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**Precision Irrigation for Maximizing Water Use Productivity Under Diverse Climate Conditions 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 in regions with limited water resources, such as Egypt. Hence, an accurate estimation of reference evapotranspiration is very important especially in agriculture. The objectives of the present study were studying the influence of climate change on weather seasons and comparing evapotranspiration estimations using Blany- Criddle and FAO-56 Penman-Monteith under present and future climatic conditions. Data of the present climate was collected from Wadi El-Natrun meteorological station, Egypt from 1991 to 2020. Meanwhile, the future climate data have been chosen for the concerned RCPs scenarios: RCP2.6, RCP4.5, RCP6.0 and RCP8.5 at 2040, 2060, 2080 and 2100. The results revealed that all month's 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 was observed at 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 ETo by BC was more than PM under all months and rate of increase was small under summer season (7.9, 4.9, 6.3), while the highest 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 by about 21.4%. It is clear that scenario (2.6) showed more harmony for the future than (8.5) scenario. With respect to 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 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. Compared between 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 (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 in same sequence. Also, 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 an increase of 3.1 and 5.6 % comparing BC and PM at Scenario 8.5 with 2.6.

**Keywords:** Climate change, evapotranspiration, Penman-Monteith, Blaney-Criddle.

**1. 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, 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 agriculture sector. Where, estimating ETo depends mainly on the climatology components, especially temperature.

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Climate change is one of the most complex and vital environmental problems. Every country in the world suffers from its impacts. Recent studies suggest that droughts will occur in some seasons in areas such as the Mediterranean region and Africa (Youssef, 2024; Muñoz-Rojas *et al.*, 2017). Egypt's climate is dry, hot, and dominated by desert. It has a mild winter season with rain falling along 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<sup>-1</sup>) and decreasing dramatically with depth (Egyptian Environmental Affairs Agency, 2016), whereas, (Hakami-Kermani and, 2026) stated the Egypt has been suffering from water scarcity in recent years. A good understanding of trends in ETo is critical for scientific management of water resources in arid and semiarid regions. In the context of climate change, changes of 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 (Sharafi *et al.*, 2026; Gabr *et al.*, 2024). Shaloo *et al.* (2023) have confirmed an increase in the ETo as a result of climate change and its estimated ETo is considered essential reference data for calculating the crop water requirement, water demand, and irrigation water management, (Nam *et al.*, 2015; Ahmed, 2025).

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 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 (Deveci *et al.*, 2025). These are Blaney-Criddle, 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. Blaney-Criddle (BC) and Penman-Monteith (PM), which is considered the most physical and reliable method and is often used as a standard to verify other empirical methods (Ramezani Etedali *et al.*, 2025 and Meskelu *et al.*, 2025), 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.

The PM method (Ramezani Etedali *et al.*, 2025) is generally considered to be the best approach for estimating ETc. Crop coefficients are used to estimate 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 (Farag, 2025). Evapotranspiration involves a highly complex set of processes, which are influenced by many factors depends 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 (FAO, 2025).

**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:

1. Study the influence of climate change on weather seasons during the period (1991-2020).
2. Prediction of potential change in the annual mean, maximum, and minimum temperature in the study area during the period of (2040 and 2100).
3. Impact of climate change on irrigation water requirements (IWR) for citrus crop.

## 2. Materials and Methods

### 2.1. Study area

The study area is located between 30.78<sup>0</sup> latitude and 30.08<sup>0</sup> longitude. 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.

## 2.2. Climate data

Current climate variables, mainly Tmax, Tmin temperature and precipitation (1991-2020) were obtained from Wadi el-natron, weather station as 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 story lines, created by IPCC, (2019). A scenario may be viewed as a coherent, internally consistent and plausible description of a future estate of the world (Yu *et al.*, 2025).

## 2.3. Climate change scenarios

Climate projections were provided by Climate Change Knowledge Portal of Coupled IPCC, (2019) 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<sup>2</sup> by 2100(490 ppm CO<sub>2</sub>eq.). RCP 4.5 represents stabilization without overshoot pathway to 4.5 W/m<sup>2</sup> (~650 ppm CO<sub>2</sub>eq.) at stabilization after 2100 and RCP 8.5 represents rising radiative forcing pathway leading to 8.5 W/m<sup>2</sup>(~1370 ppm CO<sub>2</sub>eq.) by 2100, these two RCPs were selected for this study because they represent realistically low and high future climate change scenarios (Negash, 2024; Wang *et al.*, 2025). Mean, maximum, minimum temperatures and rainfall for the time series were predicted from 2020 to 20100. Future period is divided into 4 time periods of 20 years including 2040s (2020-2040), 2060s (2041-2060), 2080s (2061-2080) and 2100s (2081-2100) were prepared and compared with baseline period observation from 1991 to 2020.

