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Irrigation water requirements as affected by diverse climate conditions

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Abstract---Determination of crop water requirement is one of the key parameters for precise irrigation scheduling, especially under limited water resources, such as in Egypt. Hence, an accurate estimation of reference evapotranspiration (ET_o) is a vital factor for agriculture production, therefore the objectives of the present study were to study the influence of climate change on different seasons and comparing of ET_o estimations using Blany- Criddle (BC) and FAO-56 Penman-Monteith (PM) equations under present and future climatic conditions. Data on the present climate have been collected from Wadi El-Natrun meteorological station, Egypt from 1991 to 2020. While the future climate data have been chosen for the concerned RCPs scenarios: RCP2.6, RCP4.5, RCP6.0, and RCP8.5 in 2040, 2060, 2080, and 2100. The results revealed that all months' reordered T_{mean} above 20 °C, except December, January, and February where they ranged between 17.68 and 19.44 °C. The highest T_{mean} values were observed in July (32.3°C), August (31.9 °C), and June (31.8 °C), while February scored the lowest T_{mean} (17.7 °C). Data indicated that estimated ET_o by BC was more than PM equation under all months and the rate of increase was small under the summer season (7.9, 4.9, 6.3), while a higher increase % was observed under cold months: November (51.4), December (73.1), January (79.5) and February (48.3). Respecting to the total ET_o estimated by BC and PM equations were 2056 and 1694

mm/year, respectively with an increase percentage 21.4%. Scenario (2.6) showed more harmony for the future than (8.5) scenario. Concerning the highest change, the percentage of increase of 2.6, 4.5, 6, and 8.5 as compared 2100 with control 2020 were 3.1, 7.5, 10.1, and 18.4 % respectively. Estimated ETo by BC equation at 2.6 scenarios was homogeneity while the opposite was true at 8.5 scenarios. Comparing between ETo estimated by BC and PM equations at 2.6 and 8.5 scenarios, the minimum ETo values were 103.36 (February), 208.76 (July) and 48.45, 187.31 mm/month after 2.6 scenario and 107.13, 215.52 mm and 53.18, 198.83 mm after 8.5 scenario, respectively. Total ETo (from May to September) after BC and PM equations were 968.30, 841.10 and 998.25, 887.81 mm after 2.6 and 8.5 scenarios with increasing percentages of 3.1 and 5.6 %, respectively.

Keywords---climate change, evapotranspiration, Penman-Monteith, Blaney-Criddle.

Introduction

Increasing the irrigated agriculture water use in Egypt could be attributed mainly to the absence of appropriate irrigation management and wrong water estimation for different crops (Ismail, 2002). Precise irrigation means, the application of a specific amount in a specific time, so the precise estimation of the crop water requirement is a must. Hence accurate estimation of the evapotranspiration (ETo), is a great challenge, especially in the agriculture sector. Where, estimating ETo depends mainly on the climatology components, especially temperature.

Climate change is one of the most complex and vital environmental problems that affect directly and indirectly on the ways of life, especially agriculture (Smith et al., 2016; Munoz-Rojas et al., 2017). They suggest that droughts will occur in some seasons in areas such as the Mediterranean region and Africa Egypt's climate is dry, hot, and dominated by desert. It has a mild winter season with rain falling along with coastal areas, and a hot and dry summer season (30 °C). The majority of rain falls along the coast, with the highest amounts of rainfall received in Alexandria (200 mm Y⁻¹) and decreasing dramatically with depth (Egyptian Environmental Affairs Agency, 2016), whereas, (Ayyad et al., 2019) stated that Egypt has been suffering from water scarcity in recent years. A good understanding of trends in ETo is critical for the scientific management of water resources in arid and semiarid regions. In the context of climate change, changes in all climatic parameters including temperature, wind speed, rainfall, solar radiation, and other factors will lead to the modified ETo, thus affecting the plan of crop water demand and agricultural water usage (Scheff and Frierson, 2014; Nam et al., 2016). Gaertner et al., (2019) have confirmed an increase in the ETo as a result of climate change and its estimating ETo is considered essential reference data for estimating the crop water requirement, water demand, and irrigation water management (Nam et al., 2015; Gao et al., 2017).

