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Investigating the Impact of Climate Change on Water Requirements of Sweet Pepper Crop grown in Qassim Region.

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Abstract:
Climatic and environmental changes are important issues for present day research. In this paper, the effect of climatic and environmental changes on water requirements of Sweet Pepper crop grown in Qassim-Saudi Arabia have been investigated by incorporating the impacts of climatic and environmental changes on precipitation and temperature in the Qassim region. The base period for data is taken as 1999 -2024. The changes in precipitation and temperature have been predicted by Global Circulation Model (GCM) under RCP 2.6 (Representative Concentration Pathway 2.6) for a period of 25 years. Evapotranspiration has been estimated using Penman-Monteith equation. Its best parameters have been estimated by the General Reduced Gradient (GRG) technique. The water requirements of Sweet Pepper crop grown in Qassim have been estimated using CROPWAT model. Finally, the impact of temperature and precipitation variations on crop water requirements have been estimated. It is observed that the water requirements of Sweet Pepper will slightly increase in the future in the Qassim region. The results of this research will be useful for sustainable water planning, development and management.

Keywords : Global Circulation Model, General Reduced Gradient, Evapotranspiration, Crop Water Requirements

Introduction:

Considering impacts of climate change have become essential in water resources planning, development and management all over the globe. Global freshwater resources are being significantly impacted by climate and environmental changes. The whole ecosystem services are under its threat. Climate change implies variations in the climate of a zone estimated with the help of the long-term climatic records. Over the previous few decades, the global environment and climate have undergone considerable modifications. The excess of industrial activities and the extensive use of fossil fuels have caused intensified concentrations of greenhouse gases. It is evident that an increase in heat-trapping gases in the atmosphere inevitably leads to a rise in the Earth's temperature (Mirzaei et al., 2023, Rastegaripour et al. 2024, Ishaque et al. 2025).

Water resources planning, development and management essentially require estimation of the climatic changes and hence investigating the impact of these changes on water requirements for various fields. Fulfilling the water requirements of different identities has become a big challenge for responsible authorities especially in the areas of the scarcity of freshwater resources and the continually increasing water requirements. Agricultural areas have additional water requirements in addition to other usual water requirements. Climatic changes are affecting the crops-water-requirements (CWR) in many regions globally (El-Rawy et al. 2023, Gade & Khedkar 2023, Yang et al. 2023, Mirzaei et al. 2024). The climatic changes have impacts on temperature and precipitation and hence is indirectly affecting the evapotranspiration and resulting in changes in crop-water-consumption. A detailed study on reference evapotranspiration estimation has been presented by (Yassen et al. 2020, Eltarabily et al. 2023, Rahmawati 2023, Dorai et al. 2025). Long records of temperature and precipitation are used to predict climatic changes. There is a vast range of global circulation models (GCM) to forecast future temperature and precipitation (Kamruzzaman et al. 2023, Fanta et al. 2023, Zanial, et al. 2023, Yue et al. 2021). Malik et al., (2024) predicted using GCM that there will be an increase of 3.0 to 4.2 Co in the mean daily temperature over Saudi Arabia for various greenhouse gas emission scenarios. Almazroui et al. (2021) and Alotaibi et al. (2018) has predicted changes in precipitation and temperature using GCM. Almazroui et al. (2020) predicted temperature and precipitation in Arabian Peninsula. According to Almazroui et al. (2020) a comparatively lower warming is expected in the winter than that in the summer. They further explored that by the end of the twenty-first century, the region in the North of Arabian Peninsula is expected to be warmer than that of its Southern part. Alsafadi et al. 2023 has studies the impact of climatic changes on wheat crop in Syria. According to them the wheat-crop yield will decrease during 2080–2100.

There is variety of GCM models, however the most important and challenging step of prediction by GCMs is downscaling the results of GCMs. Statistical and dynamic methods of downscaling have commonly been used by various researchers working with GCMs. The statistical downscaling method developed by the Weather Generating and Research Station of Long Ashton produced comparatively higher efficiency than other statistical methods (Malik et al. 2024). Gumus et al. (2023) also used statistical method of downscaling with higher resolution and predicted climate change impacts in Türkiye.

Agriculture is the backbone of the economy in many countries worldwide. Study of impacts of climatic changes on CWR in agriculturally based economy regions is utmost important (Gade & Khedkar 2023, Yang et al. 2023). Roushdi (2024) estimated CWR under climate change conditions using GCM and CROPWAT and concluded that the CWR will increase due to climate changes. There is other research regarding the impact of climatic changes on the CWR of different crops.

The above-mentioned studies show that the climatic changes will result in an increase in CWR. Qassim Saudi Arabia is famous for agriculture. The literature shows that a very small amount of research work has been carried out in this regard in this important region. The present study

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aims to investigate the effect of climatic changes on CWR in the Qassim Region, which has not been considered so far to the best of the authors' knowledge. Accordingly, the objectives of this research are; to use state of the art GCMs for predicting the change in precipitation and temperature in Qassim Area and to estimate crop water requirements under climate change conditions using CROPWAT model.

Research Methodology:

Methodology Flow Chart

Evapotranspiration is needed to be estimated for determining the crop water requirements. The stepwise methodology flow chart for this research paper to determine the evapotranspiration and hence the crop water requirements for Qassim region under climatic changes is given in Figure 1. Figure 1 shows that two main models, including LARS-WG and CROPWAT, are being applied. The temperature and precipitation data is to be used as input to LARS-WG. The greenhouse gas emission scenario namely the RCP2.6 available in LARS-WG has been used to predict future temperatures and precipitation under climatic changes for the periods 2024-2050, because it is assumed that according to the Vision 2030 of the Kingdome of Saudi Arabia a strong effort to reduce emissions and mitigate climate change is being adopted. This includes adopting policies that have prompt shifts to renewable energy with strict emission constraints. The future temperature and precipitation data, the meteorological data (radiation & wind speed) crop data, and soil data is then be used to find crop water requirements under climatic changes using CROPWAT model.