## 2.4. Irrigation water requirements

Three steps are carried out to determine IWR as follows:

Calculating the reference crop evapotranspiration (ET<sub>0</sub>): The ET<sub>0</sub> is calculated by the FAO Penman–Monteith method, using the decision support software CROPWAT 8.0 developed by FAO, based on Ramezani Etedali *et al.* (2025). The equation used for calculating ET<sub>0</sub> 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<sub>0</sub> is the reference crop evapotranspiration (mm day<sup>-1</sup>), R<sub>n</sub> is the net radiation at the crop surface (MJ m<sup>-2</sup> day<sup>-1</sup>), G is the soil heat flux density (MJ m<sup>-2</sup> day<sup>-1</sup>), T is the mean daily air temperature at 2 m height (°C), u<sup>2</sup> is the wind speed at 2 m height (m s<sup>-1</sup>), e<sub>s</sub> is the saturation vapor pressure (kPa), e<sub>a</sub> is the actual vapor pressure (kPa), e<sub>s</sub>–e<sub>a</sub> is the vapor pressure deficit (kPa), Δ is the slope of the pressure–temperature curve (kPa °C<sup>-1</sup>) and γ is the psychrometric constant (kPa °C<sup>-1</sup>).

## 3. Results and Discussion

### 3.1. Evaluation of monthly mean temperature under climate change

Data in Fig. 1 showed the mean monthly temperature during the previous study period (1991 – 2020). Data revealed that February and March are winter season, there is a great shift in mean temperature values with positive increase trend where it increase with future years. The Sam trend was attained in May and June, with a slight increase in mean value with time. Also, data mentioned that a slight variation was noticed in the months of July, August and September.