The estimation of crop water requirements is the first step used in project planning and design. The operation commonly involves the estimation of ETo or evaluation of crop evapotranspiration (ETc) and better estimates of ETc, which plays an important role in accurately determining the crop water requirements. There are many methods used to determine ETc, which is an essential element in crop water use (Attarod et al., 2005). These are Blaney-Criddle (BC), Thornthwaite, Hargreaves, and FAO-56 Penman-Monteith (PM). The first two methods are based on the air temperature while the other ones are based on the solar radiation. Equations of BC and PM, which is considered the most physical and reliable method and is often used as a standard to verify other empirical methods (Allen et al., 2005 Dirk 2009), methods are going to be compared under current and future conditions. In addition, due to the higher performance of PM methods, it has been accepted as the sole method of computing ETo from meteorological data (Gavila, et al, 2006).

The PM method (Allen et al., 1998) is generally considered to be the best approach for estimating ETc. Crop coefficients are used to estimate the ETo of crops multiplied by calculated potential or ETo. An estimate of ETo forms the foundation for the planning and designing of all irrigation projects and efficient water usage, providing a basic tool for computing water balance and predicting water availability and requirement (Humphrey et al., 1994; Pereira et al., 1999). Evapotranspiration involves a highly complex set of processes, which are influenced by many factors depending on the local conditions. These conditions range from precipitation and meteorology factors to soil moisture, plant water requirements and the physical nature of the land covered (Dunn and Mackay 1995).

The main data source for Climate Change Knowledge Portal (CCKP) is the CMIP5 (Coupled Inter-comparison Project No.5) data ensemble, which builds the database for the global climate change projections presented in the Fifth Assessment Report (AR5) of the Intergovernmental Panel on Climate Change (IPCC, 2019). Four Representative Concentration Pathways (i.e. RCP2.6, RCP4.5, RCP6.0, and RCP8.5) were selected and defined by their total radiative forcing (a cumulative measure of GHG emissions from all sources) pathway and level by 2100. The RCP 2.6 for instance represents a very strong mitigation scenario, whereas the RCP8.5 assumes a business-as-usual scenario. For simplification, these scenarios are referred to as a low (RCP 2.6); a medium (RCP4.5) and a high (RCP8.5) emission scenario in this profile. Table 1 provides CMIP 5 projections for essential climate variables under a high emission scenario (RCP 8.5) over four different time horizons.

Table (1) CMIP5 ensemble projections

CMIP5 Ensemble Projection	2020-2039	2040-2059	2060-2079	2080-2099
Temperature anomaly (°C)	(1.6°C)	(2.1°C)	(3.3°C)	(4.4°C)
Precipitation anomaly (mm)	(0.5 mm)	(1.9 mm)	(1.6 mm)	(2.9 mm)

The most important research objectives are summarized in the following points: i) Study the influence of climate change on weather seasons during the period (1991-2020), ii) Prediction of potential change in the annual mean, maximum,

and minimum temperature in the study area during the period of (2040 and 2100), and iii) Impact of climate change on irrigation water requirements (IWR) for the Citrus crop.

Materials and Methods

Study area: The study area locates between 30.78° latitudes and 30.08° longitudes. The selected area is a part of Behera governorate. The elevation of the investigated area is 11 meters above sea level. Due to the low precipitation (90 mm/y) and high evapotranspiration (1810 mm/y) the climate of the study area can be classified as a semi-arid climate. The soil of this site is sandy loam textured.

Climate data: Current climate variables, mainly T_{max} , T_{min} temperature and precipitation (1991-2020) were obtained from Wadi El-Natrun, weather station as a baseline period including daily precipitation, temperature (minimum, maximum, and average), and relative humidity. For future climate models and scenarios, the climate characteristics of the GCM simulation are based on a set of emission scenarios, or storylines, created by IPCC. A scenario may be viewed as a coherent, internally consistent and plausible description of a future estate of the world (Carter, 1996).