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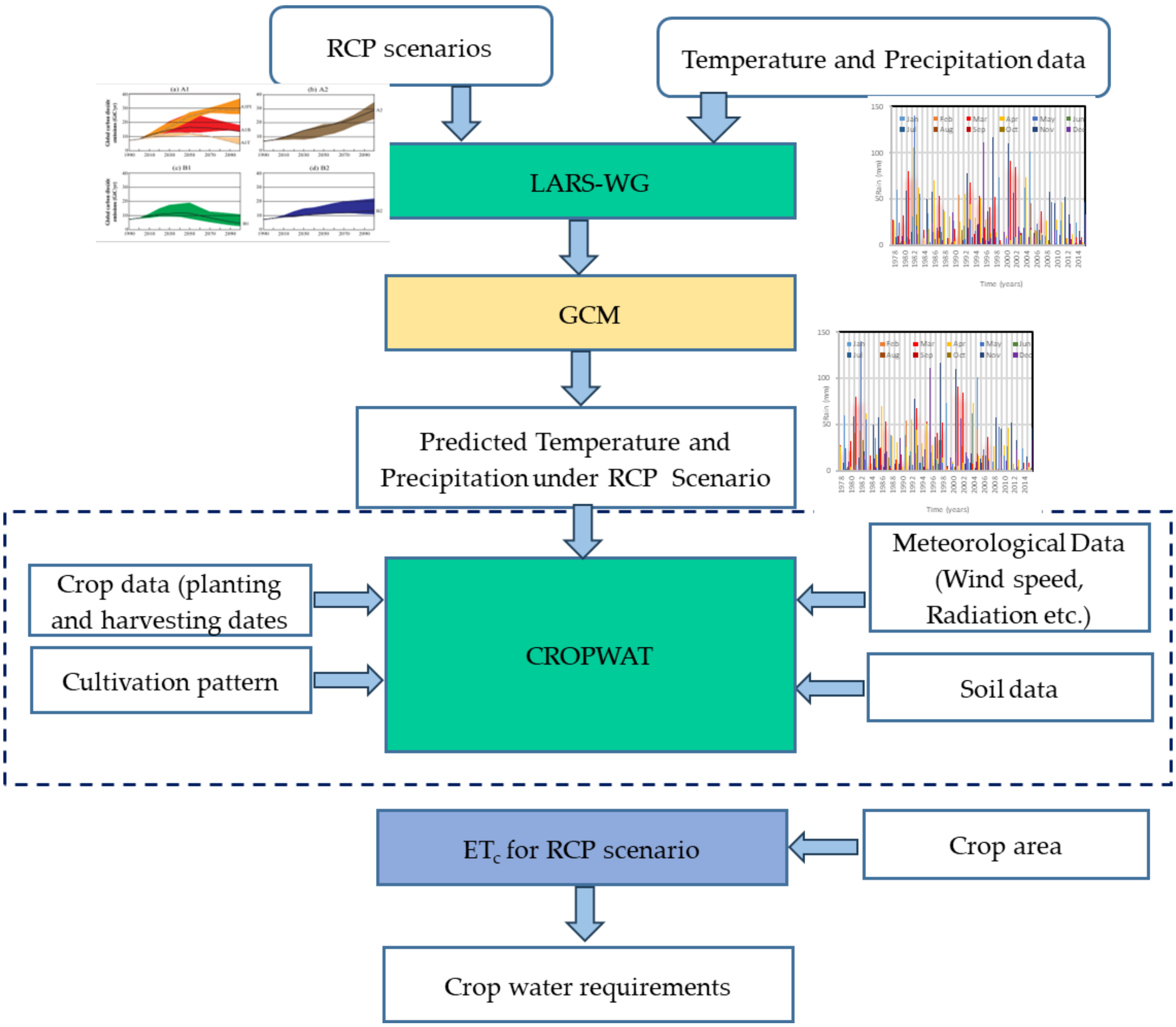

Figure 1: Methodology flow chart

Study Area

Figure 2 shows the map of Al-Qassim (study area) which is among the central regions of Saudi Arabia. It is nearly four hundred km north-west of Riyadh. Geographically this region has the coordinates of 26◦ 12′ N, 44◦ 5′ E (Aloud et al. 2023). Al Qassim province of Saudi Arabia has land with a height of approximately 600–750 meters above sea The province has an important wadi called Al-Rummah Wadi. The region has a desert climate. Winter is usually cool, having a small amount of rain. The summer is hot but less humid. Al-Qassim is a large province of Saudi Arabia famous for agriculture. This province grows dates, lemons, grapes, grapefruits, oranges, pomegranates, and plenty of vegetables. Al-Qassim produces about

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1,225,227 tons of agricultural products (Aloud et al. 2023). There are agricultural farms covering an area of nearly 94,923 hectares. Al-Qassim province has about 8 million palm trees which provide an important food item and help in increasing the food security in the country, (MEWA) Ministry of Environment, Water and Agriculture. Al-Qassim region grows at an average of 163,503 tons of vegetables per year grown on an area of about 1,018 hectares. The province also produces fruits to an extent of 109,858 tons, grown over an area of nearly 5759.97 hectares. About 400,000 tons of dates are produced annually from farms spread over an area of about 88,145.5 hectares (Aloud et al. 2023, Al-Wabel et al. 2020). A lot of greenhouses are also built in the province.

