current	2011-2040				2041-2070				2071-2100			
Delta	1334	1402	1405	1403	1408	1417	1444	1448	1486	1416	1472	1498	1583
Middle Egypt	1662	1745	1750	1748	1756	1771	1804	1809	1857	1770	1843	1873	1977
Upper Egypt	1935	2191	2199	2195	2205	2226	2267	2271	2337	2225	2312	2352	2484
P-Value		*	*	*	*	*	*	*	*	*	*	*	*

Table (6). Average water requirements for potato in Nili season under current and future conditions at Delta, Middle and Upper Egypt region.

Month		RCP2.6	RCP4.5	RCP6	RCP8.5	RCP2.6	RCP4.5	RCP6	RCP8.5	RCP2.6	RCP4.5	RCP6	RCP8.5
	Current	2011-2040				2041-2070				2071-2100			
Delta	1597	1692	1696	1692	1703	1715	1746	1753	1803	1714	1788	1824	1932
Middle Egypt	1794	1896	1905	1898	1912	1929	1964	1974	2036	1928	2014	2058	2180
Upper Egypt	2086	2327	2334	2330	2351	2375	2414	2427	2505	2372	2476	2522	2688
P-Value		*	*	*	*	*	*	*	*	*	*	*	*

Table 7. Average water requirements for potato in winter season under current and future conditions at Delta, Middle and Upper Egypt region.

Month		RCP2.6	RCP4.5	RCP6	RCP8.5	RCP2.6	RCP4.5	RCP6	RCP8.5	RCP2.6	RCP4.5	RCP6	RCP8.5
	Current	2011-2040				2041-2070				2071-2100			
Delta	1277	1353	1357	1354	1362	1370	1396	1402	1442	1370	1429	1459	1543
Middle Egypt	1456	1544	1550	1545	1556	1570	1600	1607	1659	1570	1639	1674	1774
Upper Egypt	1675	2093	2104	2099	2115	2135	2177	2186	2258	2134	2229	2274	2422
P-Value		*	*	*	*	*	*	*	*	*	*	*	*

***** Significant at $P < 0.05$** **the P-values are less than 0.05*

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3.7 Economic value of agriculture

The effects of climate change on water use arising herein are considerably larger than those used in the country wide analysis done by **McCarl *et al* (2013)** that used estimates from the second national communication (Egypt Environmental Affairs Agency,2010). In fact for one of the more prominent case, Delta Summer potatoes the estimate derived herein is about 67% greater.

To see the economic significance of this larger water consumption under climate change the model used in **McCarl *et al* (2013)** was run with increases water requirements. This was done for a 2060 climate scenario with the water use for all crops raised by 67%. The results, relative to McCarl et al's 2060 scenario for the A1F1 scenario, showed commodity prices rose by 13%, with production down by 3%, imports up by 2%, water values up by 10%, and an annual cost to Egypt of 5.8 million Egyptian Pounds. This shows that the increased water use can be costly and implies a need to carefully examine water demands under the newer projections of climate change for a wide variety of crops along with examining crop yields.

4 Adaptation

Given this situation Egyptian agriculture is likely to need to adapt as increases in available water are not likely. This adaptation would require actions such as

- Shifts to lower water using crops
- Breeding crops with improved water use efficiency
- Improving irrigation system efficiency by reducing conveyance and application losses
- Improve different agricultural practices such as better use of fertilizers and pesticides.

The above mentioned adaptation options in line with Abdrabbo et al (2007) who concluded that when irrigation water supply is limited; the best irrigation strategy would avoid moisture stress during critical crop growth stages.

5 Concluding comments

Egypt is quite vulnerable to climate change and this study shows that the important crop potatoes will have as much as a 6% increase in water use under severe climate change although it would fall under the severe mitigation implied under RCP2.6. This increase is larger than that estimated in previous studies and in our economic results is potentially quite costly and a greater stimulus for both crop adaptation and climate change mitigation. It also implies a need to carefully examine water use and yield implications for a wide variety of crops using observational and simulation approaches.

Table7. Total regional and national cultivated area (feddans) and yields (tons/feddan) by season for 2012 crop year.

Region	Season	Area Feddan	Average Yield Ton/feddan
Delta	Summer	126273	12.65
Middle Egypt		17931	10.76
Upper Egypt		911	14.50
Total		145115	12.43
Delta	Nili	11823	9.04
Middle Egypt		41857	9.76
Upper Egypt		1673	15.15
Total		55353	9.77
			2010
Delta	Winter	143359	10.74
Middle Egypt		25415	10.56
Upper Egypt		2189	18.97
Total		170963	10.82

- One feddan = 4200 square meter

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Table8. Total regional and national water requirements (million cubic meters) for potato at 2012 land use under current and future conditions.