Climate change scenarios: Climate projections were provided by the Climate Change Knowledge Portal of Coupled IPCC published a Special Report on Emission Scenarios (SRES) in 2000 to reflect how the world might evolve in the future, and seek to give an overview of uncertainties of future development. Several alternatives have been proposed and these scenarios are based on demographic, technological and socio-economic developments. SRES scenarios are divided into four storylines which represent Representative Concentration Pathway (RCP); RCP2.6, RCP4.5, RCP6 and RCP8.5, receptivity. RCP2.6 is the low-end path, where radiative forcing peaks before 2100 and decreases to 2.6 W/m^2 by 2100 (490 ppm CO_2 eq.). RCP 4.5 scenario represents stabilization without overshoot pathway to 4.5 W/m^2 (~650 ppm CO_2 eq.) at stabilization after 2100 and RCP 8.5 scenario represents rising radiative forcing pathway leading to 8.5 W/m^2 (~1370 ppm CO_2 eq.) by 2100, these two RCPs were selected for this study because they represent realistically low and high future climate change scenarios. (Van Vuuren et al., 2011, Acharjee et al., 2017). Mean, maximum and minimum temperatures (T_{max} and T_{min}), and rainfall for the time series were predicted from 2020 to 2100. A future period is divided into 4 time periods of 20 years including the 2040s (2020-2040), 2060s (2041-2060), 2080s (2061-2080) and 2100s (2081-2100) were prepared and compared with the baseline period observation from 1991 to 2020.

Calculating the reference crop evapotranspiration (ET₀): The ET₀ is calculated by two methods, namely the FAO Penman-Monteith and the Blaney-Criddle Method. FAO Penman-Monteith method, using the decision support software CROPWAT 8.0 developed by FAO, based on Allen et al. (1998). The equation used for calculating ET₀ is described as follows:

$$ET_0 = \frac{0.408 * \Delta (R_n - G) + \gamma * \frac{900}{T + 273} * U_2 (e_s - e_a)}{\Delta + \gamma (1 + 0.34U_2)} \quad (1)$$

where ET_0 is the reference crop evapotranspiration (mm day^{-1}), R_n is the net radiation at the crop surface ($\text{MJ m}^{-2} \text{day}^{-1}$), G is the soil heat flux density ($\text{MJ m}^{-2} \text{day}^{-1}$), T is the mean daily air temperature at 2 m height ($^{\circ}\text{C}$), 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), $e_s - e_a$ is the vapor pressure deficit (kPa), Δ is the slope of the pressure-temperature curve ($\text{kPa } ^{\circ}\text{C}^{-1}$) and γ is the psychrometric constant ($\text{kPa } ^{\circ}\text{C}^{-1}$).

Blaney-Criddle method

The Blaney-Criddle method is one of the simplest techniques used to calculate ET. It was widely used before the introduction of Penman-Monteith equation. This method only considers temperature changes at a particular region for measuring reference ET. The Blaney-Criddle formula for estimating ET is as follows:

