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Irrigation Requirement of Crops under Changing Climatic Scenarios in a Semi-arid Region of Northern Karnataka

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ABSTRACT: The groundwater status of Vijayapura district is under semi-critical to over-exploited category and optimal application of irrigation water is needed for the sustainable water management in this region. In the present study, the rainfall, temperature, evapotranspiration variability and irrigation requirement of major crops was analyzed for three future scenarios, namely, 2020's (2010 to 2039), 2050's (2040 to 2069) and 2080's (2070 to 2099) with respect to the baseline period (1976-2005). The ENSEMBLE data corresponding to four different emission scenarios was used. Rainfall and temperature are important factors governing the irrigation requirement and the rainfall is predicted to increase from 590 mm during baseline period to 611, 646 and 677 mm under RCP 4.5 (medium emission scenario) and 617, 674 and 742 mm under high emission scenario (RCP 8.5). The maximum temperature is predicted to increase by 0.8, 1.6, 2.0^{0}C under RCP 4.5 and 0.9, 2.0, 3.6^{0}C under RCP 8.5. The minimum temperature is predicted to increase by 1.0, 1.8, 2.3^{0}C under RCP 4.5 and 1.1, 2.5, 4.2^{0}C under RCP 8.5 respectively. Correspondingly, the evapotranspiration values (ET_0) are estimated to increase from 1851 to 1877, 1900 and 1916 mm under RCP 4.5 and 1876, 1912 and 1958 mm under RCP 8.5. The irrigation requirement of *rabi* sorghum is predicted to increase from 434 to 440, 447 and 449 mm under RCP 4.5 and 438, 445 and 453 mm under RCP 8.5. Similarly, the irrigation requirement of *rabi* maize is predicted to increase from 667 to 678, 688 and 694 mm under RCP 4.5 and 679, 694 and 712 mm under RCP 8.5, respectively. No considerable increase in the irrigation requirement for *kharif* crops was predicted in Vijayapura. In order to ensure long-term and sustainable groundwater utilization in the region, proper estimation of crop water requirement and its application are needed.

Key words: Climate change, ENSEMBLE, supplemental irrigation requirement

Introduction

The global mean surface temperature has increased by 0.74± 0.18°C during 1906-2005 (Trenberth *et al.,* 2007). The global mean surface temperature is predicted to increase by 1.4 to 5.8°C by the end of 2100 under different emission scenarios (IPCC, 2007). Earlier studies by Indian Meteorological Department (IMD) showed that mean annual temperature of India has increased by 0.5^{0}C during 1901-2003 whereas the maximum temperature increased by 0.7^{0}C. During last three decades, the rise in minimum temperature varied from 0.4 to 0.7^{0}C during winter and post monsoon seasons (Dash and Hunt, 2007). A warming trend was observed in India over the past 100 years (1901 to 2007) with an accelerated warming of 0.21°C per every 10 years since 1970 (Krishna Kumar, 2009). Climate change and global warming impacts all sectors of human life and agriculture is particularly vulnerable to it (Srinivasarao *et al.,* 2016a). The annual per capita water availability in India has decreased from 5177 m^3 in 1951 to 1654 m^3 in 2007 and it is projected to decrease to 1341 m^3 by 2025 and 1140 m^3 by 2050, approaching the water scarce condition (MOWR, 2008; Sneh Gangwar, 2013; Rejani *et al.,* 2015).

Increase in atmospheric and surface temperature increases evaporation rates at the earth's surface (IPCC, 2007; Chattopadhyay and Hulme, 1997). This leads to more vigorous hydrologic cycle, influences precipitation, its intensities, frequencies, extreme events and changes in soil moisture status (Srinivasarao *et al.,* 2014). Many studies reported that irrigated agriculture would be severely affected by climate change due to increased crop water requirement and decreased water resources availability especially in the arid and semi-arid regions of world including India (Mahmood, 1997; Goyal, 2004; De Silva *et al.,* 2007; INCCA, 2010; Shahid, 2011; Kambale *et al.,* 2015; Srinivasarao *et al.,* 2015; Behera *et al.,* 2016; Srinivasarao *et al.,* 2016b). Longer drought periods, considered to be the expected impact of climate change, increases the water stress in crops and reduces the growing period and crop productivity (IFPRI, 2009; Manekar and Bharadiya, 2012). Rainwater management is very important in rainfed farming and the successful production of crops depends on how efficiently the soil and water are conserved *in-situ* and the surplus runoff is harvested and utilized (Srinivasarao *et al.,* 2013; Rejani *et al.,* 2016).

An analysis carried out using PRECIS data and SWAT model for Akola (Maharashtra) showed that the rainfall would increase by 48.7%, ET would reduce by 8%, PET would increase by 13.1%, sorghum yield would increase by 183%, cotton yield would increase by 103% and piegonpea showed no significant increase in yield by the end of the century (ICAR Network Annual Report, 2008-09). Increasing rainfall intensities under changing climatic scenarios (mid and end centuries) would increase the erosivity and soil loss in Seethagondi cluster of Adilabad (PRECIS data) (Rao *et al.,* 2016). An increase of 14.8% of total ET demand with increase in temperature by 20% (maximum 8^{0}C) due to global warming will have a larger impact on resource-poor, fragile arid zone ecosystem of Rajasthan (Goyal *et al.,* 2004). In Rajasthan, climate change increased the evapotranspiration in irrigated corn by 15 mm and resulted in an additional irrigation water requirement of 34.27 MCM (Tung and Haith 1998). The strategies to cope up with climate change impacts on irrigated crops needs to be planned based on the changes in crop water requirement and water availability for irrigation (Srinivasarao *et al.,* 2013; Kambale *et al.,* 2015; Srinivasarao *et al.,* 2016c). It was predicted that irrigation water requirement of potato in West Bengal would be increased by 7 to 8% by 2020, while it may increase about 14 to 15% by 2050 (Chatterjee *et al.,* 2012). Hence, there is a need to adjust the site specific conservation planning in order to meet the continually changing rainfall intensities and temperature of the selected area. With respect to water conservation, the issues like water balance and evapotranspiration are extremely diverse and depends on climate. The objective of the present study is to assess the potential impact of climate change on the sustainability of irrigated agriculture in northern Karnataka, particularly the potential changes in irrigation water requirements.