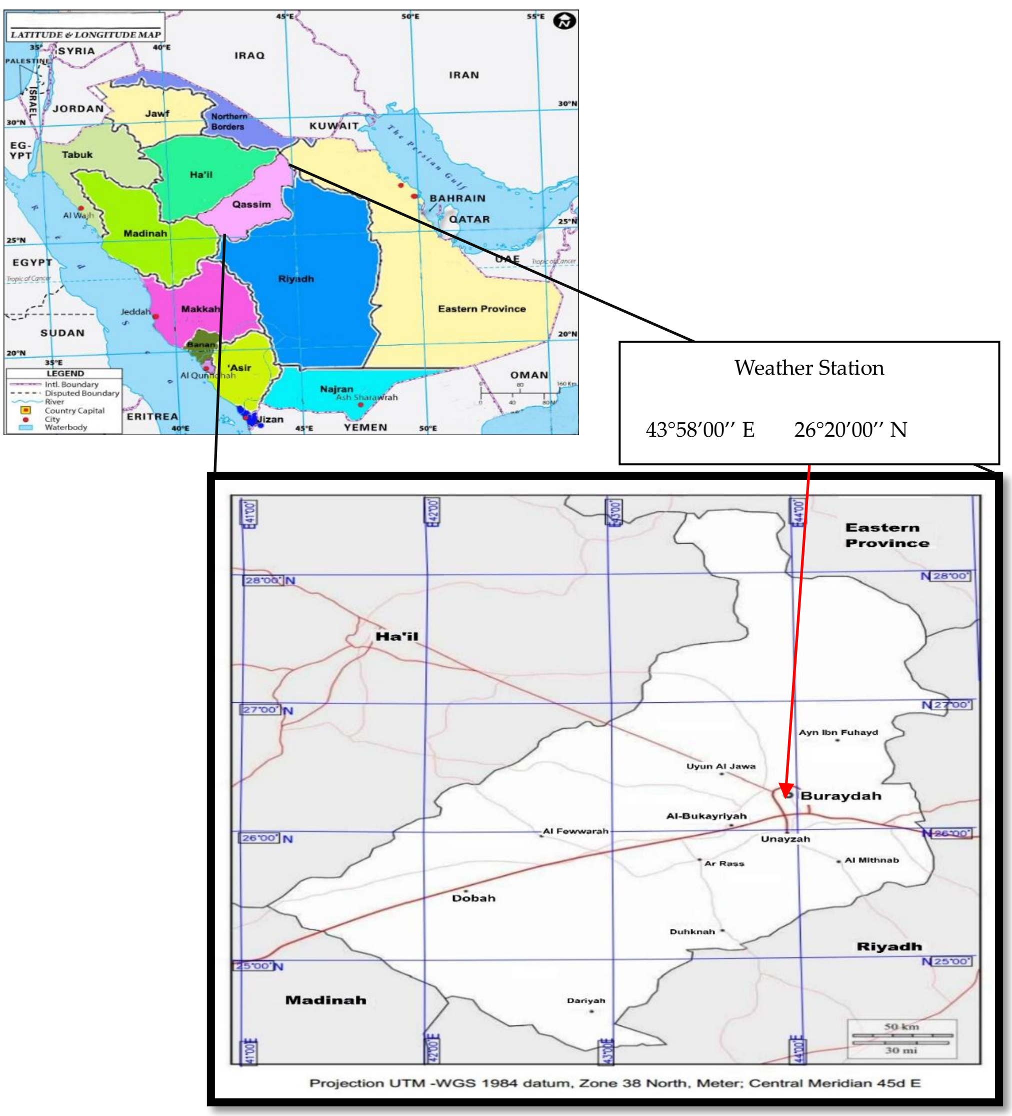

Figure 2: Map of Qassim Region

CROPWAT Model

CROPWAT model is prepared by the Food and Agriculture Organization (FAO) of the United Nations. The model estimates the reference evapotranspiration (Eto) by applying Penman–Monteith equation (Shuttleworth1993). The crop water requirements and net irrigation water are then estimated using crop data, soil data, crop coefficient, rainfall and meteorological data.

The Penman–Monteith equation is given as (Lang et al. 20217):

$$E = \frac{\Delta}{\Delta+\gamma}\frac{R_{net}-S}{\lambda} + \frac{\gamma}{\Delta+\gamma}0.0026\left(1+0.54\bar{u}\right)(1-r)e_{sa}n \quad (9)$$

$$E = \frac{\Delta}{\Delta+\gamma}\frac{R_{net}}{\lambda} + \frac{\gamma}{\Delta+\gamma}\frac{p_1}{\lambda}(1+p_2\bar{u})(e_{sa}-e_a) \quad (9a)$$

where, S is heat-storage change in some given time period, R_{net} is the net-radiation in units of Joule, λ represents the latent-heat of evaporation which can be taken as 2.46 x 10^6 J/ kg, the symbol γ is for the daily- average relative humidity which should be ≤1.0, $\bar{u}$ is the daily- average velocity of wind in m/s for the specific time period, e_{sa} is the symbol for daily- average vapor-pressure under saturation condition in units of Pa, Δ is the slope of the temperature & vapor-pressure curve under saturation condition and n is number of days in the specific time period. P_1 and p_2 are parameters which might be different for various regions and may be identified using optimization.