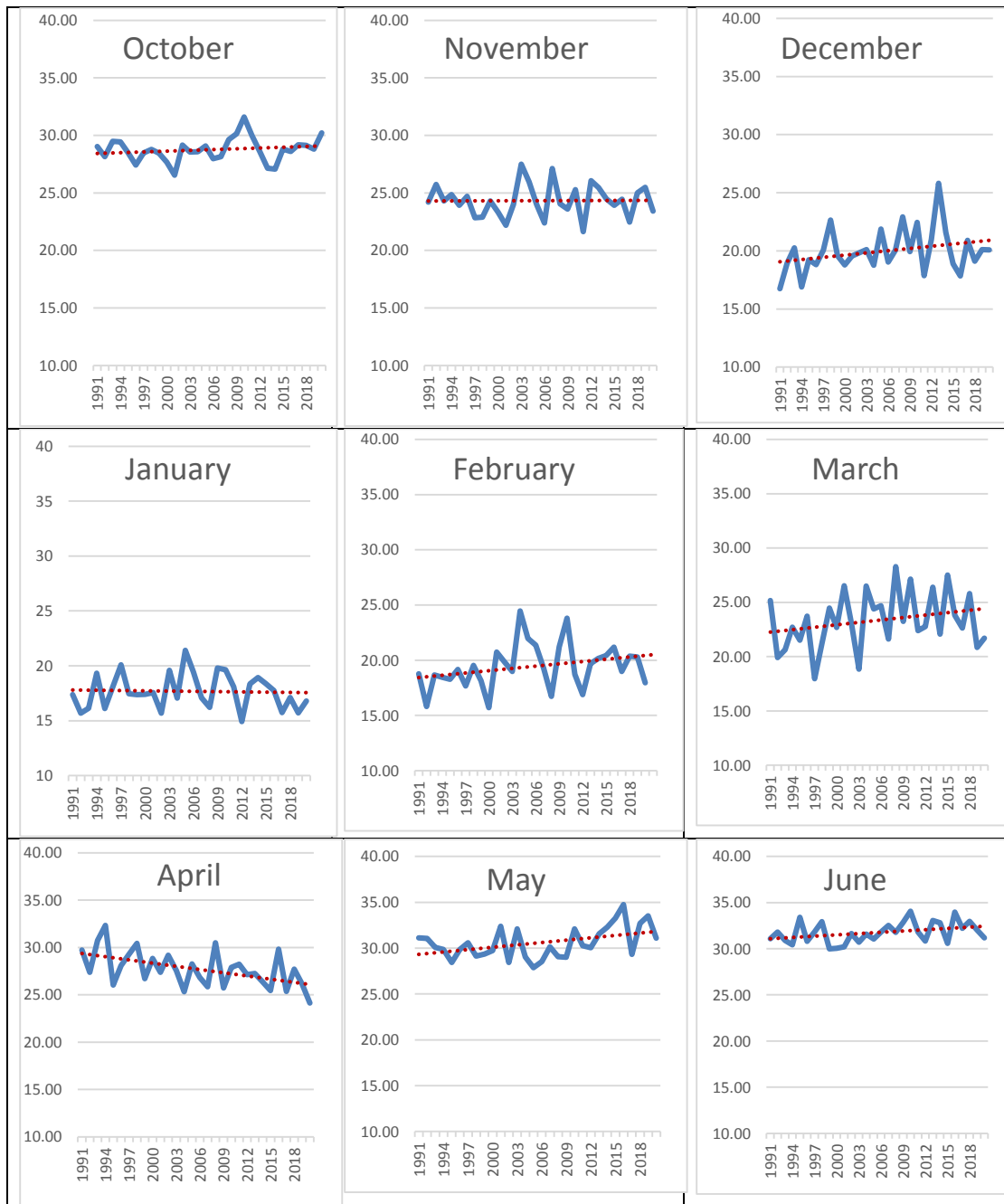
$$ET_0 = P(0.46 T_{\text{mean}} + 8.128) \quad (2)$$

Where, p is the mean daily percentage of annual daytime hours due to the latitude of a region, and T_{mean} is mean temperature ($^{\circ}\text{C}$).

Results and Discussion

Evaluation of monthly T_{mean} under climate change:

Data in Fig. 1 showed the mean monthly temperature during the previous study period (1991 – 2020). Data revealed that in February and March as the winter season, there is a great shifting in mean temperature values (T_{mean}) with a positive increase trend where it increases with future years. Same trend was attained in May and June, where a slight increase in T_{mean} value with time. Also, data mentioned that there is slight variation was noticed in July, August and September months. Whereas, T_{mean} values in December during the study period have highly deviated around the trend with a positive increase. From the abovementioned, winter months extend till April while early winter months tend to exceed the T_{mean} . Table 2 and Fig. 2 illustrated the months' mean value of the T_{mean} during the study period (1991-2020). Data pointed out that all months reordered T_{mean} above 20°C , except December, January and February where they ranged between 17.68 and 19.44°C . Also, data revealed that July, August and September scored T_{mean} above 30°C , whereas, the rest of the months (March and April) and October recorded less than 30°C . But the T_{mean} of the December still worms with a mean value of 20.0°C .



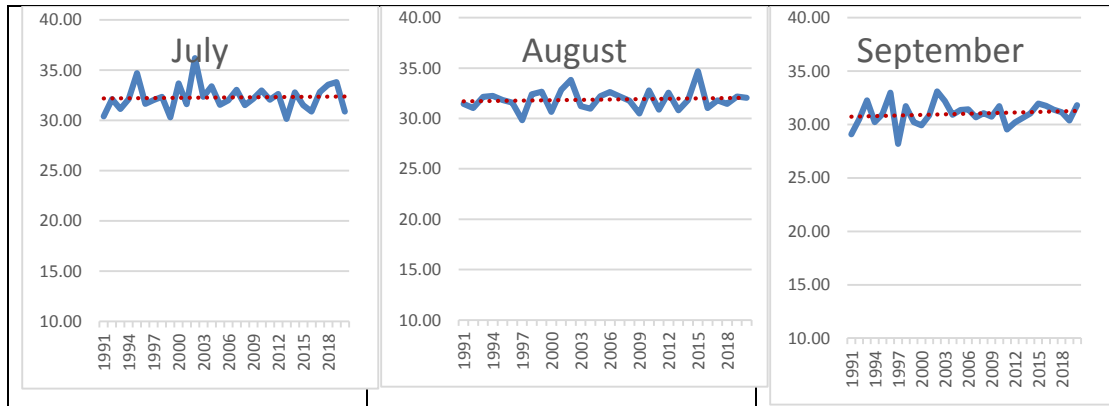


Fig (1) Mean temperature during (1991-2020)

