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Implementing of RCPs Scenarios for the Prediction of Evapotranspiration in Egypt

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Authors' contributions

This study was carried out in collaboration between all authors. All authors managed the literature searches, read and approved the final manuscript.

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ABSTRACT

This study investigates the projected changes in evapotranspiration in Egypt, with a focus on the Delta, Middle and Upper Egypt regions. Maximum and minimum air temperature were statistically downscaled and compared with current climate (defined as the period 1971–2000). FAO-56 Penman-Monteith equation was used to estimate ETo using climatic data Evapotranspiration is estimated based on the predicted maximum and minimum temperature under four Representative Concentration Pathway (RCP) scenarios (RCP2.6 – RCP4.5 – RCP6.0 and RCP8.5) during three time series (2011-2040, 2041-2070 and 2071-2100) Other climate factors i.e., radiation, relative humidity and wind speed, used from current climate data. The obtained results revealed that maximum and minimum air temperatures 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 all agro-meteorological zones by uneven values. Results also revealed that ETo increased significantly in different tested time series compared to current ETo values. The values of ETo for the 2071-2100 period were higher than that for the 2011-2040 period or mid-term (2041-2070) period. The highest ETo values was predicted in this study by RCP8.5 during the 2071 – 2100 time series in the Upper Egypt region.

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1. INTRODUCTION

Climate change scenario development is a rapidly evolving field. Technological advances in modeling capacity and the ever-improving scientific basis of the models themselves ensure that technical aspects of modeling endeavors are always changing. However, although these advances are clearly important, they are less significant than the fundamental change in climate change modeling (including socio-economic) brought about by the shift from using IPCC SRES scenarios to representative concentration pathways (RCPs) that "will provide a framework for modelling in the next stages of scenario-based research" [1].

AR5 uses four Representative Concentration Pathway (RCP) scenarios with widely differing emissions pathways, reflecting different levels of ambition in tackling climate change. The lowest, RCP2.6 is a very strong mitigation scenario, with CO_2 levels peaking by 2050 at ~443 ppmv. RCP4.5 has a continuing rise in CO_2 concentrations to the end of the century, when they reach ~538 ppmv. In RCP6.0, CO_2 concentrations rise more rapidly, reaching ~670 ppmv by 2100. RCP8.5 continues current rapidly increasing CO2 emission trends with CO_2 concentration reaching 936 ppmv by 2100 [2]. The RCP 8.5 was developed using the MESSAGE model and the IIASA Integrated Assessment Framework by the International Institute for Applied Systems Analys is (IIASA), Austria. This RCP is characterized by increasing greenhouse gas emissions over time, representative of scenarios in the literature that lead to high greenhouse gas concentration levels [3]. Whereas, RCP6.0 was developed by the AIM modeling team at the National Institute for Environmental Studies (NIES) in Japan. It is a stabilization scenario in which total radiative forcing is stabilized shortly after 2100, without overshoot, by the application of a range of technologies and strategies for reducing greenhouse gas emissions [4,5]. While, RCP 4.5 was developed by the GCAM modeling team at the Pacific Northwest National Laboratory's Joint Global Change Research Institute (JGCRI) in the United States. It is a stabilization scenario in which total radiative forcing is stabilized shortly after 2100, without overshooting the long-run radiative forcing target level [6,7]. Furthermore, RCP2.6 was developed by the IMAGE modeling team of the PBL Netherlands Environmental Assessment Agency. The emission pathway is representative of scenarios in the literature that lead to very low greenhouse gas concentration levels. It is a "peak-and-decline" scenario; its radiative forcing level first reaches a value of around 3.1 W/m2 by mid-century, and returns to 2.6 W/m2 by 2100. In order to reach such radiative forcing levels, greenhouse gas emissions (and indirectly emissions of air pollutants) are reduced substantially, over time [8].

The expected climate changes in Egypt according to the applied scenarios will cause an increase in ETo depending on the climate region. The increase in the Delta region was between 2.4% to 16.2%, in the Middle Egypt region between 5.9% to 21.1% and in the Upper Egypt region between 5.8% to 22.5% up to the year 2100 as compared to current situation [9].

Bazzaz et al. [10] reported that the projected future temperature rises are likely to reduce the productivity of the major crops, and increase its water requirements thereby directly decreasing crop water use efficiency. On the other hand, it will cause a general increase of ETo value, this will lead to increase of irrigation demands.