The variables and constants required for evaluation of the γ (slope) and Δ can be written in form of the following equations:

$$\frac{\Delta}{\Delta+\gamma} = 0.439 + 0.0112T_a \quad (10)$$

$$\Delta = \frac{2503\exp\left(\frac{17.27*T_{mean}}{237.3+T_{mean}}\right)}{(237.3+T_{mean})^2} \quad (10a)$$

$$\frac{\gamma}{\Delta+\gamma} = 0.5495 - 0.01119T_a \quad (11)$$

Where T_a or T_{mean} is mean air temperature. The following Arden-Buck-Formula (Lang et al. 20217) may be used to calculate the saturation vapor-pressure.

$$e_{sa} = 611.21\exp\left[\frac{(18.678 - T_a/234.5)T_a}{257.14+T_a}\right] \quad (12)$$

$$R_{net} = R_{ns} - R_{nl} \quad (13)$$

$$R_{net} = (1-\alpha)R_s + R_l \quad (13a)$$

Where R_{net} is the net-radiation in units of MJ /m^2/day, R_{ns} represents the net- incoming-shortwave-radiation, R_{nl} is symbol for the net- outgoing-long-wave-radiation. R_s is the

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shortwave radiation in MJ m^{-2} day^{-1}, □ is called as coefficient of albedo. Its value should be carefully taken from a well-known reference. R_l is the longwave solar radiation.

$$R_s = \left(as + \left(\frac{bs*n}{N}\right)\right) * \left(\frac{1440}{\pi}\right) * G_{sc} * dr * (\omega s * sin(Ø) * sin(\delta) + cos(Ø) * cos(\delta) * sin(\omega s)) \quad (14)$$

where *n* is day light duration in hours, *N* is the possible maximum daylight duration in hours, "*as*" represents the constant of regression, "$as+b_s$" denotes the fraction of extraterrestrial type radiation coming to the earth during clear days (no clouds) (for $n = N$), G_{sc} is the constant having value of 0.0820 MJ/ m^2 /min^1, and d_r is the relative inverse distance for Sun and Earth.

$$d_r = 1 + 0.033 * cos\left(\frac{2\pi J}{365}\right) \quad (15)$$

In this equation the symbol *J* denotes the total days in a year, (from First January to Thirty-First of December. It is normally 365 and will change to 366 for a leap year.
The solar declination δ is given as follows:

$$\delta = \left[sin\left(\frac{2*\pi*J}{365} - 1.39\right)\right] * 0.409 \quad (16)$$

The sunset hour angle ω_s and the latitude Ø expressed in radians are related to eachother as follows:.

$$\Omega_s = Cos^{(-1)}\{(-TAN(Ø)) * TAN(\delta)\} \quad (17)$$

The longwave outgoing net-radiation R_l in MJ/ m^2 / day^1 is given as follows:

$$R_l = \sigma * \left(\frac{(Tmax+273.16)^4+(Tmin+273.17)^4}{2}\right) * \left(0.34 - 0.14 * SQRT(ea)\right) * \left(1.35 * \frac{R_s}{R_{so}} - 0.35\right) \quad (18)$$

In this equation R_{so} denotes the radiations from sun with sky having no clouds, and σ is the Stefan-Boltzmann constant which can be taken as 4.903/ (10^9) MJ/(K^4 m^2 day^1) .

$$e_a = \frac{\left(e_{(T_{max})} * \frac{R_{h(min)}}{100} + e_{(T_{min})} * \frac{R_{h(max)}}{100}\right)}{2} \quad (19)$$

$$e_{(T_{max})} = (0.6108) * exp\left[\frac{(17{\cdot}27 * T_{max})}{(T_{max} + 237.3)}\right] \quad (20)$$

$$e_{(T_{min})} = (0.6108) * exp\left[\frac{(17{\cdot}27 * T_{min})}{(T_{min} + 237.3)}\right] \quad (21)$$

$$e_{sa} = e_{(T_{mean})} = (0.6108) * exp\left[\frac{(17{\cdot}27 * T_{mean})}{(T_{mean} + 237.3)}\right] \quad (22)$$

$$T_{mean} = \frac{(T_{max} + T_{min})}{2} \quad (23)$$

Here, $T_{mean}$is the average daily temperature of air in ^oC, T_{max} is maximum daily temperature of air in ^oC, and T_{min} is minimum daily temperature of air in ^oC.
Different temperatures of water body are defined below (Lang et al. 20217)

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$$T_{wb} = (T_w + T_b)/2 \quad (24)$$

(25)

Where T_{wb} is the average monthly water body temperature, T_w is water body-surface temperature, T_b is lake bottom temperature, j represents the j^{th} month.

The variation in water body temperature between consecutive two months may be approximately the same when $T_w > T_b$ for shallow water body and insignificant for deep water body (T_b weakly changing), which is true when $T_w = T_b$. The related variation in the heat storage between two months j-1 and j per unit area can be calculated by:

$$S = C_\rho * \rho * h * \Delta T_{wb} / n \quad (26)$$

Where, C_ρ expresses water-specific-heat (4186 J kg^{-1} C^{-1}), ρ represents density of water (1000 kg m^{-3}), *h* is pond/reservoir average-depth and n represent the days (number) in month.

Model Performance

The CROPWAT and GCM performance can be judged by the efficiency NSE as follows:

$$NSE = \left(1 - \frac{\sum_{i=1}^{n}\left(Eto_{mi} - Eto_{pi}\right)^2}{\sum_{i=1}^{n}(Eto_{mi} - \bar{E}to_{mi})^2}\right) \quad (33)$$

where Eto_{mi} is the value of the recorded evapotranspiration for ith point of data, Eto_{pi} is the simulated value of evapotranspiration for the same point of data, $\overline{Eto}_{mi}$ is the average value of Eto_m, and *n* is the total data points.

Another assessment parameter can be estimated as mean bias error as calculated by the following equation

.
$$MBE = \sum_{i=1}^{n}\left(\frac{Eto_{pi} - Eto_{mi}}{n}\right) \quad (35)$$

General Reduced Gradient Method of Optimization

There is a long history of solving non-linear problems in water resources management and engineering. This research paper apply the General Reduced Gradient (GRG) Method of Optimization. It is one of the most efficient nonlinear programming methods for dealing the nonlinear problems (Zhou et al. 2019). The GRG algorithm is developed by Abadie and Carpentier (1969). This technique has been used by many experts of water resources engineering for identification of parameters of empirical equations. The details of the method can be seen from (Abadie and Carpentier 1969).