Concerning the standard deviation (SD) values, data manifested in Table (2) illustrated that the highest SD values were attained in Feb, March and April, which means that the great change in the climate of these months and there is instability in the temperature. That is attributed mainly to the maximum temperature (T_{max}). Resulted data notice that most of the months going forward are hot and consequently could affect directly the ETo and/or indirectly through the change in the crop growth stages and its requirements.

Data in table (2) Fig (2) showed T_{mean} values during the last thirty years (1991-2020). Data pointed out that the highest T_{mean} were observed in July (32.3°C), August (31.9 °C), and June (31.8 °C), while February scored the lowest T_{mean} (17.7 °C). data observed that the highest SD values were recorded in February, March and April, which means that there were heat waves during these months, that lead to an increase in the T_{max} , while the lowest SD was attained in August, October and September which was ascribed to the base of harmony of the values during these months.

Data in Fig (3) showed the estimated ETo by the BC and PM equations. Data indicated that ETo value estimated by BC was more than PM under all months, and the rate of increase was small under the summer season (7.9, 4.9, 6.3), while a higher increase % was observed under cold months: November (51.4), December (73.1), January (79.5) and February (48.3). Respecting the total ETo estimated by BC and PM were 2056 and 1694 mm/year, respectively, which indicated that BC was higher than PM equation by about 21.4%.

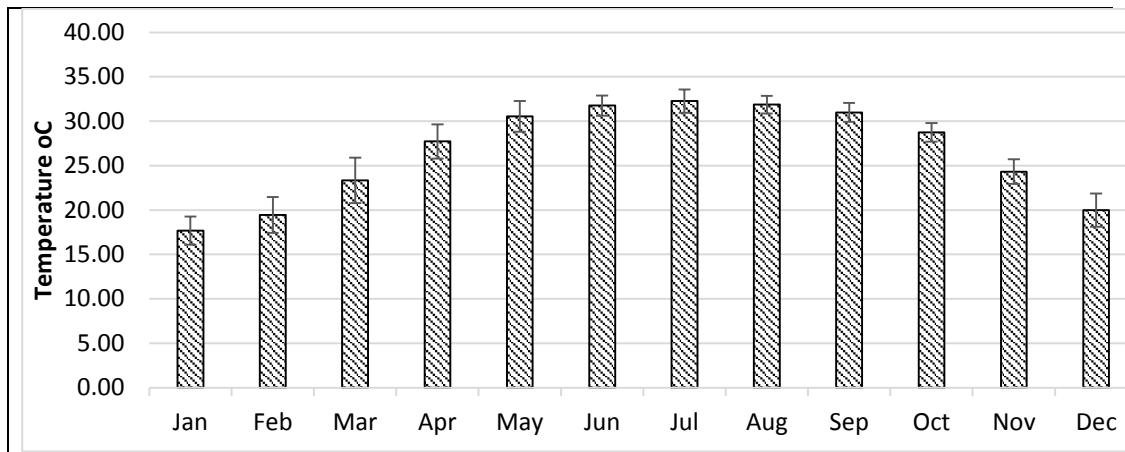
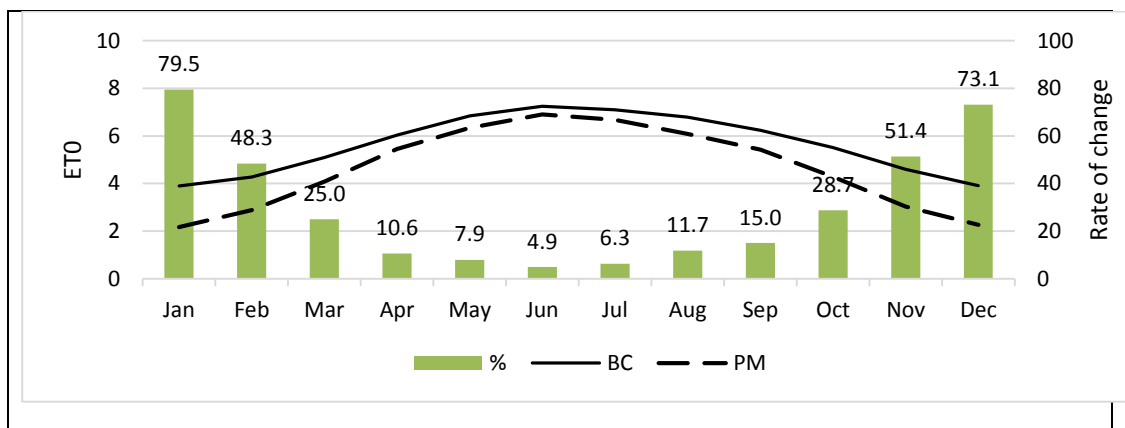