Smith et al. [11] recommended the use of FAO-Penman Equation to calculate crop-water requirements, especially under limited climatic data conditions. Since ETo is computed from radiation, temperature, humidity and wind Speed, any change in these variables due to climate change are likely to change the ETo value. In 2002 Egyptian Environmental Affairs Agency [12] 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". Water is one of the sectors that face a lot of pressures under the current and the future conditions. [13] Stated that the water gap in Egypt will increase to reach 21.0 billion m^3 by the year 2025. Competition among the limited water resources could escalate even without climate change and the country could face an explosive situation [14]. Agriculture water-demand is one of the serious pressures to water sector [15]. The climate change impacts on evapotranspiration and crop water requirements, under Egyptian conditions, have been studied in scattered and limited studies [16,17,18,19,20,9] and most of these studies were focusing on specific regions in Egypt and specific crops.

The aim of this study is to trace the ETo values over time throughout major agro-climatic zones of Egypt under RCPs scenarios, then to determine the trend of future water demand according to the ETo trends.

2. MATERIALS AND METHODS

2.1 Representative Concentration Pathway (RCPs) scenarios

Clima Scope is a data visualization engine providing maps and data on projected climate changes for a range of global greenhouse gas emission scenarios. Outputs are stamped with metadata on which GCM was used, which carbon cycle was used, which emission scenario was used, and the source of the data in order to provide traceability (Table 1). The data come from peer-reviewed models linked together within the Community Integrated Assessment System (CIAS) developed at the Tyndall Centre for Climate Change Research within the School of Environmental Sciences at the University of East Anglia [21,22,23].

2.2 Agro-climatic Regions

Egypt has been divided into several agro-climatic regions according to the average temperature values. The most important agro-climatic regions are: the Delta region (30°N – 31°N), represented by seven governorates (Kafr El-shiekh, Dakahlia, Sharqia, Ismailia, Portsaid, Suez and Cairo); the Middle Egypt region (28°N – 30°N), represented by four governorates (Giza, Fayoum, Beni Suif and Menya) and the Upper Egypt region (24°N – 28°N) represented by five governorates (Asyut, Sohag, Qena, Luxor and Aswan).

The average agro-meteorological data were collected for the concerned governorates to calculate the average data for each agro-climatic zone (Fig. 1). The maximum and minimum temperature for the current period (1971 to 2000) and for the diffferent time series (2011-2040, 2041-2070 and 2071 - 2100) under different RCPs scenarios (RCP2.6, RCP4.5, RCP6.0 and RCP8.5) were downscalled from ClimaScope internet website http://climascope.tyndall.ac.uk/ Whereas, the Daily historical data of relative humidity, wind speed, preciptation and solar radiation were collected from automated weather stations of the Central Laboratory for Agriculture Climate (CLAC) to calculate the evapotranspiration of each agro-climatic zone. The data from 1998 to 2007 for different governorates

2.3 Evapotranspiration calculation

Evapotranspiration was calculated, for both current and future conditions, from different agro-climatic regions using Food and Agricultural Organization (FAO) Penman- Monteith (PM) procedure, FAO 56 method, presented by [24]. Evapotranspiration then estimated based on the predicted maximum and minimum under the RCPs scenarios (RCP2.6 – RCP4.5 – RCP6.0 and RCP8.5) for the three time series (2011-2040, 2041-2070 and 2071-2100). Other climate factors i.e., radiation, relative humidity and wind speed, were collected from current climate data. In this method, ETo is expressed as follows:

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

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

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

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 [24].

Table 1. Description of IPCC representative concentration pathway (RCP) up to 2100 compared to the average data from 1971 to 2000 year

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

Fig. 1. Location of the automatic weather stations in Egypt used in this study

2.4 Statistical Analysis

Statistical analysis was carried out using SAS software. The paired t– test was used to establish whether there exist significant differences in the Current ETo in 1971 to 2000 and estimated ETo under different climate change scenarios in 2011-2040s, 2041-2070s and 2071-2100s at significant level 0.05 [25]. The hypotheses tested are:

H_0: $\mu_{i1} = \mu_{i2}$
H_A: $\mu_{i1} \neq \mu_{i2}$ (i.e. $\mu_{i2} > \mu_{i1}$)

The t-calculated is given as

$$T - Calculated = \frac{\mu i1 - \mu i2}{SEi}$$

Where μ_{i1} and μ_{i2} are the means for the current and the estimated ETo compared for i climate variable respectively and SEi is the standard error for i climate variable.

Monthly ETo data have been compiled from three Agro climate region and compared with current data. The observed data where 144, compiled 12 months records for 4 RPCs scenarios under three time series per each region, that's compared with current data.