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Data Analysis

Average values of data used in this research are expressed in graphical form as given below in Figures 3 to 8. Figure 3 represents average values of daily temperature in the Qassim Region. The average values are based on the Temperature records from 1999 to 2024. It is observed that the maximum daily temperature becomes over 40^{o}C in the region during summer. Figure 4 shows the average values of relative humidity during the growth period of Sweet Pepper in Qassim. The relative humidity is low during summer. Its minimum average value is about 10%. Due to this fact of high temperature and low relative humidity, the water requirements become comparatively higher during summer. Figure 5 shows wind speed and figure 6 represents sunshine duration. Figure 7 shows monthly pan evaporation and figure 8 represents the daily pan evaporation. All these data values tends to result into significantly higher values of water requirements for crops grown during this period of summer.

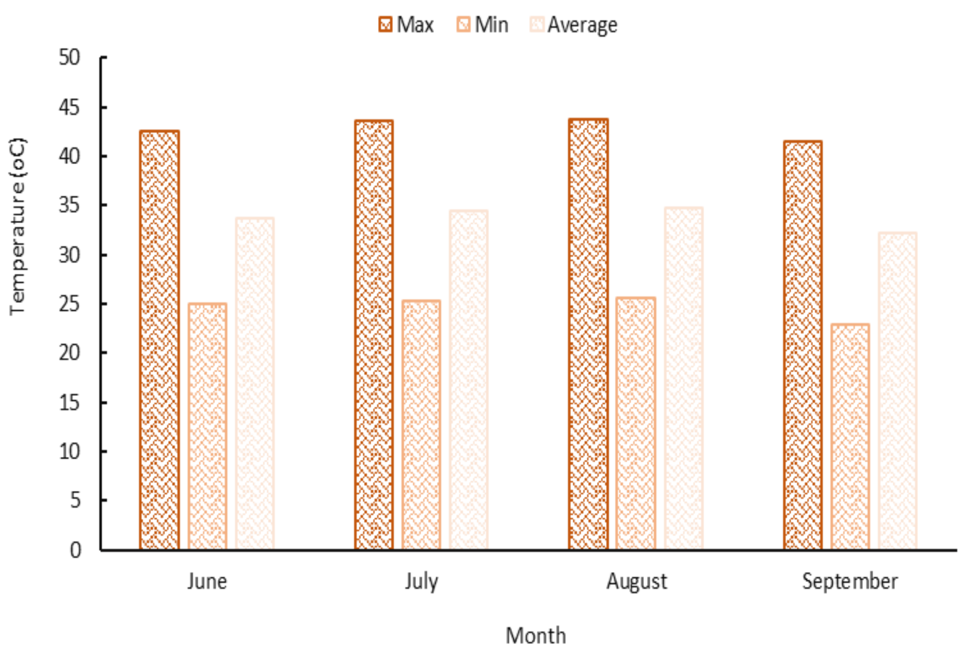

Figure 3: Temperature during the growth period of Sweet Pepper in Qassim

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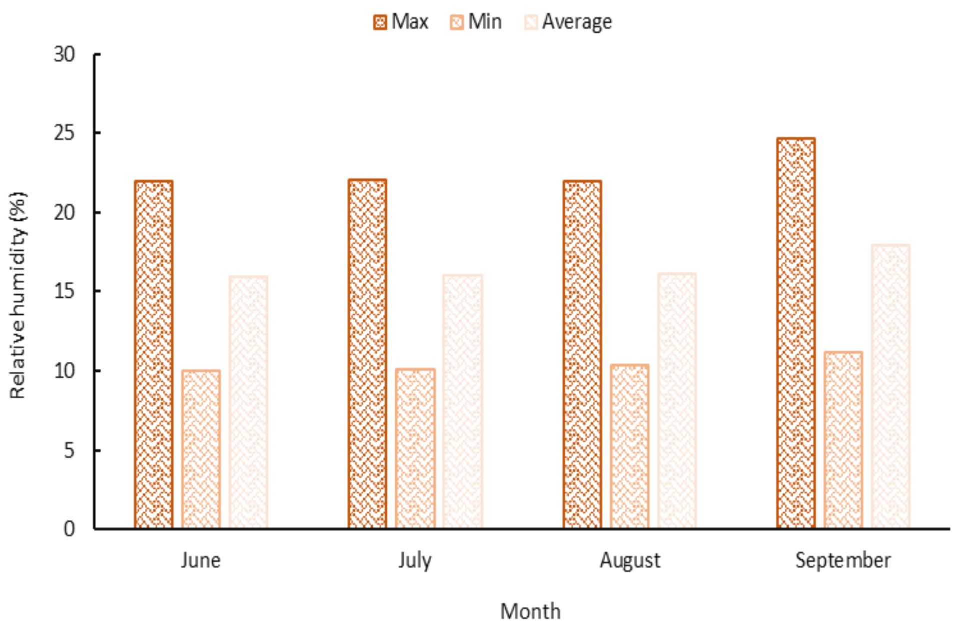