Fig (2) Mean temperature during (1991-2020)

Table (2) standard deviation for mean temperature during (1991-2020)

Month	Jan	Feb	Mar	Apr	Ma y	Jun	Jul	Aug	Sep	Oct	Nov	Dec
Tmean	17. 7	19. 4	23. 3	27. 7	30. 6	31. 8	32. 3	31. 9	31. 0	28. 8	24. 3	20. 0
S. Deviation	1.5 8	2.0 2	2.5 7	1.9 2	1.7 2	1.1 4	1.3 1	1.0 0	1.0 7	1.0 4	1.3 9	1.8 8



Fig(3) Mean ETO during (1991-2020) under Blamey& Criddle and Penman Monteith equations.

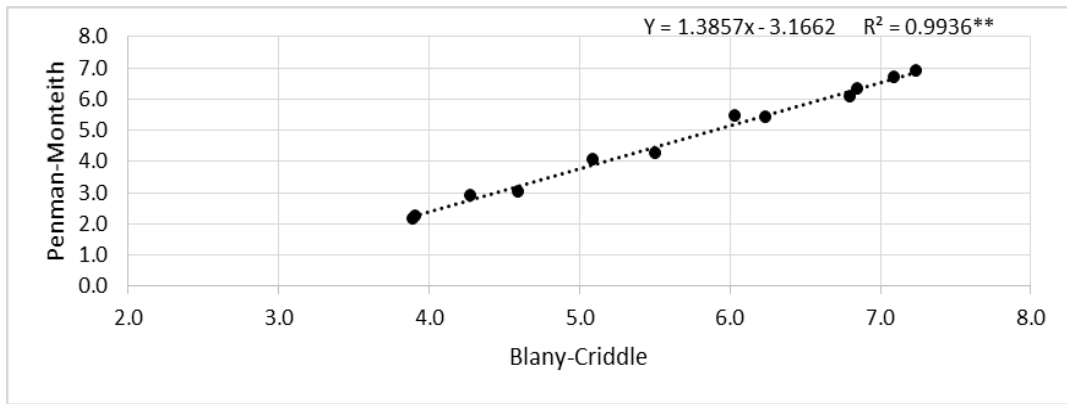


Fig (4) Relation between Blamey& Criddle and Penman Monteith equations.

Fig. 4 showed the relation between estimated ETo during the last 30 years (1991-2020). The resulted regression equation was highly significant with an r value of 0.9936**, and could be used to predict future ETo under future scenario (2.6, 4.5, 6 and 8.5).

