Journal of Agrometeorology

ISSN : 0972-1665 (print), 2583-2980 (online)
Vol. No. 25 (2) : 224 - 238 (June- 2023)
DOI : https://doi.org/10.54386/jam.v25i2.2151
https://journal.agrimetassociation.org/index.php/jam

Invited Articles (Silver Jublee Publication)

Climate variability, trends, projections and their impact on different crops: A case study of Gujarat, India

VYAS PANDEY

Former Emeritus Scientist (ICAR), and Professor and Head, Department of Agricultural Meteorology, Anand Agricultural University, Anand 388110, Gujarat
Email: vyask.pandey@gmail.com

ABSTRACT

Gujarat, being a coastal state, is likely to be impacted by global warming and climate change not only due to sea level rise and salinity ingress but also due to an increase in the frequency of cyclonic storms and other extreme weather events, causing uncertainty in crop production. An attempt has therefore been made to understand the climate of Gujarat in the past, present, and future based on the works done at the Department of Agricultural Meteorology, Anand. Analysis carried out on climatic trends and climatic extremes using past available data from different stations in Gujarat has been highlighted. Crop simulation models validated with experimental data collected for different crops across Gujarat state were used to understand the response of crops to climatic variability. The climate change impact studies and adaptation strategies carried out under the NPCC project have also been highlighted. And lastly, the work done by the author as an emeritus scientist on climate projections under RCP 4.5 and RCP 8.5 for all the districts of Gujarat and their likely impact on selected crops is presented. The results revealed that in the past, temperatures have shown increasing trends but not reached significant levels except at certain locations at night. Rainfall has also increased, but marginally. Future temperatures have been projected to increase in different parts of Gujarat under RCP4.5 and RCP8.5 with varying magnitudes. Similarly, the rainfall has also been projected to increase, while the sunshine hours are projected to decrease. The ultimate impact would be a drastic reduction in yields in spite of the increase in CO_2 level, suggesting that the present-day crop varieties would not be able to sustain crop production levels under a changing climatic scenario.

Key words: Climate change, Climate variability, RCP 4.5, RCP 8.5, Impact on crops, Climatic extremes

Gujarat is the westernmost state of India, having a 1600-km-long sea coast with the Arabian Sea. It is surrounded by the mountain ranges of the Aravalli, Saputara, and Sahyadri from the northeast, east, and southeast directions. The Gulf of Khambhat separates the western peninsula (Saurashtra region) from the main land, which has alluvial soils. Kutch is the largest district, having a long stretch of desert area known as the Rann of Kutch. Climatologically, three main climatic regions exist: arid in the northwest part, dry sub-humid in the southeast part, and most of the remaining part is under a semi-arid climate. Based on rainfall, soil, and cropping patterns, Gujarat has been divided into eight agroclimatic zones, with Navsari (Zone I), Bharuch (Zone II), Anand (Zone III), S K Nagar (Zone IV), Bhachau (Zone V), Taragadia (Zone VI), Junagadh (Zone VII), and Arnej (Zone VIII) as the zonal headquarters (Fig. 1). Rainfall is highly variable in space and time, from less than 250mm in some parts of Kutch district to more than 1500mm in Valsad and Dangs districts (Pandey and Patel 2011). About 90–95 percent of rainfall is confined to a four-month period (June to September) of the SW monsoon, influenced by the monsoon currents of the Arabian Sea as well as the Bay of Bengal branches. The absence and presence of one or both causes dry spells and heavy rainfall, resulting in the simultaneous occurrence of droughts in one part of the state and floods in other parts, which makes the planner's tasks more difficult.

The soils of the Gujarat state vary in texture and structure due to variation in their origin and are mainly classified into black soils, mixed black and red soils, residual sandy soils, alluvial soils, alkaline/saline soils, laterite soils, desert soils, etc. As a result of variations in soils and rainfall, a variety of crops are grown in the state. Paddy, maize, pearl millet, and sorghum are the principal cereal crops, while groundnut, castor, sesame, and mustard are the oilseed crops.