The studied samples consist of seven governorates in Delta, four governorates in Middle Egypt and five governorates in Upper Egypt. Using monthly temperature for current and different RPCs scenarios with all climate variable to calculate ETo. Aiming to compiling the current and RPCs, ETo data were calculated for each agro-climatic region. T-Test where used to compare two paired of monthly data of current and RPCs one.

3. RESULTS AND DISCUSSION

3.1 Current and Future Air Temperature

3.1.1 Trend of annual maximum air temperature

Fig. 2 shows the average annual trend of the maximum air temperature for Delta region under current (1971- 2000) and future periods (2011-2040, 2041-2070 and 2071 - 2100) for the concerned five governorates (Kafr El-shiekh, Dakahlia, Sharqia, Ismailia, Portsaid, Suez and Cairo). Data show that the annual maximum temperature in the Delta increased for all RCPs scenarios under all time series (2011-2040, 2041-2070 and 2071 - 2100) compared with current annual maximum temperature (26.3°C). The highest annual maximum air temperature values were found under RCP8.5 scenario during all time series (2011-2040, 2041-2070 and 2071 - 2100), while the lowest annual maximum air temperature values were found under the RCP2.6 scenario during different time series. The results also indicated that the range of annual maximum air temperature values was 27.6 (under RCP2.6 at 2011-2040) to 31.2°C (under RCP8.5 at 2071-2100). Regarding the predicted maximum air temperature in the Delta, the difference between RCPs scenarios was less than 0.5°C during the short term time series (2011-2040) while the differences increased during the long term time series (2071 – 2100) about 3.2°C (difference between RCP2.6 and RCP8.5 at 2071-2100). The same trend was found in the Middle and Upper Egypt agro-climatic regions (Figs. 3 and 4). Regarding the Middle Egypt region the range of annual maximum air temperature values ranged between 29.5 (under RCP2.6 at 2011-2040) to 33.2°C (under RCP8.5 at 2071-2100). It is clear that the average annual maximum air temperature under current and future conditions in middle Egypt is higher than Delta region by about 2°C. The highest annual maximum air temperature under current and future RCPs scenarios for Upper Egypt region are shown in Fig. 4. The range of annual maximum air temperature values were from 32.1 (under RCP2.6 at 2011-2040) to 36.1°C (under RCP8.5 at 2071-2100). The difference between the highest maximum air temperature (36.1°C) and the current annual maximum air temperature (30.9) was about 5.2°C. These results agreed with several previous studies [26,27,28]. In addition, recent climatological studies found that global surface air temperature increased from 1850 to 2005 by 0.76ºC and the linear warming trend over the last 50 years is determined by 0.13ºC per decade [26,29,30].

3.1.2 Trend of annual minimum air temperature

Data in Figs. 5, 6 and 7 show the average annually trend of minimum air temperature under current (1971- 2000) and future (2011-2040, 2041-2070 and 2071 - 2100) conditions for Delta, Middle and Upper Egypt, respectively. The lowest average annual minimum temperature was found during the current conditions in the different agro-climatic regions (14.9, 13.7 and 15.3 for Delta, Middle and Upper Egypt, respectively).

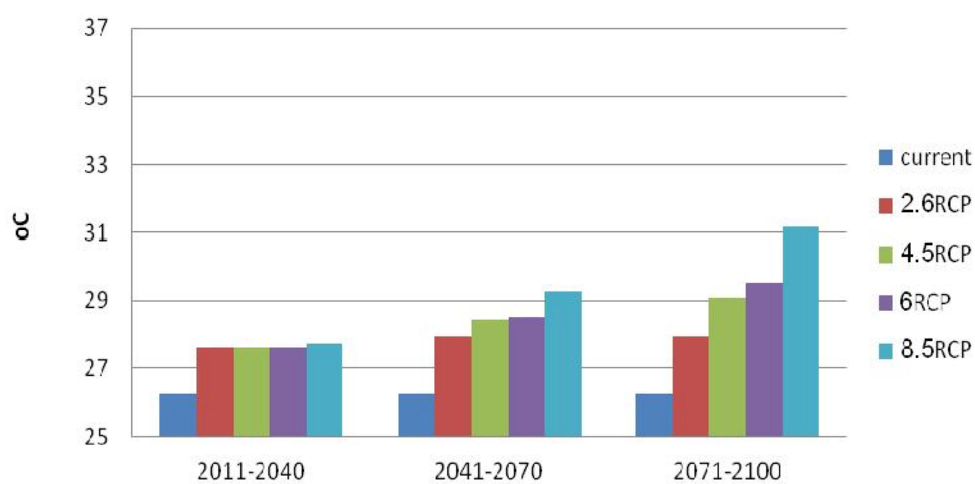

Fig. 2. Average annual maximum air temperature in Delta region under current and future conditions for different RCPS scenarios