Figure 4: Relative humidity during the growth period of Sweet Pepper in Qassim

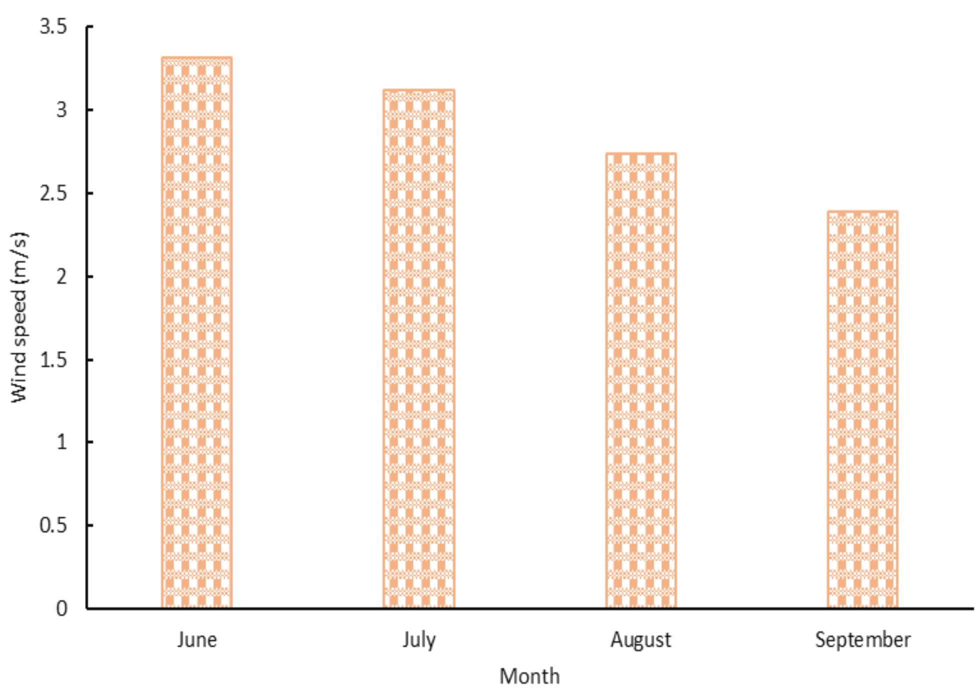

Figure 5: Wind speed during the growth period of Sweet Pepper in Qassim

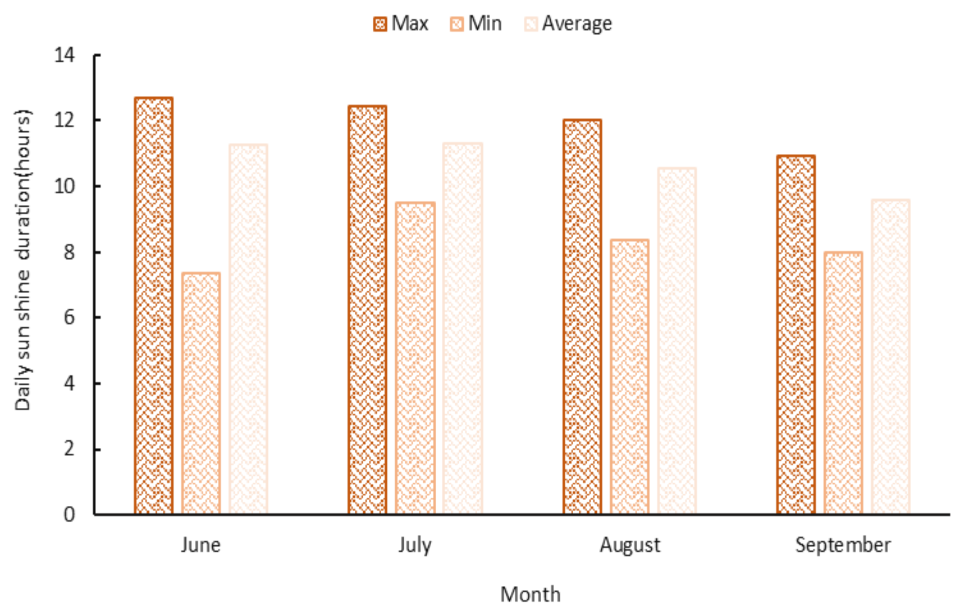

Figure 6: Daily sun-shine duration during the growth period of Sweet Pepper in Qassim

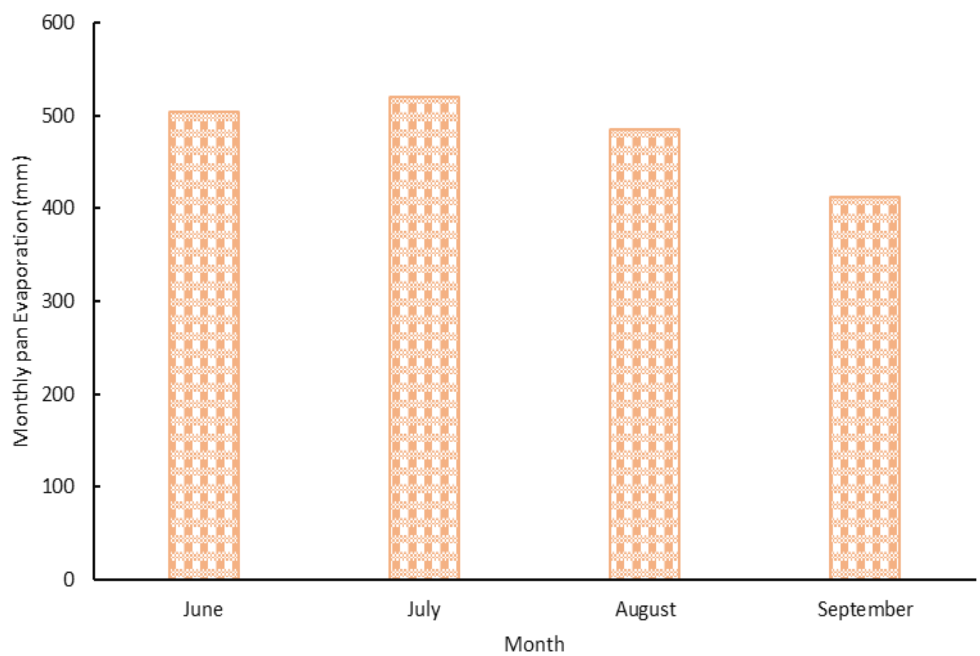

Figure 7: Monthly pan evaporation for the growth period of Sweet Pepper in Qassim