Methodology

Study area

The study area, Vijayapura district lies in northern part of Karnataka State, covers an area of 10,541 km² (Figure 1). It lies between 16°09'to 17°29' N latitude and 75°20' to 76°29' E longitude and is located in the semi-arid region of Deccan plateau and cultivation depends mainly on seasonal rainfalls. The elevation ranges from 273 to 708 m above MSL and major portion of district is characterized by clayey and loamy soil with moderate to severe erosion. The depth of the soil is generally deep with some areas have shallow soil (Source: NBSS&LUP). The constant rate of infiltration in clayey soils varies from 0.75 to 2.5 cm/hr whereas loamy soil ranges from 2.6 to 3.8 cm/hr (CGWB, 2008). The topography is flat, gently sloping forming broad valleys and flat-topped hills. Salinity is also prevalent in some areas. The mean annual rainfall was estimated at 568 mm with 80% of its contribution during southwest monsoon from June to September (Source: NICRA, CRIDA). The temperature of the region varies from a minimum of 10.2^{0}C in December-January to 42.5^{0}C in April-May (Srinivasarao *et al.,* 2016a). The dust storms and severe heat waves are common during April and May months. The selected area is prone to weather shocks like deficient South West monsoon, drought/deficient rainfall, delayed and deficient monsoon. Ground water is extracted by bore wells and dug wells and utilized for drinking and irrigation. Ground water contributes nearly 68% of the total irrigation in Vijayapura district. The hardness of ground water ranges from 75 to 2860 mg/l. Excess fluoride is also reported in many parts of the district and is ranging from 0.3 to 4.8 mg/l. Around 15% of the area recorded groundwater level fluctuation of < 2m, 65% of area showed 2 to 4 m fluctuation and rest of the area has the fluctuation of >4.00 m (CGWB, 2008). The over exploitation of groundwater for irrigation by bore wells in recent years has resulted in declining groundwater levels and the ground water status comes under semi-critical to over-exploited category. Long term water level data of the Central Ground Water Board showed that the water levels falls from 0.20 to 16.70 m at different locations. More than 70% of the district is under rainfed agriculture. The major crops grown are *rabi* sorghum, maize, sunflower, pearl millet, red gram, green gram, chilli, tomato, grapes and citrus fruits. Changing and increasingly variable climate is recognized as a potent threat to agriculture of Vijayapura district.

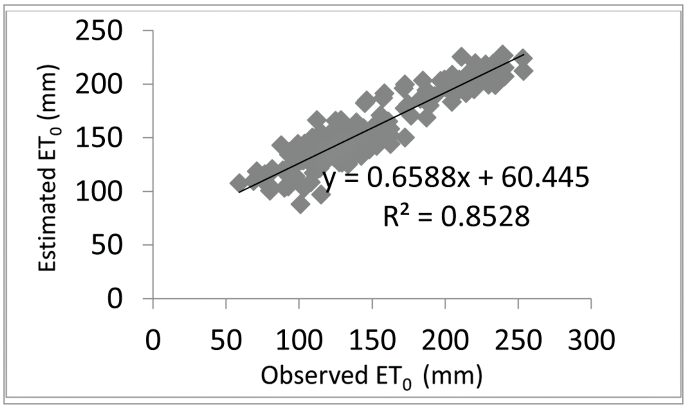

Fig. 1 : Validation of estimated evapotranspiration (ET_0) with observed evapotranspiration

Rainfall data

The rainfall is the major factor governing daily irrigation requirement and hence rainfall data analysis was carried out. The weather data (1970 to 2015) recorded at All India Coordinated Research Project for Agrometeorology (AICRPAM) Vijayapura Centre was used in this study. The effective rainfall and irrigation requirement of crops under future climate scenarios was estimated using CMIP 5 ENSEMBLE data. The daily rainfall ENSEMBLE data pertaining to base line (1976 to 2005) and 2020's (2010 to 2039), 2050's (2040 to 2069) and 2080's (2070 to 2099) for three emission scenarios namely, RCP 2.6 (low), RCP 4.5 (medium), RCP 6.0 (high) and RCP 8.5 (very high) was used. The rainfall data was analyzed to find its variability.

Determination of irrigation requirement

The crop water requirement under changing climatic scenarios was estimated for *kharif*, *rabi*, summer and some perennial crops. The selected crops includes sorghum, maize, pearl millet, sunflower, green gram, groundnut, tomato, chilli, grapes and citrus. Even though, different methods are available for estimating the reference crop evapotranspiration, based on the availability of meteorological data, the suitable method could be selected. The FAO Penman-Monteith method has been recommended as a sole standard method for ETo calculation (Allen *et al.,* 1998). However, the desired solar radiation data for the selected area for future climate scenarios is not available and hence the Hargreaves and Samani (1985) method was used for estimating ETo. This method requires extra terrestrial radiation, minimum temperature, maximum temperature and latitude of the area.

Hargreaves and Samani (1985) equation is given below:

$$\lambda ET_0 = 0.0023 R_a T_d^{0.5} (T+17.8) \quad (1)$$

where, R_a = extra terrestrial solar radiation ($MJm^{-2}d^{-1}$); T_d = difference between the daily maximum and daily minimum temperature (^0C); T= mean temperature (^0C); λ = latent heat of vaporization (MJ/kg) and ET_0 = reference crop evapotranspiration (mm/day).

The extraterrestrial radiation R_a, for each day of the year and for different latitudes can be estimated from the solar constant, the solar declination and the time of the year by *Eqn* (2)

$$R_a = \frac{(24x60)}{\pi} G_{sc} d_r [\omega_s \sin(\varphi) \sin(\delta) + \cos(\varphi) \cos(\delta) \sin(\omega_s)] \quad (2)$$

where G_{sc} = solar constant (0.0820 MJ m^{-2} min^{-1}); ω_s = sunset hour angle [rad] in *Eqn* (3);

d_r = inverse relative distance Earth-Sun in *Eqn* (4); δ = solar declination [rad] in *Eqn* (5);

φ = latitude [rad]

$$\omega_s = \arccos(-\tan\varphi \tan\delta) \quad (3)$$

$$d_r = 1 + 0.033 \cos\left(\frac{2\pi}{365} J\right) \quad (4)$$

$$\delta = 0.409 \sin\left(\frac{2\pi}{365} J - 1.39\right) \quad (5)$$

where J is the number of the day in the year between 1st January to 31st December.