Region	Season	Current	RCP2.6	RCP4.5	RCP6	RCP8.5	RCP2.6	RCP4.5	RCP6	RCP8.5	RCP2.6	RCP4.5	RCP6	RCP8.5
			2011-2040				2041-2070				2071-2100			
Delta	Summer	168.49	177.12	176. 98	177. 42	177.75	178.96	182.29	182. 84	187.70	178.84	185.90	189.14	199.88
Middle Egypt	Summer	29.79	31. 34	31. 29	31. 38	31.48	31.76	32.35	32.44	33.29	31.74	33.04	33.58	35.45
Upper Egypt	Summer	1.76	2.00	2.00	2.00	2.01	2.03	2.06	2.07	2.13	2.03	2.11	2.14	2.26
Delta	Nili	18.88	20.00	20.05	20.00	20.13	20.27	20.64	20.72	21.32	20.27	21.14	21.57	22.84
Middle Egypt	Nili	75.09	79. 36	79. 45	79. 73	80.01	80.75	82.20	82.63	85.24	80.71	84.29	86.13	91.26
Upper Egypt	Nili	3.49	3. 89	3.90	3. 90	3.93	3.97	4.04	4.06	4.19	3.97	4.14	4.22	4.50
Delta	Winter	183.02	193.98	194.53	194.08	195.28	196.37	200.18	201.04	206.72	196.37	204.85	209.14	221.25
Middle Egypt	Winter	37.02	39. 23	39. 39	39. 27	39.54	39.90	40.66	40.85	42.16	39.89	41.66	42.53	45.08
Upper Egypt	Winter	3.67	4. 58	4. 60	4. 59	4.63	4.67	4.76	4.79	4.94	4.67	4.88	4.98	5.30
Delta	Annual	370.39	390.96	392.2	391.1	393.16	395.6	403.11	404.06	415.74	395.48	411.89	419.85	443.97
Middle Egypt	Annual	141.9	149.88	150.50	150.06	151.03	152.41	155.21	155.92	160.69	152.34	158.99	162.24	171.79
Upper Egypt	Annual	8.92	10.47	10.50	10.49	10.57	10.67	10.86	10.92	11.26	10.67	11.13	11.34	12.06
All Egypt	Annual	**521.21**	**551.31**	**553.0**	**551.6**	**554.76**	**558.68**	**569.18**	**571.44**	**587.69**	**558.49**	**582.01**	**593.43**	**627.82**
Percent increase	Annual	--	**5.8%**	**6.1%**	**5.9%**	**6.4%**	**7.2%**	**9.2%**	**9.6%**	**12.8%**	**7.2%**	**11.75**	**13.9%**	**20.5%**

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Table 9. Water use efficiency for potatoes by region and season calculated using 2012 yields under current and future conditions.

Year			RCP2.6	RCP4.5	RCP6	RCP8.5	RCP2.6	RCP4.5	RCP6	RCP8.5	RCP2.6	RCP4.5	RCP6	RCP8.5
		Current	2011-2040				2041-2070				2071-2100			
Delta	Summer	9.48	9.03	9.00	9.02	8.99	8.93	8.76	8.74	8.51	8.93	8.59	8.44	7.99
Middle Egypt		6.48	6.17	6.15	6.16	6.13	6.08	5.97	5.95	5.80	6.08	5.84	5.75	5.44
Upper Egypt		7.49	6.62	6.58	6.60	6.57	6.51	6.40	6.38	6.20	6.52	6.27	6.16	5.84
Delta	Nili	5.66	5.34	5.33	5.34	5.31	5.27	5.18	5.16	5.01	5.28	5.06	4.96	4.68
Middle Egypt		5.44	5.15	5.12	5.14	5.11	5.06	4.97	4.94	4.79	5.06	4.85	4.74	4.48
Upper Egypt		7.26	6.51	6.48	6.50	6.45	6.38	6.28	6.24	6.05	6.39	6.12	6.01	5.64
Delta	Winter	8.41	7.94	7.94	7.92	7.89	7.84	7.69	7.66	7.45	7.84	7.52	7.36	6.96
Middle Egypt		7.25	6.84	6.83	6.81	6.79	6.72	6.60	6.57	6.36	6.73	6.44	6.31	5.95
Upper Egypt		11.33	9.06	9.04	9.02	8.97	8.89	8.72	8.68	8.40	8.89	8.51	8.34	7.83
Average		**7.64**	**6.96**	**6.95**	**6.94**	**6.91**	**6.85**	**6.73**	**6.70**	**6.51**	**6.86**	**6.58**	**6.45**	**6.09**
Percent decrease		**--**	**8.9%**	**9.3%**	**9.1%**	**9.6%**	**10.3%**	**12.0%**	**12.3%**	**14.9%**	**11.3%**	**14.0%**	**15.6%**	**20.3%**

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