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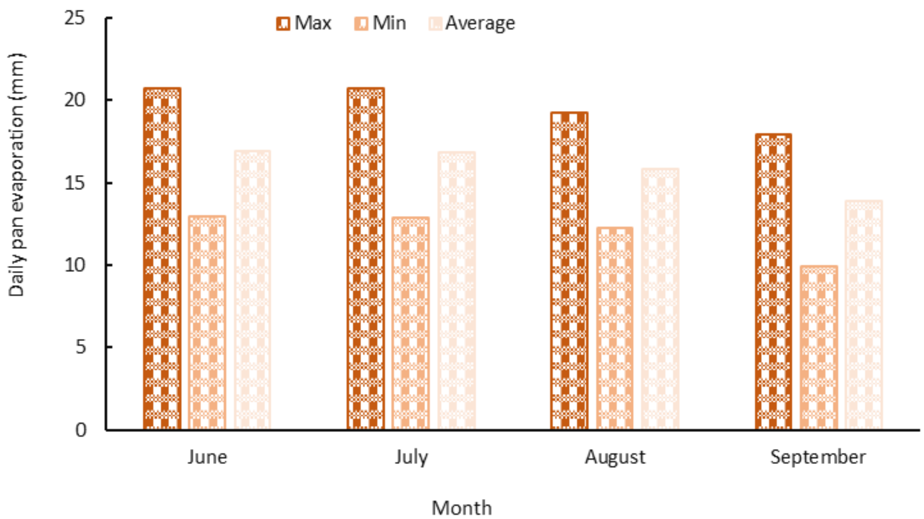

Figure 8: Daily pan evaporation for the growth period of Sweet Pepper in Qassim

Results and Discussion

Figure 9 shows the predicted values of temperature in the Qassim region during summer under climate change conditions. There are many climate change scenarios. In this research the Representative Concentration Pathway 2.6 (RCP 2.6) has been adopted. Figure 9 shows the results of temperature predictions under RCP 2.6. This scenario results in minimum possible climate change due to strict control of the government on emission of greenhouse gases. Because of this reason the temperature changes are minimal. Only 2 to 3 ^{o}C change during the coming 25 years is predicted. Figure 10 shows that the precipitation during summer is negligibly low. So, its change will not have any significant impact on water requirements of the crops grown during this period of summer. Figure 11 and figure 12 shows the estimated evapotranspiration for Sweet Pepper (Etc). The water requirements shown by Figures 11 and 12 are comparatively higher under the impact of climate change. About 3% change has been observed in Etc due to climate change. This change obviously has been predicted for minimal climate change conditions. The other scenarios of climate change will result in higher values of crop water requirements.

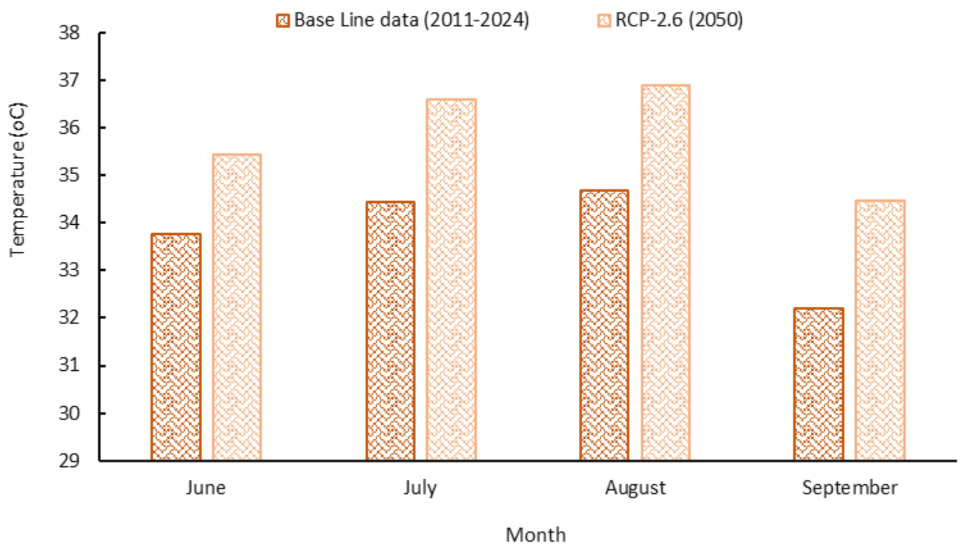

Figure 9: Predicted average daily temperature for the growth period of Sweet Pepper in Qassim

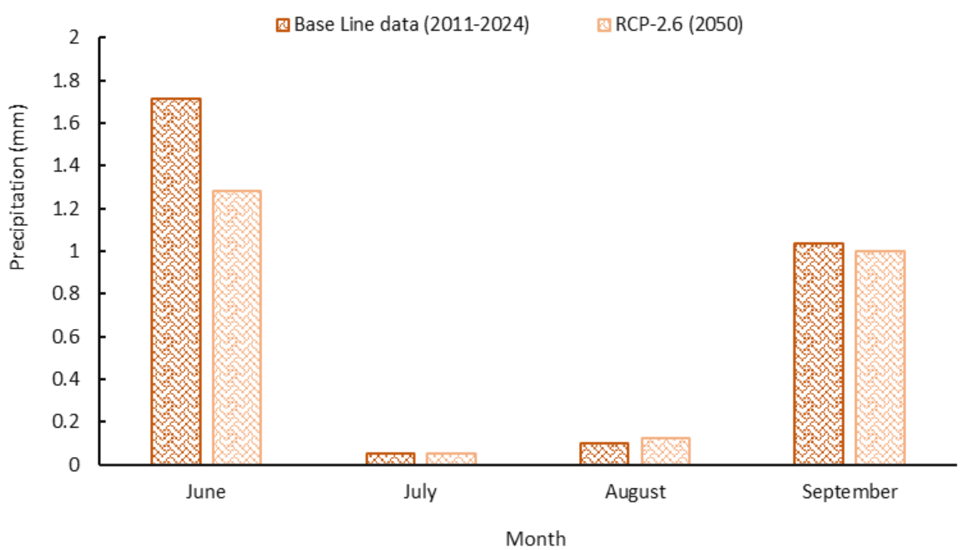

Figure 10: Predicted average monthly precipitation for the growth period of Sweet Pepper in Qassim