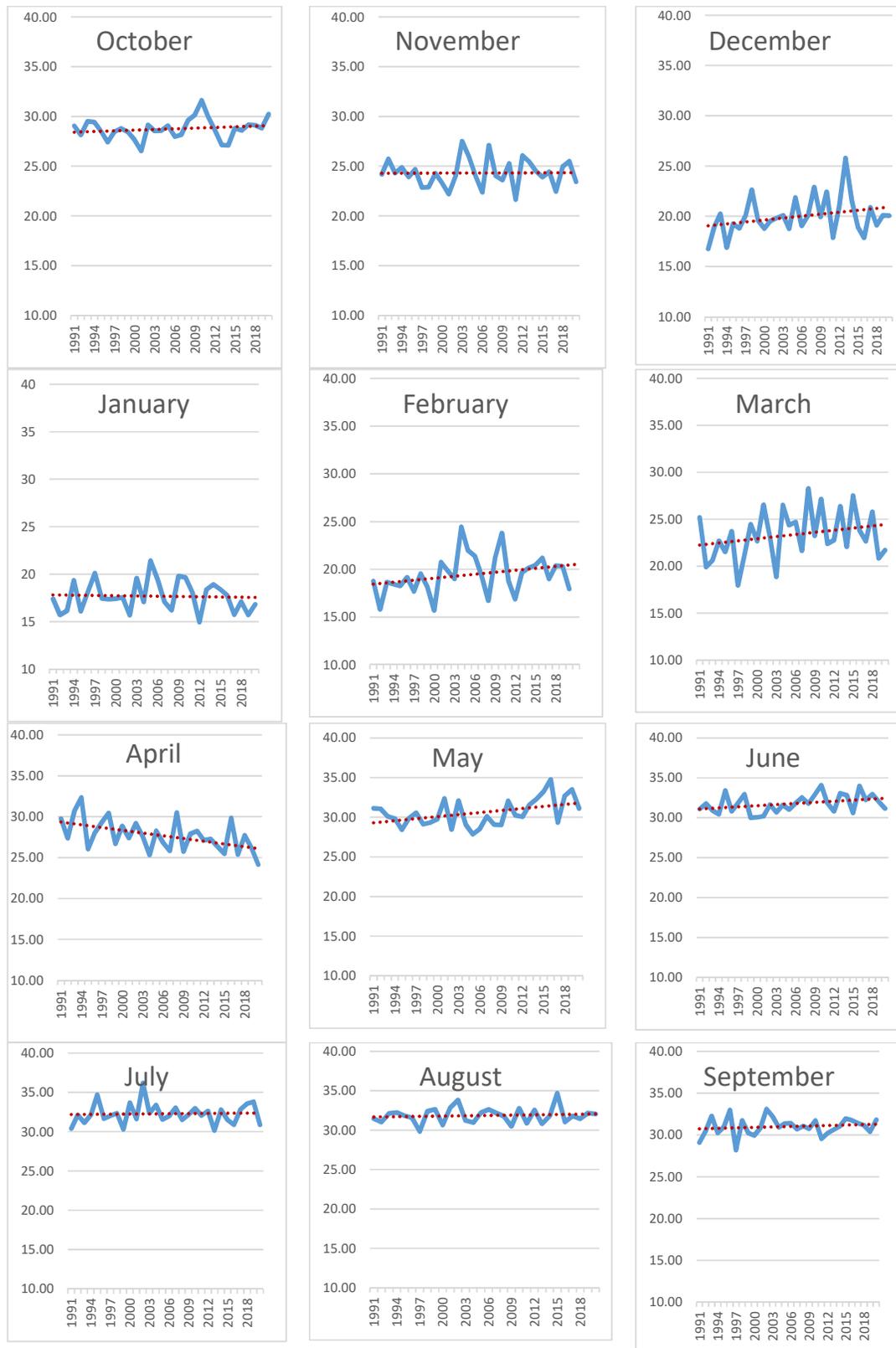


Fig. 1: Mean temperature during (1991-2020)

Whereas, mean temperature values in December during the study period were highly deviated around the trend with positive increase. From the abovementioned, winter months extend till April while early winter month tend to exceed mean temperature.

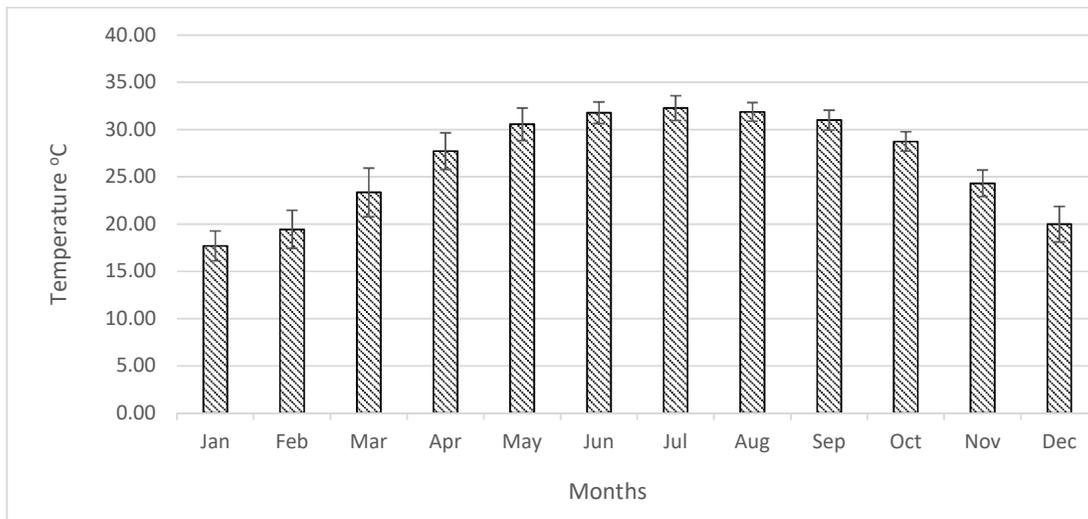
Table 2 and Fig. 2 illustrate the mean monthly temperatures during the study period (1991-2020). Data pointed out that all month's reordered mean temperature above 20 °C, except December, January and February where they ranged between 17.68 and 19.44 °C. Also, data revealed that July, August and September scored mean temperature above 30 °C, whereas, the rest of the months (March and April) and October recorded less than 30 °C. But the mean temperature of the December is still worm with mean value 20.0 °C.