The crop evapotranspiration ET_c was calculated using *Eqn* (6)

$$ET_c = k_c ET_0 \quad (6)$$

where K_c is the crop coefficient depends on the crop growth stages

$$GIR = \frac{ET_c - R_e}{n_p} \quad (7)$$

where GIR = gross irrigation requirement (mm); R_e = effective rainfall (mm); n_p = project efficiency (application efficiency x conveyance efficiency x field canal efficiency)

Effective rainfall is estimated from daily rainfall using empirical *Eqns* (8 & 9)

$$R_e = 0.24 P (4.16 - 0.2 P) \quad \text{for } P \leq 8.33 \quad (8)$$

$$R_e = 4.16 + 0.1P \text{ for } P > 8.33 \quad (9)$$

where P = daily rainfall (mm)

Variability of rainfall, temperature, evapotranspiration and irrigation requirement

Seasonal variability (coefficient of variation-CV) of rainfall, temperature, evapotranspiration and irrigation requirement of crops over three different cropping seasons was analyzed to find its variability over the years during baseline period, 2020's, 2050's and 2080's under different emission scenarios. The seasonal variation was also considered for three periods namely, June to September, October to February and March to May.

Results and Discussion

Rainfall analysis showed that 90% of the rainy days with 65.1% of the rainfall received was below 25 mm/day during 1970 to 2011. In this paper, a preliminary analysis of the seasonal ET and irrigation requirement of crops over past few decades in Vijayapura district was done. The daily evapotranspiration was estimated using Hargreaves method. Monthly data was derived from the daily data and validated with the recorded data for the period 1976 to 2005 (R^2 = 0.85) (Figure 1).

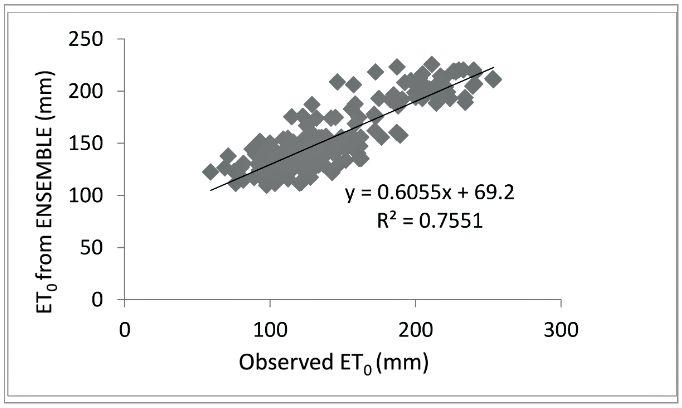

Fig. 2 : Validation of evapotranspiration ET_0 (ENSEMBLE) with observed evapotranspiration

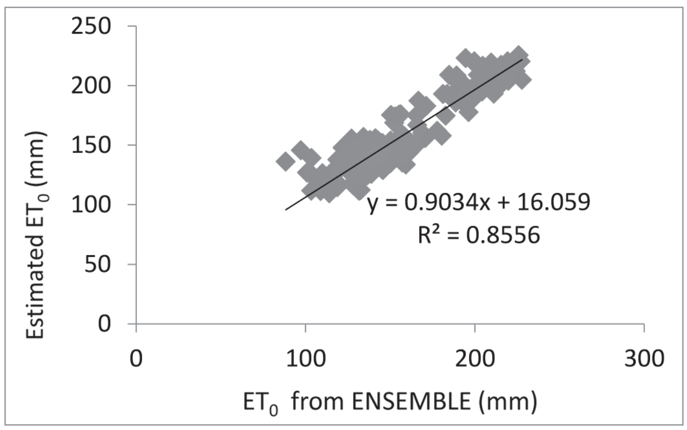

Fig. 3 : Validation of estimated evapotranspiration ET_0 from ENSEMBLE with estimated evapotranspiration from observed data

The temporal variation in ET and irrigation requirement of crops in Vijayapura due to greenhouse gas induced climate change was also determined. The evapotranspiration under changing climatic scenarios was estimated using ENSEMBLE data with Hargreaves method. The evapotranspiration during baseline period (1976-2005) was also validated with the observed data (R^2 = 0.76) (Figure 2) and estimated evapotranspiration (R^2 = 0.86) (Figure 3). Hence, ENSEMBLE data could be utilized for predicting the future irrigation requirement in the selected area. With changing the climatic scenarios, to meet the food and water demand for the increasing population in future is a great challenge. Hence, it is necessary to improve the water resources management particularly for agriculture by adopting the optimal irrigation schedule instead of flooding the whole field. Irrigation schedule depends on the frequency and quantity of irrigation water required based on the type of crop and rainfall over the time period in the selected region.

The rainfall, evapotranspiration, temperature variability and irrigation requirement of major crops was determined with respective to base line period (1976 to 2005) for three scenarios, namely, 2020's (2010 to 2039), 2050's (2040 to 2069) and 2080's (2070 to 2099) using ENSEMBLE data pertaining to RCP 2.6, 4.5, 6.0 and 8.5 (Table 1).The rainfall is predicted to increase from 590 mm during base line period to 611, 646 and 677 mm during 2020's, 2050's and 2080's under RCP 4.5, medium emission scenario. *i.e.,* the rainfall would increase by 3.5, 9.5 and 14.7%, respectively. Under high emission scenario (RCP 8.5), it is predicted as 617, 674 and 742 mm. *i.e.,* the rainfall would increase by 4.5, 14.2 and 25.7%, respectively. Compared to baseline period, the mean annual rainfall during RCP 2.6 would increase from 590 mm to 622, 645 and 646 mm and under RCP 6.0, the mean annual rainfall would increase from 590 mm to 602, 629 and 673 mm during 2020's, 2050's and 2080's.

The maximum temperature is predicted to increase by 0.8, 1.6, 2.0^{0}C under RCP 4.5 and 0.9, 2.0, 3.6^{0}C under RCP 8.5. The minimum temperature is also predicted to increase by 1.0, 1.8, 2.3^{0}C under RCP 4.5 and 1.1, 2.5, 4.2^{0}C under RCP 8.5, respectively. Correspondingly, the evapo-transpiration values ET_0 estimated showed an increasing trend from 1851 to 1877, 1901 and 1917 mm under RCP 4.5 and 1851 to 1877, 1912 and 1958 mm under RCP 8.5. Similarly, the mean annual evapotranspiration would increase from 1851 to 1875, 1886 and 1896 mm respectively under RCP 2.6 and 1851 to 1879, 1897 and 1912 mm, respectively under RCP 6.0.