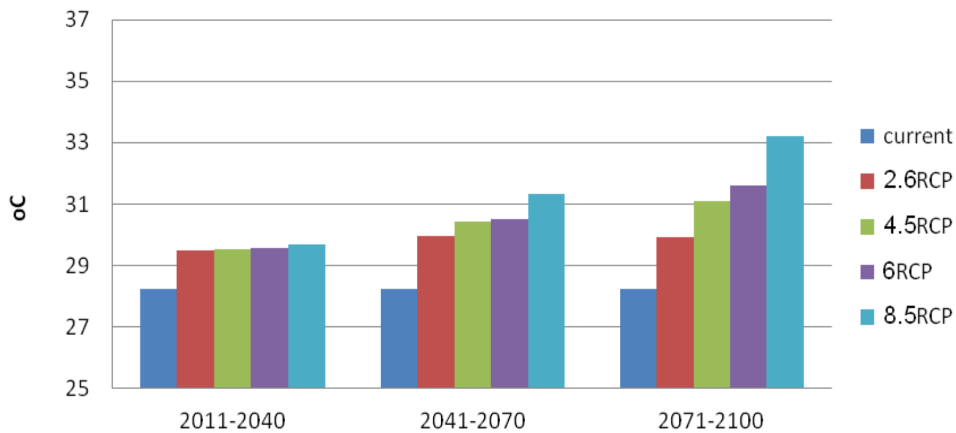

Fig. 3. Average annual maximum air temperature in middle Egypt region under current and future conditions for different RCPS scenarios

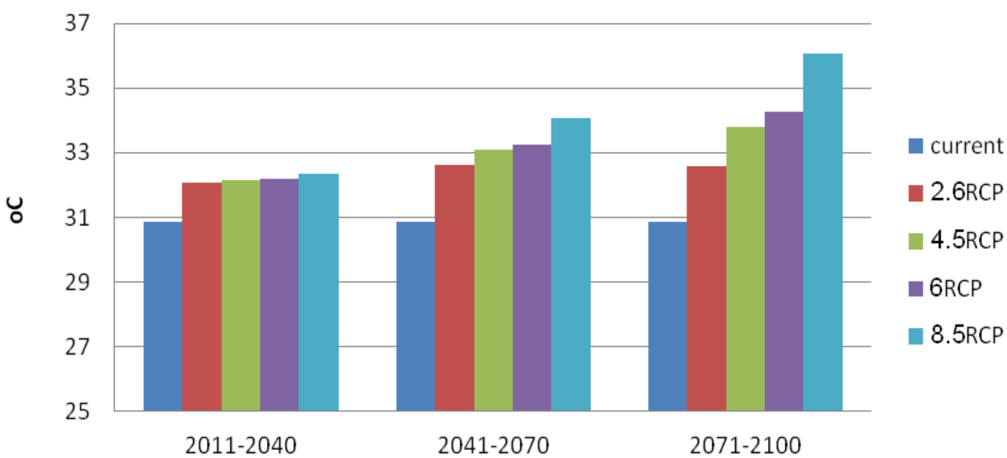

Fig. 4. Average annual maximum air temperature in upper Egypt region under current and future conditions for different RCPS scenarios

Fig. 5. Average annual minimum air temperature in Delta region under current and future conditions for different RCPs scenarios