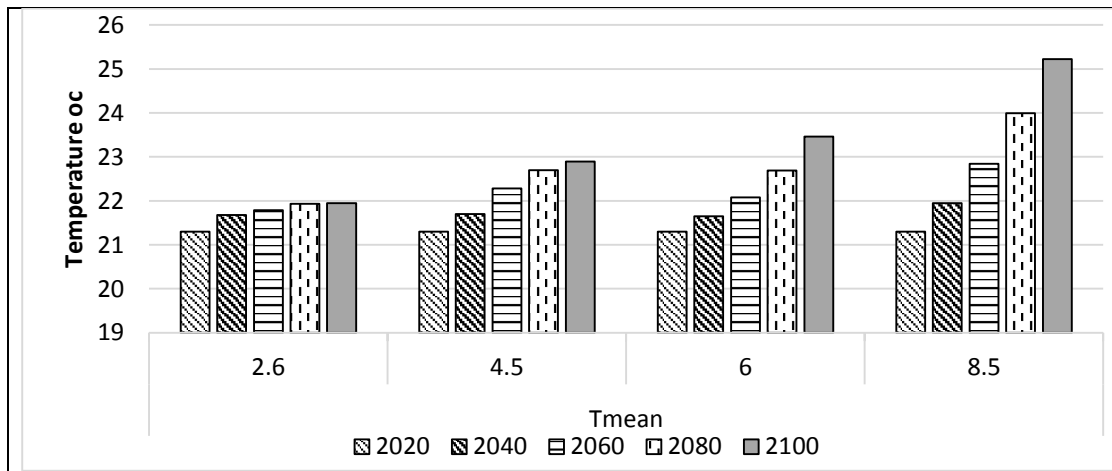


Fig (5) Mean temperature for the four scenarios under four-time periods 2021-2040, 2041-2060, 2061-2080 and 2081-2100 besides the current climate situation

Data in Fig (5) showed the relation between T_{mean} values at different predicting scenarios during (2040, 2060, 2080 and 2100) compared with the baseline year (2020). Data indicated that the lowest variation was obtained at (2.6) optimistic one, whereas, the pessimist one (8.5) record the highest variation with time from 2020 to 2100. Data cleared that scenario (2.6) showed more harmony for the future than (8.5) scenario. Also, data mentioned that the percentage of increase in the 2.6, 4.5, 6 and 8.5 scenario were 1.8, 0.5, 0.6, 0.1; 1.9, 2.7, 1.9, 0.8; 1.6, 2, 2.8, 3.4 and 3.1, 4.1, 5, 5.1 % for 2040, 2060, 2080 and 2100 as compared with baseline year 2020, respectively. About the highest change the percentage of increase of 2.6, 4.5, 6, and 8.5 as compared to 2100 with the baseline year 2020 were 3.1, 7.5, 10.1, and 18.4 % respectively. Our finding is supported by GERICS

(2019) which reported that temperatures in Egypt have increased at a rate of 0.1°C per decade on average between 1901– 2013. However, substantially stronger warming was observed over the past 30 years, with average annual temperatures increasing by 0.53°C per decade.

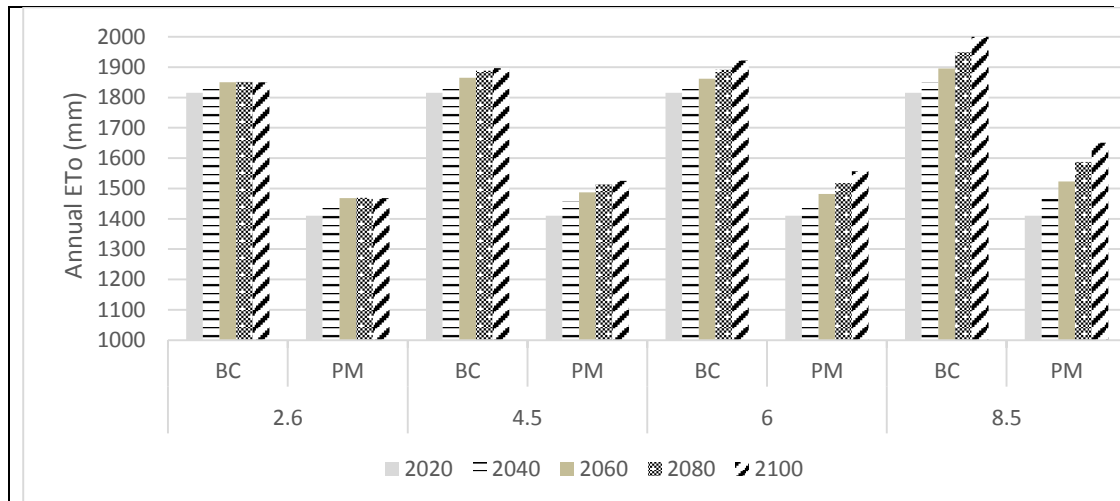


Fig (6) Differences between Blamey& Cridle and Penman Monteith for the four scenarios under periods 2021-2040, 2041-2060, 2061-2080 and 2081-2100 besides the current climate situation.