Table 1 : Mean annual rainfall, ET_0 and irrigation requirement of different crops under changing climatic scenarios

		2020				**2050**				**2080**			
	Baseline	**RCP 2.6**	**RCP 4.5**	**RCP 6.0**	**RCP 8.5**	**RCP 2.6**	**RCP 4.5**	**RCP 6.0**	**RCP 8.5**	**RCP 2.6**	**RCP 4.5**	**RCP 6.0**	**RCP 8.5**
Mean annual ET_0 (mm)	1851	1875	1876	1879	1877	1886	1901	1897	1912	1896	1917	1912	1958
Mean annual rainfall (mm)	590	622	611	602	617	645	646	629	675	646	677	673	742
Crops													
Sunflower_*kharif*	188	189	190	192	191	190	191	192	193	192	192	193	197
Sunflower_*rabi*	304	309	308	309	308	311	314	313	315	311	317	316	324
Pearl millet_*kharif*	267	270	271	273	272	272	274	277	277	275	276	278	284
Sorghum_*rabi*	434	439	440	439	438	441	447	443	445	443	449	445	453
Piegon pea	253	255	256	258	257	256	258	259	260	259	259	260	265
Maize_ *kharif*	363	361	364	366	364	362	365	367	365	366	367	365	371
Maize_ *rabi*	667	679	678	679	679	683	688	685	694	685	694	691	712
Chick pea	245	248	249	248	247	250	253	251	252	251	254	252	258
Onion_*kharif*	513	511	514	516	514	513	517	518	516	518	519	517	524
Onion_*rabi*	577	583	584	584	582	586	594	590	592	589	597	593	605
Tomato_*kharif*	427	425	428	429	428	426	430	431	429	430	431	429	435
Tomato_*rabi*	548	557	557	557	555	560	567	563	567	561	571	568	581
Tomato_summer	701	718	717	719	719	722	727	729	738	726	734	739	758
Grape	1001	1021	1020	1021	1021	1026	1035	1032	1044	1029	1045	1043	1072
Citrus	1419	1439	1440	1443	1441	1446	1459	1457	1468	1454	1470	1468	1502
Chilli_ *kharif*	230	228	230	231	230	229	231	232	231	232	232	231	234
Chilli_ *rabi*	272	276	276	276	275	277	281	279	280	279	283	280	286
Chilli_ summer	449	457	456	457	457	459	463	461	467	461	467	466	480
Green gram_*kharif*	255	257	259	260	259	258	260	261	261	261	261	262	267
Green gram_*rabi*	306	311	311	311	310	313	317	314	316	314	319	316	323
Groundnut	334	331	333	335	334	332	335	336	335	336	336	335	340

Relatively higher temperatures predicted during future scenarios resulted in higher evapotranspiration. Even though higher mean annual rainfall was predicted, its variation during *kharif* season was less (CV = 35 to 36%) compared to October to February and March to May (CV = 70 to 77%). Hence, irrigation requirement of *kharif* crops predicted under changing climatic scenarios are not rising considerably whereas *rabi* and summer crops are showing increasing trend. Main crops cultivated includes sunflower, pearl millet, pigeon pea, maize, chick pea, green gram, groundnut, onion, tomato and chilli. The seasonal irrigation requirement of *rabi* sorghum is predicted to increase from 434 to 440, 447 and 449 mm under RCP 4.5 and 434 to 438, 445 and 453 mm under RCP 8.5, respectively (Table 1). Similarly, the seasonal irrigation requirement of *rabi* maize is predicted to increase from 667 to 678, 688 and 694 mm under RCP 4.5 and 667 to 679, 694 and 712 mm under RCP 8.5. The seasonal irrigation requirement for tomato cultivated in summer is expected to increase from 701 to 717, 727 and 734 mm under RCP 4.5 and 701 to 719, 738 and 758 under RCP 8.5. The seasonal irrigation requirement for summer chilli is expected to increase from 449 to 456, 463 and 467 mm under RCP 4.5 and 449 to 457, 467 and 480 mm under RCP 8.5. In *rabi* sunflower, the seasonal irrigation requirement may slightly increase under RCP 4.5 and RCP 8.5 (Table 1). Results indicated that climate change may not have much impact on sustainability of prevailing cropping system as the crop seasonal water requirement of *kharif* crops are concerned.

Considerable variation in the irrigation requirement of different crops over the years was observed during 2020's, 2050's and 2080's under different emission scenarios with respect to base line period (Figure 4a & b; Figure 5a & b; Figure 6a & b; Figure 7a & b; Figure 8a & b; Figure 9a & b; 10a & b). The higher irrigation requirements was observed during 2080's (end century) especially under high emission scenarios. Based on water requirement under various climate change scenarios, appropriate strategies to cope up the climate change impact on *rabi* crops needs to be planned. Rainwater harvesting and artificial groundwater recharge need to be made mandatory in the study area for increasing the groundwater recharge and water availability (Kambale *et al.,* 2015). It is concluded that in order to ensure long-term and sustainable groundwater utilization in the region, proper estimation of crop water requirement and optimal water management are needed.

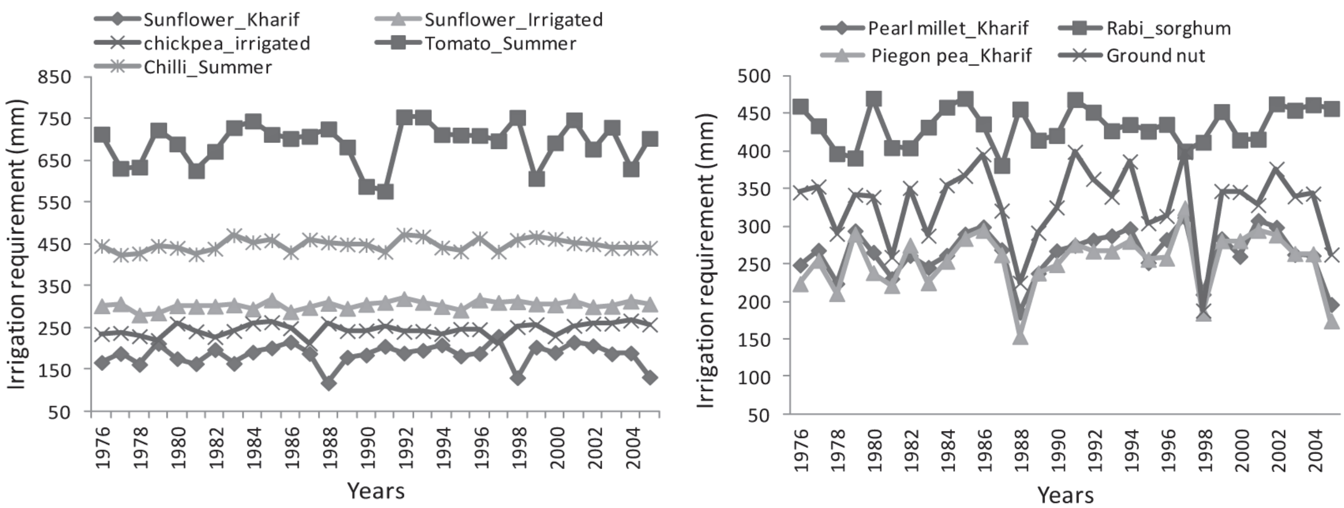

Fig. 4a & b : Irrigation requirement of crops during baseline period (1976-2005)