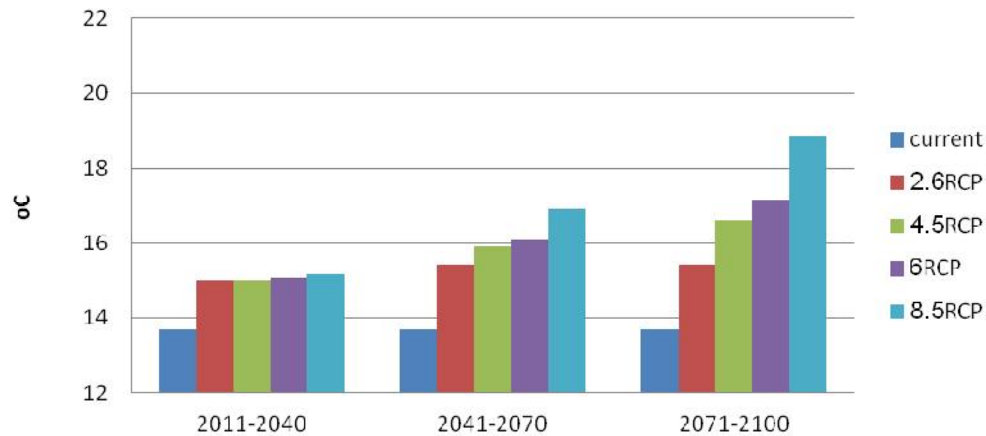

Fig. 6. Average annual minimum air temperature in middle Egypt region under current and future conditions for different RCPs scenarios

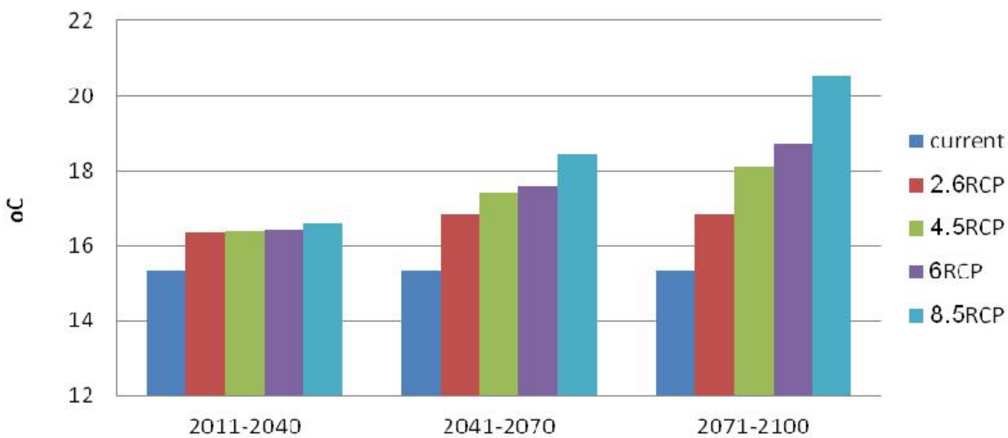

Fig. 7. Average annual minimum air temperature in upper Egypt region under current and future conditions for different RCPs scenarios

The projected annual minimum air temperature values were ranged by16.2, 15.0 and 16.4 (under RCP2.6 at 2011-2040) to 19.9, 18.8 and 20.6°C (under RCP8.5 at 2071-2100) for Delta, Middle and Upper Egypt, respectively. Generally, the same trends of the values of average annual minimum air temperature were found in the Delta, Middle and Upper Egypt. The highest average annual minimum air temperature was found in the Upper Egypt region under current situation as well as under future conditions. From the above, it could be concluded that Upper Egypt had the highest average annual minimum air temperature, under current and future conditions, as expected, followed by Delta, while the Middle Egypt region had the lowest annual minimum air temperature. These results are in line with the report of [31] which mentioned that "temperature will increase by uneven values in different climatic regions under climate change conditions". Moreover, Climate changes may have important impacts on agriculture. Based on the simulation of GCMS, future changes of global average temperature are expected to be between 2.8°C and 4.5°C in this century [32], and some regional areas would be even warmer than the global average [33]. So, both for policymakers and scientists, impacts of global warming on agriculture and water resources are referred to as an important issue [34,15].

3.2 Trend of Current and Future Eto

Data in Table 2 illustrate the average projected ETo values for the Delta region under current and future conditions (2011-2040, 2041-2070 and 2071 - 2100). Regarding the monthly ETo values, the highest ETo of the Delta region in the current situation was recorded during June (6.06 mm/day), while the lowest ETo was recorded in the January month (2.26 mm/day). The all projected ETo values during the different time series (2011-2040, 2041-2070 and 2071 - 2100) under different RCPs scenarios (RCP2.6, RCP4.5, RCP6.0 and RCP8.5) were higher than the current ETo values. The increasing percentage of the ETo values under 2071-2100 had the highest percentage increase of the ETo values (12.81%) compared to 2011-2040 (5.21%) and 2040-2071(9.11%). The lowest increasing percentage of ETo values was projected under RCP 4.5 at 2011-2040 time series (5.02%); while the highest was expected under RCP8.5 scenario at 2071-2100 (20.09%). All ETo values under climate change scenarios increased significantly compared to current conditions. Generally, the RCP8.5 scenario had the highest ETo values during different time series followed by RCP6.0 and then RCP4.5; the lowest ETo values was found under RCP2.6 scenario.