With respect to the 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 climate of these months and there is instability in the temperature of these months. Also, may be the maximum temperature is the main cause of these phenomena.

Based on the results mentioned above, it is evident that most months are likely to experience higher temperatures. This increase could directly impact the ETo or indirectly influence crop growth stages and their requirements.

Data in table (2) Fig (2) showed mean temperature (Tmean) values during the last thirty years (1991-2020). Data pointed out that the highest Tmean was observed in July (32.3°C), August (31.9 °C), and June (31.8 °C), while February scored the lowest Tmean (17.7 °C).

One can observe that the highest standard deviation (SD) values were recorded in February, March, and April, indicating the occurrence of heat waves during these months. That lead to increase the Tmax, while the lowest SD were attained in August, October and September which ascribed on the base of harmony of the values during these months. Data in Fig (3) showed the estimation of ETo of the BC and PM equations. Data indicated that estimated ETo by BC was more than PM under all months. Also, it clear to mention that the rate of increase was small under summer season (7.9, 4.9, 6.3), while the higher increase % was observed under cold months: November (51.4), December (73.1), January (79.5) and February (48.3). Respecting to the total ETo estimated by BC and PM were 2056 and 1694 mm/year, respectively, which indicated that BC was higher than PM 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	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
<b>T mean</b>	17.7	19.4	23.3	27.7	30.6	31.8	32.3	31.9	31.0	28.8	24.3	20.0
<b>S. Deviation</b>	1.58	2.02	2.57	1.92	1.72	1.14	1.31	1.00	1.07	1.04	1.39	1.88

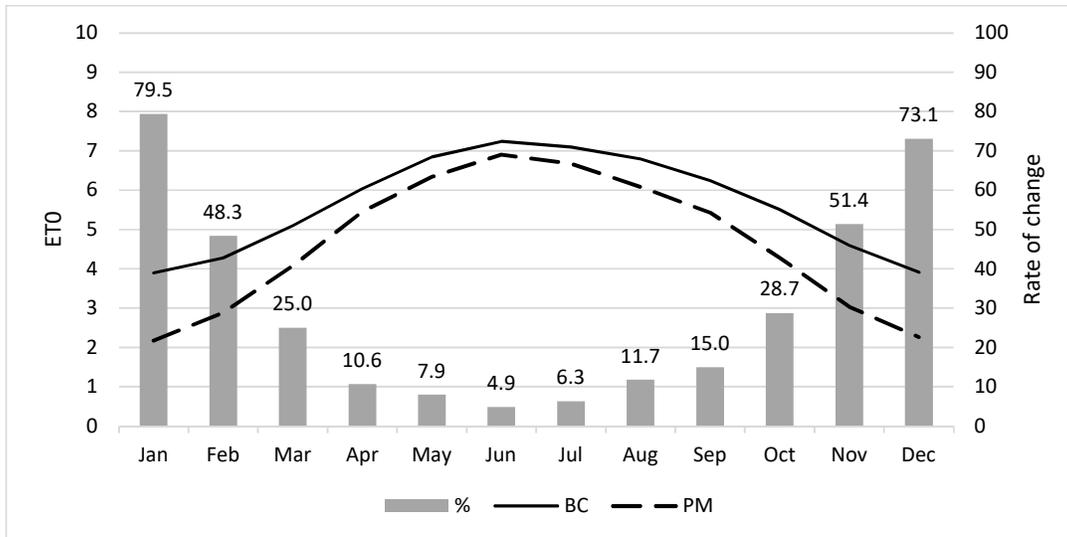


Fig. 3: Mean ET0 during (1991-2020) under PM and BC equations

Fig. 4 showed the relation between estimated ET0 during the last 30 years (1991-2020). The resulted regression equation was highly significant with r value 0.9936\*\*, and could be used to predicting future ET0 under future scenario (2.6, 4.5, 6 and 8.5).