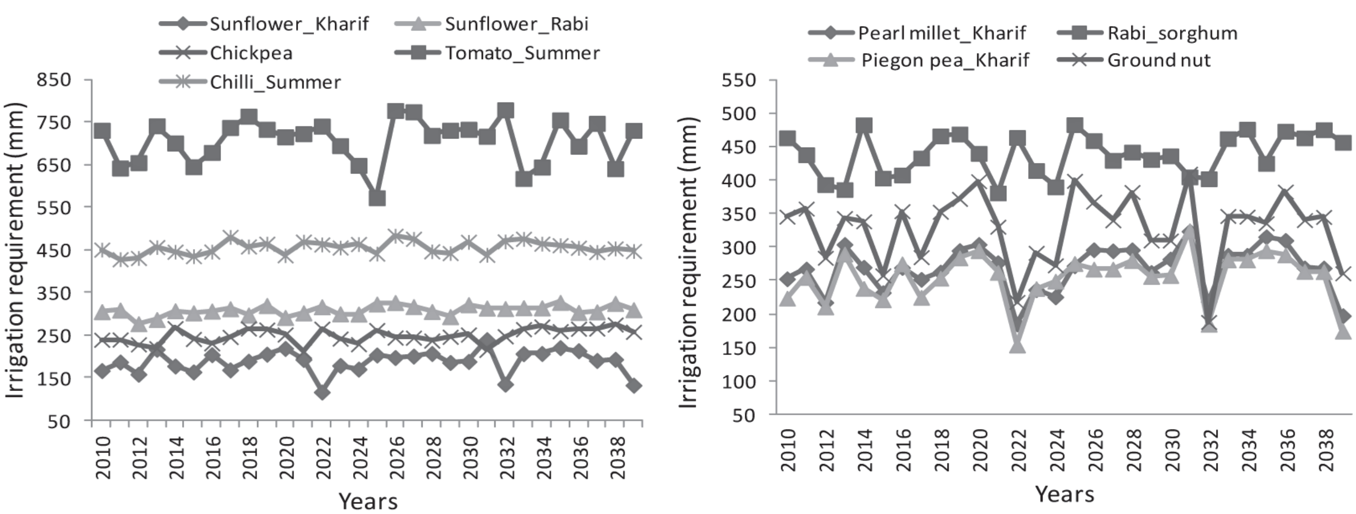

Fig. 5a & b : Irrigation requirement of crops under RCP 4.5 in 2020's

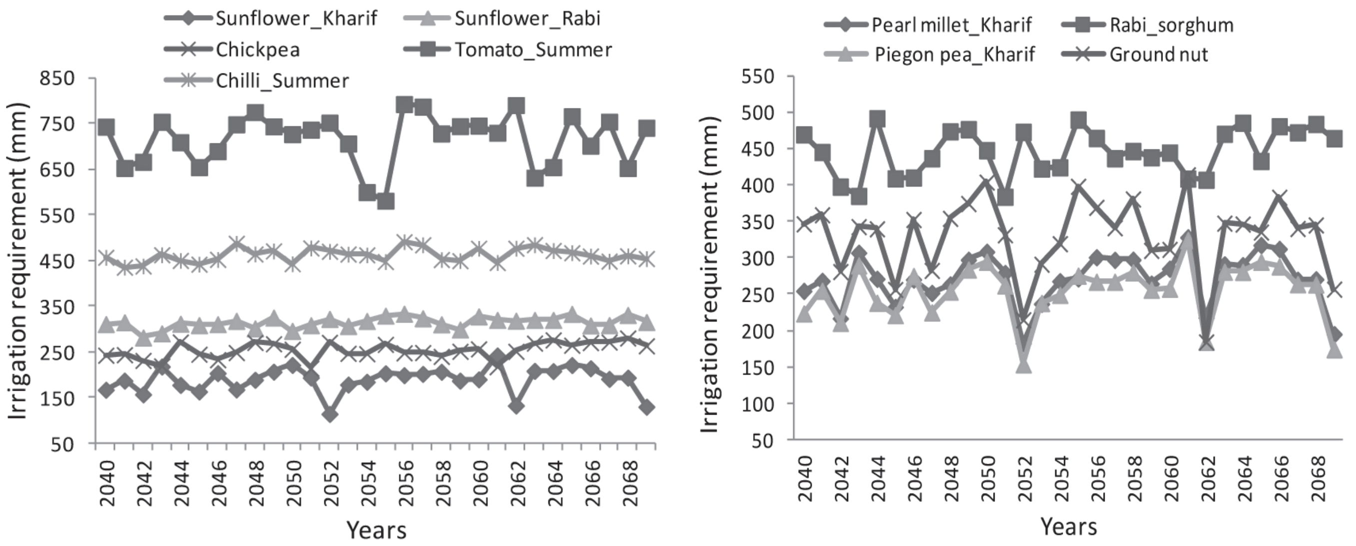

Fig. 6a & b : Irrigation requirement of crops under RCP 4.5 in 2050's

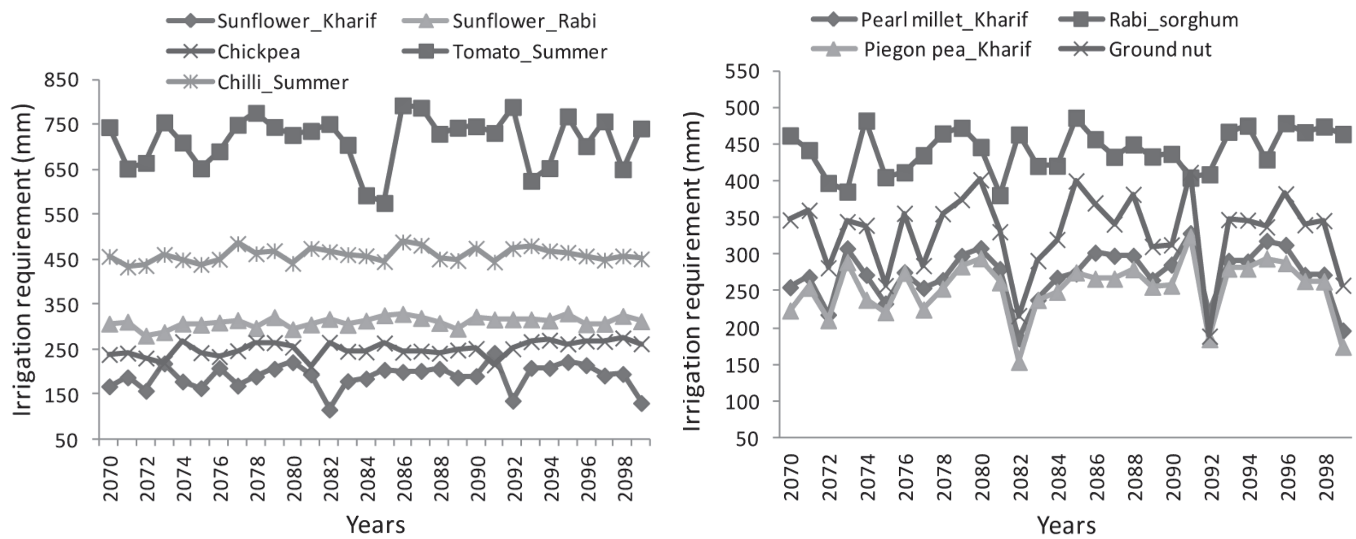

Fig. 7a & b : Irrigation requirement of crops under RCP 4.5 in 2080's

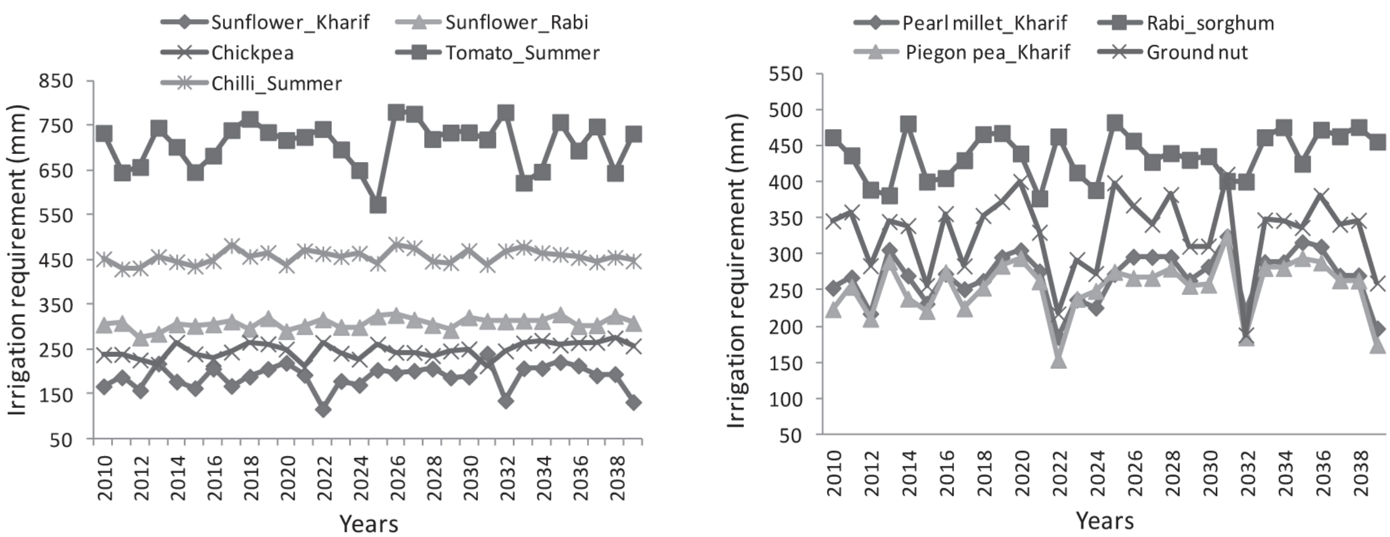

Fig. 8a & b : Irrigation requirement of crops under RCP 8.5 in 2020's

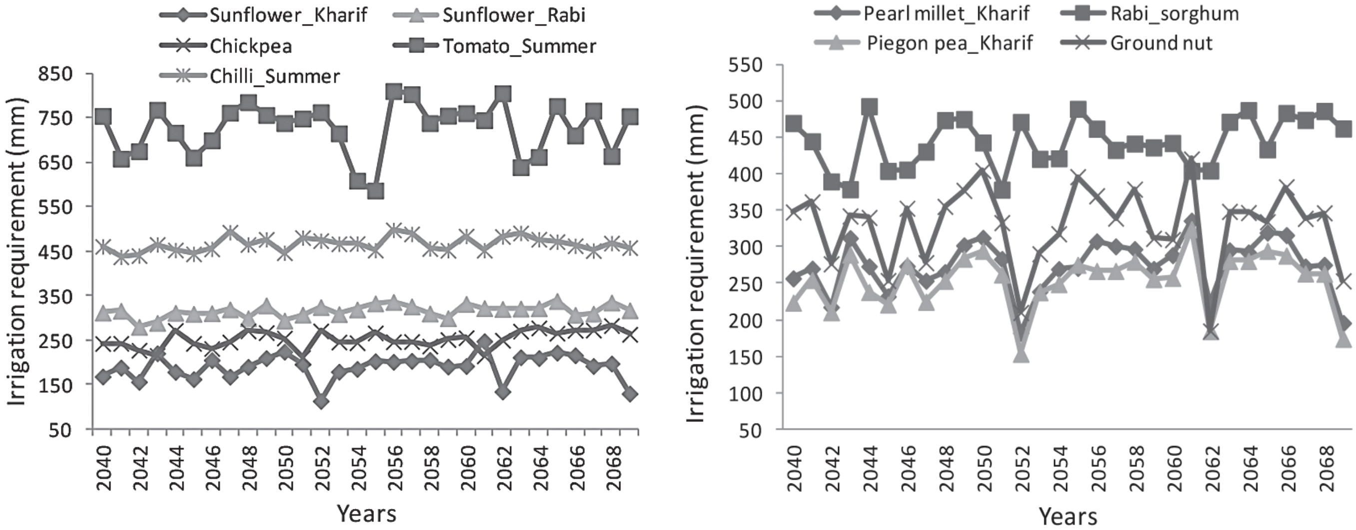

Fig. 9a & b : Irrigation requirement of crops under RCP 8.5 in 2050's

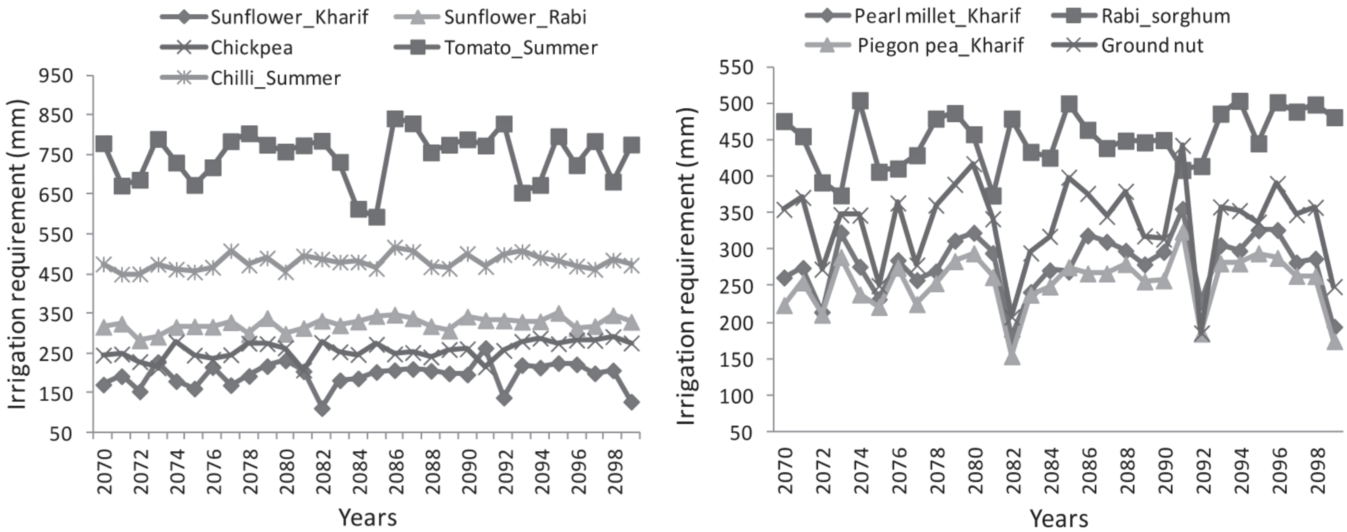

Fig. 10a & b: Irrigation requirement of crops under RCP 8.5 in 2080's

Seasonal variability of rainfall, temperature and evapotranspiration under changing climate scenarios

Seasonal variability during baseline period

During base line period (1976-2005), the seasonal variability (CV %) of rainfall, minimum temperature, maximum temperature and evapotranspiration for the period June to September was 35, 1.5, 1.9 and 3.3% with mean values of 429.3 mm, 22.1^{0}C, 31.4^{0}C and 589.9 mm respectively. Similarly, the