Regarding the average current and future ETo values for the Middle Egypt region (Table 3), current ETo values had the same trend as the Delta region with higher values. 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 between 4.67(RCP4.5 at 2011-2040) to 19.55% (RCP8.5 at 2071-2010) compared to current conditions. The ETo values in Middle Egypt region under RCPs climate change scenarios increased significantly compared to current values. Table 4 illustrates the average ETo for Upper Egypt region. It is clear that the Upper Egypt region had significantly higher average ETo values under current and future conditions (2011-2040, 2041-2070 and 2071 - 2100) than the Delta and the Middle Egypt regions. The percentage increase of average ETo values ranged between 11.03% (RCP4.5 at 2011-2040) to 26.76% (RCP8.5 at 2071-2010) compared to current conditions. The average ETo percentage increase values under 2071-2100 was higher than those found under other RCPs scenarios as well as under current conditions. With respect RCPs scenarios, the average percentage increase of average ETo value under 2071-2100 was 19.20%; while under 2011-2040 it was11.40%. It is clear from Tables (2, 3 and 4) that there are uneven increasing values of monthly ETo under different tested RCPs scenarios. These results are in match with [35,36,37,38,30].

3.3 Annual Current and Future Eto

Data in Figs. 8, 9 and 10 show the average annual ETo values under different RCPs scenarios for Delta, Middle and Upper Egypt regions, respectively. The annual ETo values had the same trend in all studied climatic regions. The ETo values under RCPs scenarios ranged between 4.85, 5.90 and 7.37 (RCP2.6 at 2011-2040) and between 5.54, 6.74 and 8.40 (RCP8.5 at 2071-2010) for delta, Middle and Upper Egypt regions, respectively. From all previous data, it could be concluded that the highest increase of predicted annual ETo was found in Upper Egypt during different time series; while the lowest increase of ETo was found in Delta.

Generally, the predicted annual ETo gradually increased with time series (2011-2040, 2041-2070 and 2071 - 2100) under different RCPs scenarios to reach the maximum predicted values during 2071 – 2100. The Upper Egypt region had the highest Eto than Delta and Middle Egypt regions due to the highest temperature during the year (located between 24ºN – 28ºN latitude lines). The same trend was found by [9] who expected the increase of ETo in the Delta region by 2.4% to 16.2%, in the Middle Egypt region by 5.9% to 21.1% and in the Upper Egypt region by 5.8% to 22.5% up to the year 2100 as compared to current situation. Moreover, [37] projected that the first order impacts of climate change on the Mediterranean hydrological systems as wetter winters and dryer summers, hotter summers and heat waves, and more variability and extreme weather events will take their toll. These impacts may induce an increase in evaporation (E) from natural and artificial water bodies and soils which reduce the available water supply [39]. Additionally; adapting to climate change will have close resonance with adapting to water scarcity and is likely to require implementation of water demand management strategies which may require capacity building and awareness raising across institutions and society. Adaptation measures on the supply-side include ways to improve rain-harvesting techniques, increasing extraction of ground water, water recycling, desalination, and improving water transportation. In addition, regular reviewing and updating of drought responses and research into improved long-term forecasting is essential to enhance Egypt's ability to cope with prolonged drought [40].

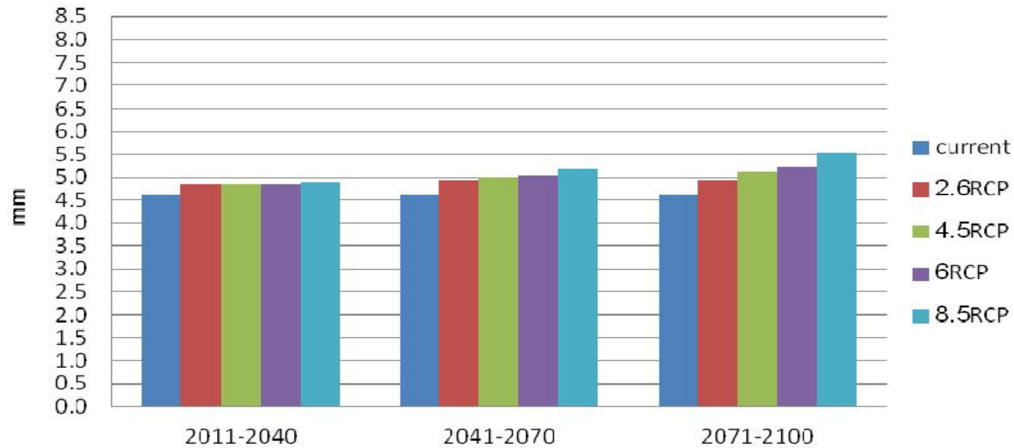

Fig. 8. Average annual ETo (mm) in Delta region under current and future conditions for different RCPs scenario