Data in Fig (6) indicated that values of ETo estimated by BC was higher than PM under different studied scenarios and periods. Also, data showed that the variation in estimated ETo under BC at different years (2020, 2040, 2060, 2080; 2100) increased with years. ETo estimated by BC at 2.6 scenario was homogeneity while the opposite was true at 8.5 scenario. The same trend was observed at ETo estimated by PM.

The author compared BC and PMs ETo at 2.6 and 8.5 scenarios (Fig. 7), data pointed out that the minimum ETo values estimated by BC and PM equations were 103.36 (Feb), 208.76 (Jul) and 48.45, 187.31 mm/month after 2.6 scenario and 107.13, 215.52 mm and 53.18, 198.83 mm after 8.5 scenario in the same sequence. However, data cleared that the total ETo (from May to September) after BC and PM were 968.30, 841.10 and 998.25, 887.81 mm after 2.6 and 8.5 Scenarios respectively, with increasing percentages of 3.1 and 5.6 % comparing BC and PM at Scenario 8.5 with 2.6. This finding was in harmony with those obtained by Tukimat, et al.,2012, they mentioned that there was an increase of the ET over the period 2010–2099, also projected a sharp rise in temperature which would certainly accelerate the evapotranspiration process with the highest changes prediction ETo (2000mm year⁻¹ to 2150 mm year⁻¹).

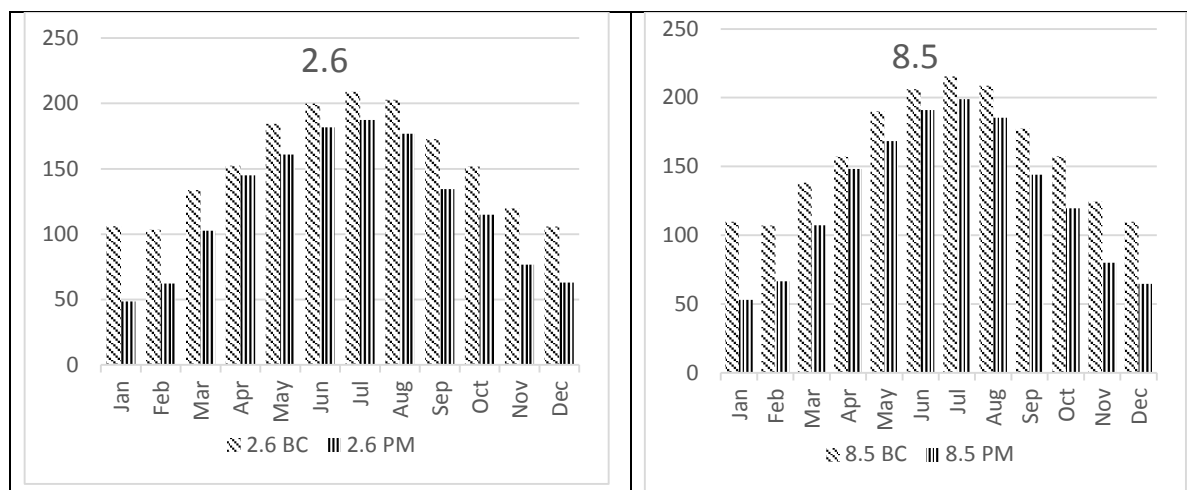


Fig (7) Differences between monthly ETo under PM and BC under 2.6 and 8.5 scenarios

Conclusion

Evapotranspiration becomes more important if climatic data are available to calculate because of its use in agricultural irrigation equations. Estimating the exact value of ETo in an area is so difficult due to the unsafe criteria that must be taken place. The expected climatic changes in Egypt according to the RCPs scenarios will lead to an increase in annually ETo. Compared between BC and PMs ETo at 2.6 and 8.5 scenarios indicated the minimum ETo values estimated by BC and PM equations were found in February and July after the 2.6 scenarios and after the 8.5 scenario. Total ETo (from May to September) after BC and PM were 968.30, 841.10 and 998.25, 887.81 mm per season relative to 2.6 and 8.5 Scenarios respectively, with an increasing percentage of 3.1 and 5.6 % comparing BC and PM at Scenario 8.5 with 2.6. The results recommended being careful when estimating the water needs of the crop in the future, and whether it corresponds to the amount of water available or not. Different management should be used to ensure that the crop is not exposed to a decrease in yield or quality, or changes in the composition of the crop will be applied.

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