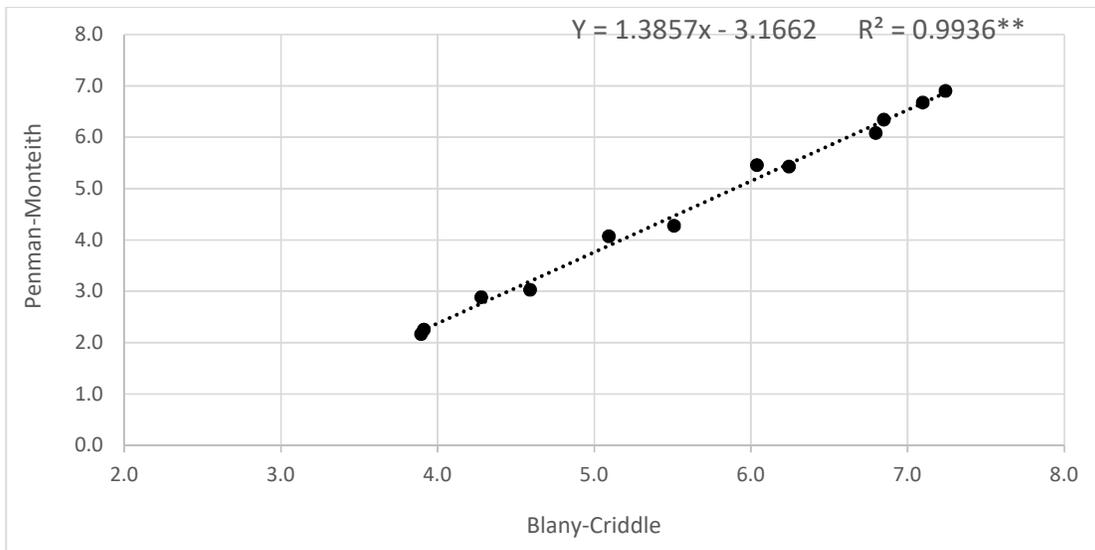
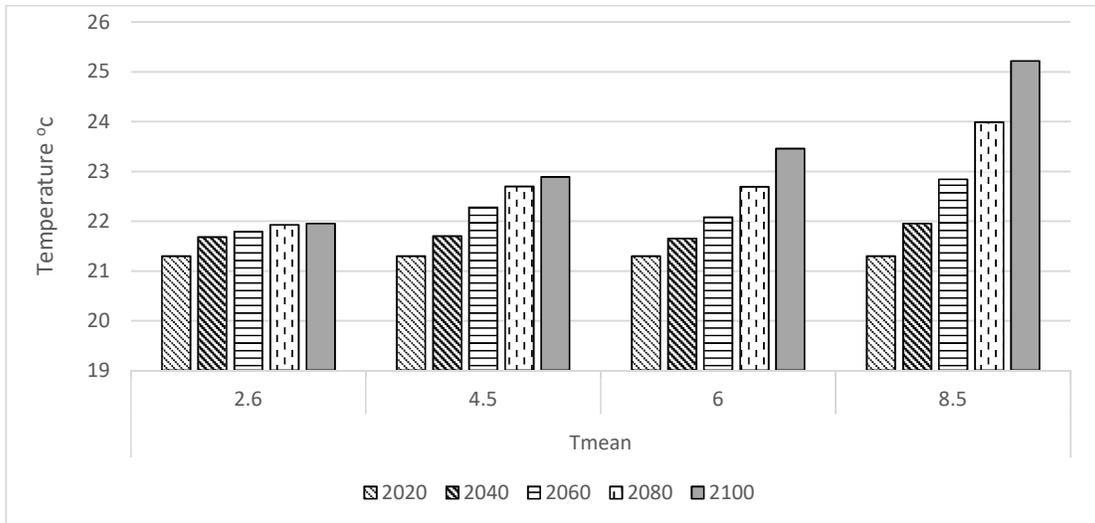


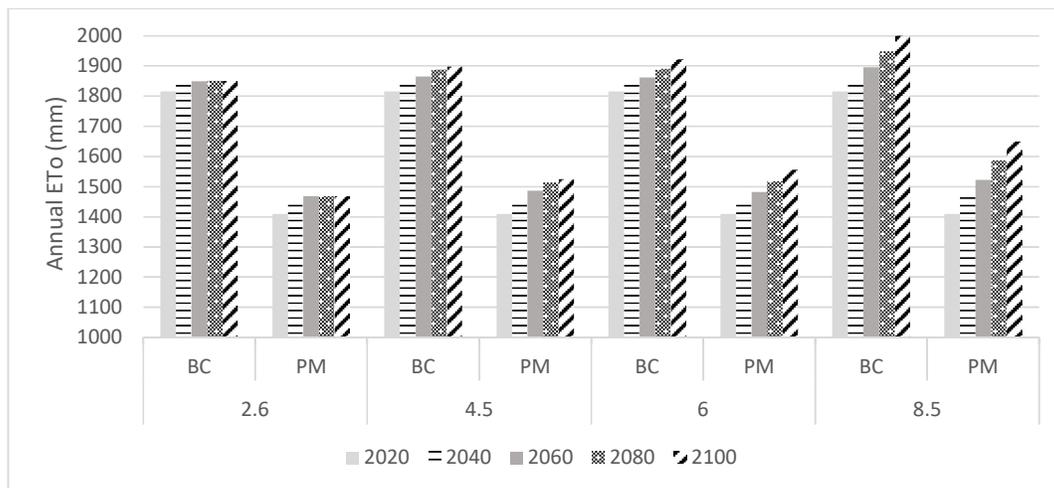
Fig. 4: Relation between PM and BC.