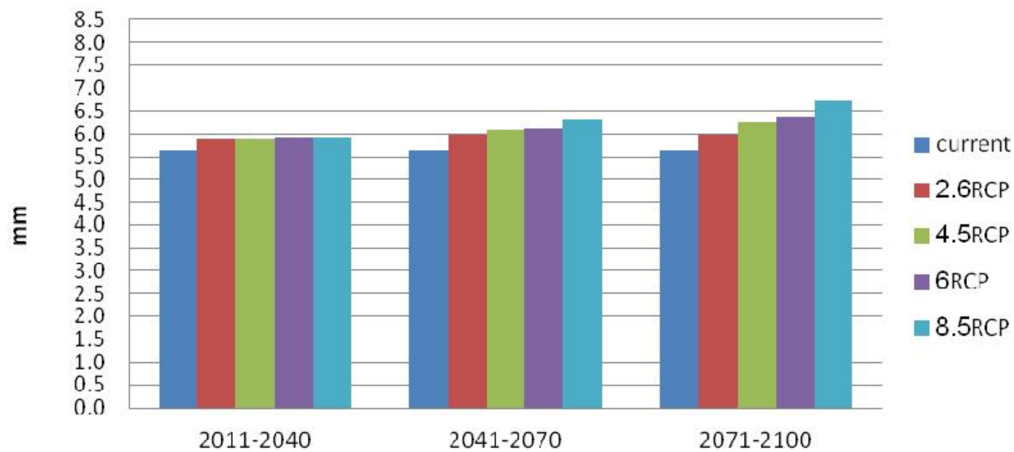

Fig. 9. Average annual ETo (mm) in middle Egypt region under current and future conditions for different RCPs scenarios

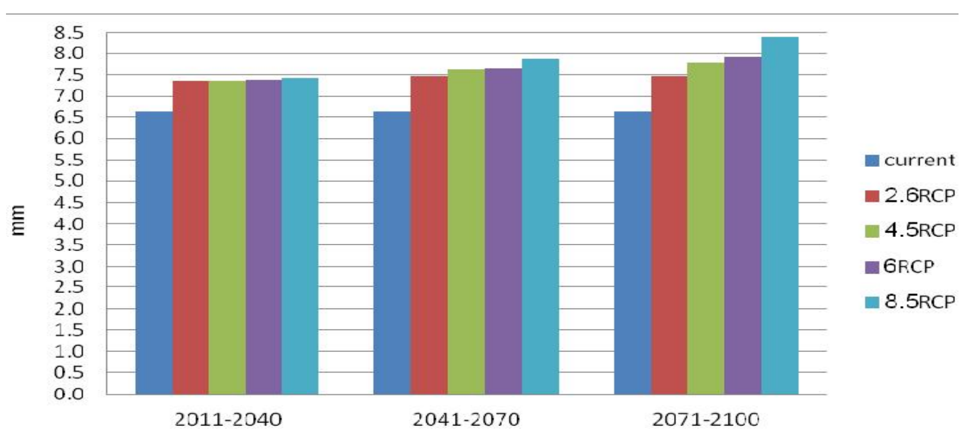

Fig. 10. Average annual ETo (mm) in upper Egypt region under current and future conditions for different RCPs scenarios