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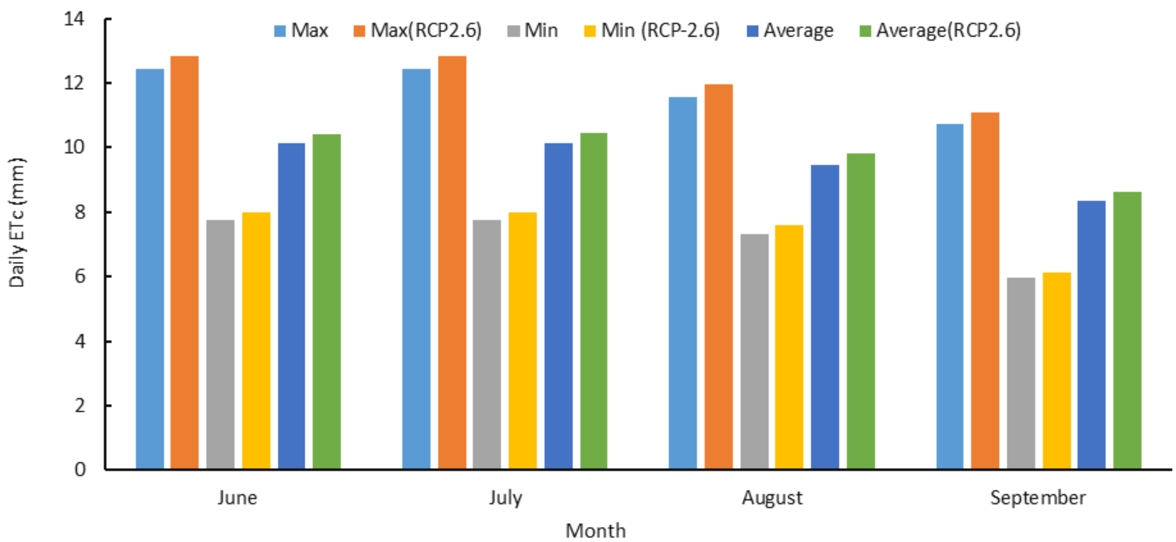

Figure 11: Predicted average daily Etc for the growth period of Sweet Pepper in Qassim

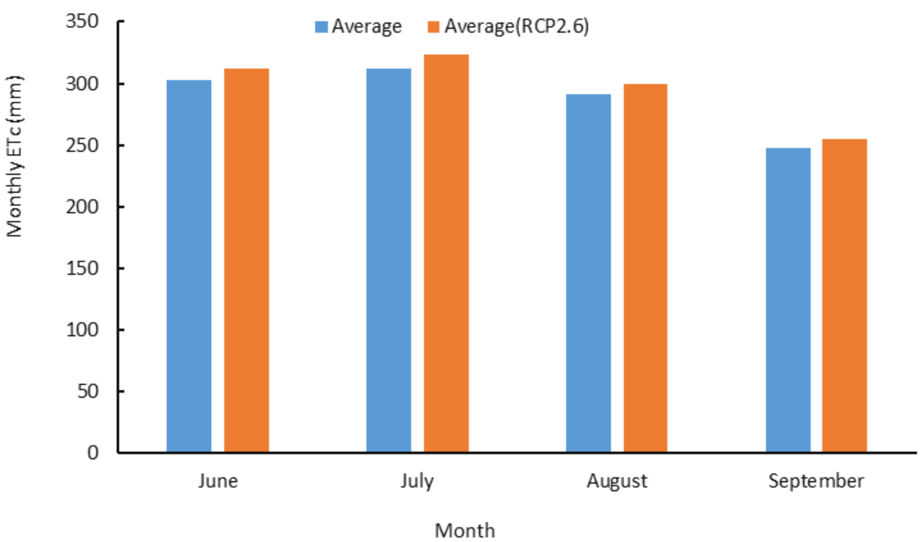

Figure 12: Predicted average monthly Etc for the growth period of Sweet Pepper in Qassim

Summary, Conclusion and Recommendations for Future

In this research, the minimal impacts of climatic change have been investigated on water requirements of Sweet Pepper crop grown in Qassim-Saudi Arabia GCM model has been applied first to predict the impacts of climatic changes on precipitation and temperature in the region. The base period for data is taken as 1999 -2024. RCP 2.6 has been adopted for the future period of 25 years. Evapotranspiration has been estimated using Penman-Monteith equation. The water requirements of Sweet Pepper crop grown in Qassim have been estimated using CROPWAT model. Finally, the impact of temperature and precipitation variations on crop water requirements have been calculated. The temperature changes are observed to be minimal. Only 2 to 3 ^{o}C change during the coming 25 years is predicted. The precipitation during summer is found to be negligibly low and it is concluded that its change has not had any significant impact on water requirements of the crops grown during this period of summer. The water requirements for Sweet Pepper are comparatively higher under the impact of climate change. About 3% change has been observed in ETc due to climate change. This change has been predicted for strictly controlled conditions of climate change; hence the other scenarios of climate change will result in higher values of crop water requirements. It is recommended that the data may be collected on a comparatively broader scale for all the crops grown in the Qassim Region and crop water requirements of crops may be investigated in detail using various but latest GCM models with all possible and innovative climate change scenarios.

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