seasonal variability during October to February was 70, 3.1, 1.5 and 2.8% with mean values of 118.5 mm, 17.9^{0}C, 31.2^{0}C and 653.7 mm. During March to May, its variability was 84.5, 2.1, 1.4 and 1.9% with mean values of 43 mm, 23.4^{0}C, 38.2^{0}C and 607.0 mm respectively. The seasonal variability of rainfall was less during June to September compared to October to February and March to May.

Seasonal variability under RCP 2.6

During 2010-2039 (2020's), the seasonal variability (CV %) of rainfall, minimum temperature, maximum temperature and evapotranspiration for the period June to September was 35, 1.6, 2.3 and 4.1% with mean values of 458.7 mm, 23.0^{0}C, 32.2^{0}C and 598.4 mm respectively. Similarly, the seasonal variability during October to February was 77.1, 3.5, 1.9 and 2.9% with mean values of 124.3 mm, 18.9^{0}C, 31.9^{0}C and 660.3 mm. During March to May, its variability was 82.1, 2.4, 1.4 and 1.9% with mean values of 38.6 mm, 24.3^{0}C, 39.1^{0}C and 616.6 mm respectively. During 2040-2069 (2050's), the seasonal variability (CV %) of rainfall, minimum temperature, maximum temperature and evapotranspiration for the period June to September was 35.6, 1.7, 2.4 and 4.4% with mean values of 465.3 mm, 23.0^{0}C, 32.5^{0}C and 603.1 mm respectively. Similarly, the seasonal variability during October to February was 72.4, 3.6, 2.0 and 3.2% with mean values of 136.5 mm, 19.4^{0}C, 32.3^{0}C and 663.2 mm. During March to May, its variability was 89.3, 2.4, 1.4 and 1.9% with mean values of 43.4 mm, 24.8^{0}C, 39.5^{0}C and 619.7 mm respectively. During 2070-2099 (2080's), the seasonal variability (CV %) of rainfall, minimum temperature, maximum temperature and evapotranspiration for the period June to September was 36.2, 1.9, 2.5 and 4.4%

with mean values of 462.3 mm, 23.4^{0}C, 32.7^{0}C and 609.5 mm respectively. Similarly, the seasonal variability during October to February was 70.8, 3.3, 1.9 and 3.1% with mean values of 141.1 mm, 19.5^{0}C, 32.4^{0}C and 665.0 mm. During March to May, its variability was 90.3, 2.6, 1.4 and 2.0% with mean values of 43.5 mm, 24.8^{0}C, 39.6^{0}C and 621.3 mm respectively. The variability of rainfall was less during June to September in all the scenarios of RCP 2.6.