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

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

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

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

RCP8.5	RCP6	RCP4.5	RCP2.6	RCP8.5	RCP6	RCP4.5	RCP2.6	RCP8.5	RCP6	RCP4.5	RCP2.6	Current	month
2071-2100				**2041-2070**				**2011-2040**					
3.20	3.02	2.96	2.82	2.99	2.89	2.88	2.82	2.80	2.79	2.77	2.77	2.62	Jan
3.88	3.69	3.62	3.49	3.67	3.57	3.57	3.49	3.47	3.45	3.45	3.45	3.25	Feb
4.82	4.59	4.51	4.34	4.53	4.44	4.42	4.34	4.31	4.30	4.29	4.30	4.08	Mar
6.84	6.44	6.36	6.09	6.40	6.20	6.20	6.10	6.03	6.01	6.00	6.00	5.76	Apr
8.09	7.72	7.60	7.34	7.65	7.46	7.43	7.35	7.24	7.24	7.24	7.24	7.00	May
8.98	8.50	8.35	8.06	8.46	8.23	8.21	8.06	8.00	7.96	7.94	7.94	7.59	Jun
9.15	8.57	8.38	7.96	8.47	8.19	8.15	7.97	7.90	7.87	7.82	7.83	7.48	Jul
9.12	8.54	8.33	7.95	8.46	8.17	8.08	7.96	7.83	7.80	7.78	7.80	7.37	Aug
8.13	7.72	7.64	7.32	7.68	7.49	7.48	7.33	7.29	7.26	7.24	7.25	7.03	Sep
7.62	7.24	7.10	6.82	7.14	6.96	6.93	6.82	6.79	6.74	6.71	6.71	6.44	Oct

RCP8.5	RCP6	RCP4.5	RCP2.6	RCP8.5	RCP6	RCP4.5	RCP2.6	RCP8.5	RCP6	RCP4.5	RCP2.6	Current	month
2071-2100				2041-2070				2011-2040					
5.90	5.56	5.44	5.22	5.51	5.35	5.33	5.22	5.16	5.16	5.14	5.14	4.83	Nov
5.09	4.79	4.68	4.47	4.74	4.58	4.55	4.48	4.42	4.41	4.40	4.40	4.15	Dec
*	*	*	*	*	*	*	*	*	*	*	*	*P-Value*	
19.55%	12.97%	10.91%	6.34%	11.97%	8.79%	8.31%	6.41%	5.38%	5.00%	4.67%	4.78%		%
12.44%				8.87%				4.96%				Average %	

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

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

RCP8.5	RCP6	RCP4.5	RCP2.6	RCP8.5	RCP6	RCP4.5	RCP2.6	RCP8.5	RCP6	RCP4.5	RCP2.6	Current	month
2071-2100				2041-2070				2011-2040					
4.02	3.75	3.67	3.49	3.72	3.59	3.57	3.50	3.44	3.43	3.41	3.43	3.03	Jan
4.72	4.50	4.42	4.26	4.48	4.35	4.35	4.26	4.24	4.22	4.19	4.20	3.73	Feb
6.19	5.86	5.77	5.57	5.83	5.67	5.66	5.57	5.53	5.52	5.52	5.51	4.79	Mar
8.59	8.13	8.00	7.68	8.06	7.84	7.82	7.69	7.59	7.57	7.55	7.57	6.74	Apr
10.06	9.54	9.41	9.01	9.48	9.25	9.22	9.03	8.98	8.94	8.93	8.94	8.23	May
11.03	10.48	10.28	9.92	10.39	10.14	10.04	9.93	9.83	9.81	9.75	9.76	8.81	Jun
11.45	10.74	10.53	10.04	10.64	10.31	10.27	10.06	9.96	9.80	9.94	9.91	8.85	Jul
11.59	10.82	10.57	10.11	10.71	10.41	10.33	10.12	10.03	9.93	9.92	9.91	8.95	Aug
10.20	9.74	9.59	9.23	9.67	9.45	9.42	9.23	9.20	9.19	9.17	9.19	8.33	Sep
9.44	8.93	8.82	8.50	8.88	8.65	8.60	8.53	8.43	8.35	8.33	8.33	7.64	Oct
7.37	6.92	6.79	6.50	6.87	6.67	6.63	6.50	6.46	6.42	6.41	6.42	5.74	Nov
6.12	5.73	5.62	5.37	5.69	5.50	5.47	5.38	5.32	5.27	5.26	5.26	4.66	Dec
*	*	*	*	*	*	*	*	*	*	*	*	*P-Value*	
26.76%	19.66%	17.55%	12.82%	18.78%	15.49%	14.96%	12.93%	11.97%	11.40%	11.03%	11.22%		%
19.20%				15.54%				11.40%				Average %	

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

4. CONCLUSION

The expected climate changes in Egypt according to the RCPs scenarios will cause an increase in annual ETo depending on the climate region. The increase in the Delta region was between 5.02% and 20.09%, in the Middle Egypt region between 4.67% and 19.55% and in the Upper Egypt region between 11.03% and 26.76%, up to the 1971-2100 time series as compared to current situation.

Further studies are needed to compare different empirical equations in order to calculate evapotranspiration under current and future conditions.

COMPETING INTERESTS

Authors have declared that no competing interests exist.

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