Data in Fig (5) showed the relation between mean temperature values at different predicting scenarios during (2040, 2060, 2080 and 2100) compared with the base line 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. Also, it is clear that scenario (2.6) showed more harmony for the future than (8.5) scenario. Also, it is clear to mention that the percentage 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 2020, respectively. With respect to 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. Our finding supported by GERICS (2019) it mentioned that temperatures in Egypt have increased at a rate of 0.1°C per decade on average between 1901– 2013. However, we have observed a significantly stronger warming over the past 30 years, with an average annual temperature increase of 0.53°C per decade.



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

Data in Fig. (6) indicated that ETo estimated by BC was higher than PM under different studied scenarios and years. Also, data noticed 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.



**Fig. 6:** Differences between PM and BC for the four scenarios under four time periods 2021-2040, 2041-2060, 2061-2080 and 2081-2100 besides current climate situation

The author compared between 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 same sequence. Also, 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 increase percentage 3.1 and 5.6% comparing BC and PM at Scenario 8.5 with 2.6. These finding was in harmony with those obtained by Tiruye *et al.* (2025), they mentioned that there was an increase of the ET over the time period 2010–2099, also projected a sharp rise of temperature which would certainly accelerate

the evapotranspiration process with the highest predicted changes ET (2000mm year-1 to 2150mm year-1).

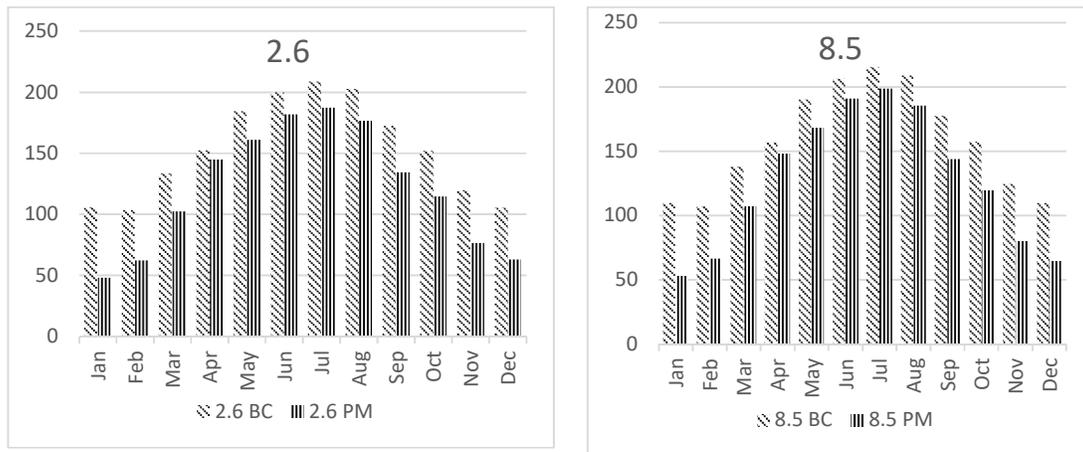


Fig. 7: Differences between monthly ETo under PM and BC for 2.6 and 8.5 scenarios.

#### 4. 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 ETo annually.

Compared between BC and PMs ETo at 2.6 and 8.5 scenarios indicate the minimum ETo values estimated by BC and PM equations were found in February, July after 2.6 scenario and after 8.5 scenario. 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 percentage increases 3.1 and 5.6 % comparing BC and PM at Scenario 8.5 with 2.6.

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