Seasonal variability under RCP 4.5

During 2010-2039 (2020's), the seasonal variability (CV %) of rainfall, minimum temperature, maximum temperature and evapotranspiration for the period June to September was 33.8, 1.6, 2.3 and 4.2% with mean values of 450.8 mm, 23.0^{0}C, 32.2^{0}C and 599.7 mm respectively. Similarly, the seasonal variability during October to February was 77.1, 3.5, 1.9 and 3.0% with mean values of 122.5 mm, 18.9^{0}C, 32.0^{0}C and 660.9 mm. During March to May, its variability was 80.5, 2.4, 1.5 and 2.0% with mean values of 37.8 mm, 24.3^{0}C, 39.1^{0}C and 615.5 mm respectively. During 2040-2069 (2050's), the seasonal variability (CV %) of rainfall, minimum temperature, maximum temperature and evapotranspiration for the period June to September was 37.1, 1.9, 2.5 and 4.5% with mean values of 467.1 mm, 23.7^{0}C, 32.9^{0}C and 606.1 mm respectively. Similarly, the seasonal variability during October to February was 73.7, 3.7, 2.0 and 3.3% with mean values of 137.0 mm, 19.8^{0}C, 32.8^{0}C and 670.7 mm. During March to May, its variability was 83.6, 2.6, 1.4 and 2.0% with mean values of 41.9 mm, 25.2^{0}C, 39.9^{0}C and 624.0 mm respectively. During 2070-2099 (2080's), the seasonal variability (CV %) of rainfall, minimum temperature, maximum temperature and evapotranspiration for the period June to September was 38.2, 2.2, 2.6 and 4.7% with mean values of 486.5 mm, 24.1^{0}C, 33.3^{0}C and 612.7 mm respectively. Similarly, the seasonal variability during October to February was 71.9, 3.5, 2.0 and 3.5% with mean values of 150.1 mm, 20.5^{0}C, 33.3^{0}C and 674.8 mm. During March to May, its variability was 87.8, 2.9, 1.5 and 2.1% with mean values of 41.9 mm, 25.8^{0}C, 40.4^{0}C and 628.9 mm, respectively. The variability of rainfall was less during June to September in all the scenarios of RCP 4.5.

Seasonal variability under RCP 6.0

During 2010-2039 (2020's), the seasonal variability (CV %) of rainfall, minimum temperature, maximum temperature and evapotranspiration for the period June to September was 34, 1.5, 2.2 and 4.01 with mean values of 644 mm, 23.0^{0}C, 32.0^{0}C and 593 mm respectively. Similarly, the seasonal variability during October to February was 77.1, 3.3, 1.8 and 2.8% with mean values of 126.5 mm, 18.8^{0}C, 31.9^{0}C and 660.5 mm. During March to May, its variability was 83.9, 2.4, 1.4 and 1.9% with mean values of 38.8 mm, 24.3^{0}C, 39.1^{0}C and 616.3 mm respectively. During 2040-2069 (2050's), the seasonal variability (CV %) of rainfall, minimum temperature, maximum temperature and evapotranspiration for the period June to September was 36.5, 1.7, 2.4 and 4.5% with mean values of 456.2 mm, 23.6^{0}C, 32.9^{0}C and 609.0 mm respectively. Similarly, the seasonal variability during October to February was 72.4, 3.4, 1.9 and 3.2% with mean values of 131.8 mm, 19.6^{0}C, 32.5^{0}C and 666.0 mm. During March to May, its variability was 86.1, 2.5, 1.4 and 2.0% with mean values of 40.9 mm, 25.2^{0}C, 39.8^{0}C and 621.6 mm, respectively. During 2070-2099 (2080's), the seasonal variability (CV %) of rainfall, minimum temperature, maximum temperature and evapotranspiration for the period June to September was 38.0,2.2, 2.5 and 4.6% with mean values of 482.7 mm, 24.4^{0}C, 36.6^{0}C and 614.5 mm respectively. Similarly, the seasonal variability during October to February was 69.7, 3.3, 2.0 and 3.5% with mean values of 153.3 mm, 20.7^{0}C, 33.3^{0}C and 670.9 mm. During March to May, its variability was 95.9, 2.8, 1.4 and 2.0% with mean values of 38.2 mm, 26.4^{0}C, 40.6^{0}C and 626.1 mm, respectively. The variability of rainfall was less during June to September in all emission scenarios of RCP 6.0.

Seasonal variability under RCP 8.5

During 2010-2039 (2020's), the seasonal variability (CV %) of rainfall, minimum temperature, maximum temperature and evapotranspiration for the period June to September was 34.6, 1.7, 2.4 and 4.3% with mean values of 451.5 mm, 23.1^{0}C, 32.3^{0}C and 601.0 mm respectively. Similarly, the seasonal variability during October to February was 75.8, 3.6, 2.0 and 3.2% with mean values of 127.7 mm, 19.0^{0}C, 32.0^{0}C and 659.3 mm. During March to May, its variability was 81.8, 2.5, 1.4 and 1.9% with mean values of 37.7 mm, 24.5^{0}C, 39.2^{0}C and 616.7 mm respectively. During 2040-2069 (2050's), the seasonal variability (CV %) of rainfall, minimum temperature, maximum temperature and evapotranspiration for the period June to September was 37.3, 2.2, 2.7 and 4.9% with mean values of 488.7 mm, 24.30^{0}C, 33.4^{0}C and 611.9 mm, respectively. Similarly, the seasonal variability during October to February was 70.0, 3.7, 2.2 and 3.8% with mean values of 146.3 mm, 20.5^{0}C, 33.2^{0}C and 670.2 mm. During March to May, its variability was 85.1, 2.8, 1.5 and 2.2% with mean values of 39.8 mm, 26.1^{0}C, 40.6^{0}C and 629.6 mm respectively. During 2070-2099 (2080's), the seasonal variability (CV %) of rainfall, minimum temperature, maximum temperature and evapotranspiration for the period June to September was 38.8, 2.8, 3.2 and 6.1% with mean values of 528.4 mm, 25.7^{0}C, 34.8^{0}C and 628.6 mm respectively. Similarly, the seasonal variability during October to February was 69.5, 4.0, 2.6 and 5.0% with mean values of 173.1 mm, 22.5^{0}C, 34.7^{0}C and 683.6 mm. During March to May, its variability was 93.6, 3.5, 1.7 and 2.6% with mean values of 41.6 mm, 28.0^{0}C, 42.2^{0}C and 645.2mm respectively. The variability of rainfall was less during June to September in all emission scenarios of RCP 8.5.

Conclusion

Increase in rainfall, maximum temperature, minimum temperature and potential evapotranspiration are predicted at Vijayapura during 2020's, 2050's and 2080's under four emission scenarios such as RCP 2.6, 4.5, 6.0 and 8.5. The irrigation requirement of *rabi* crops was predicted to increase considerably whereas in *kharif* crops, the increase in irrigation requirement is negligible under low, medium and high emission scenarios.

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