Article info - DOI: *https://doi.org/10.54386/jam.v25i2.2151*
Received: 02 March 2023; Accepted: 19 April 2023; Published online : 25 May 2023

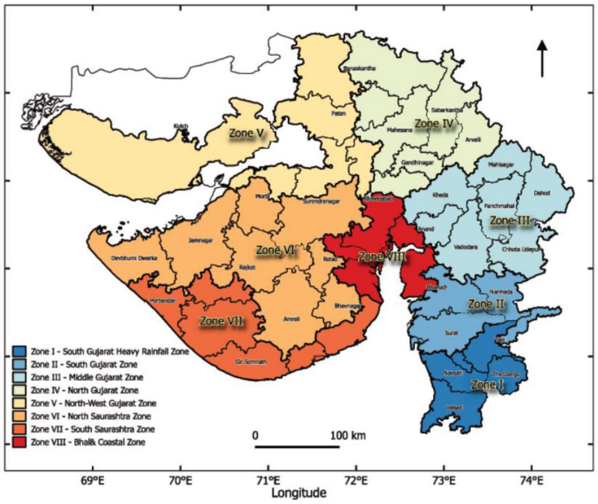

Fig. 1: Agroclimatic zones of Gujarat state

Green gram, black gram, pigeon pea, moth bean, soybean, and gram are major pulse crops grown in the state. Cotton, sugarcane, castor, and tobacco are the major commercial crops. Mango, Aonla, Sapota, Ber, Banana, and Lime are major horticultural crops. Vegetables, spices, condiments, medicinal plants, and aromatic plants are grown in different parts of the state. Agroclimatic atlases of Gujarat were prepared by the Department of Agricultural Meteorology, Anand, Gujarat, and have been updated from time to time. The recent one published in 2018 depicts the details of agroclimatic parameters and their spatial variation (Lunagaria *et al.* 2018).

CLIMATIC VARIABILITY AND TRENDS IN GUJARAT

Climatic variability

The long-term rainfall analysis of Gujarat revealed that the variability of annual rainfall is high (>60%) in low rainfall regions of Kutch districts while it is less (30%) in the heavy rainfall regions of Valsad and Dangs districts of Gujarat (Pandey and Patel, 2011). The variability is still greater on seasonal and monthly scales. Even in the peak monsoon activity period in July, the coefficient of variation of monthly rainfall in Kutch district is more than 100%. Temperature also varies substantially over space and time. In north Gujarat, during the summer season in May, the day temperature exceeds 42^{0}C and sometimes reaches 44^{0}C, while during the winter season in January, the temperature drops below 10^{0}C at night and sometimes around 4-5^{0}C, resulting in cold wave conditions. While in south Gujarat and coastal Saurashtra regions, during the summer season the maximum day temperature is around 370 °C, and during the winter season it does not fall below 150 °C.

The detailed analysis of monthly rainfall and maximum and minimum temperatures in Anand using long-term data (1958–2015) shows that there was large year-to-year variation in the rainfall and temperatures in different months (Figs. 2, 3, and 4). In the case of rainfall, although 95% of annual rainfall is received from June to September, there has been a large fluctuation in rainfall received during different months. February and March had the least amount of rainfall. July (285 mm) and August (255 mm), having the months of higher rainfall, also experienced complete dry periods in certain years (Fig. 2). The maximum temperature was also found to vary greatly from year to year during different months (Fig. 3). During the winter months, the maximum temperature was found to reach the level of the mean summer temperature. Similar variability in minimum temperature was also observed at Anand during this period (Fig. 4).

Climatic trends

The fluctuation in monthly rainfall, maximum and minimum temperatures depicted in figures (Figs. 2, 3 & 4) show the climatic variability in different months during 58 years period (1958-2015). The line drawn over the data shows the trend of the parameters over the period. The trends of rainfall show decreasing in the month of June but increasing in July, August and September months (Fig.2). During winter the rainfall is having decreasing trend in November and December but increasing trends in January. In case of maximum temperature, it is having increasing trends in all the months except January and May months in which it is decreasing trend (Fig.3). The minimum temperature is found to increase in all the months (Fig.4).

The trend analysis of annual rainfall of Anand showed a slight increasing trend at a rate of 2.86 mm per year during a 50-year period (1958–2007). However, the annual variability was found to be much greater than the total increase in the rainfall over the period. The maximum and minimum temperatures were also found to have increased trends at Anand in all three seasons (monsoon, winter, and summer), with a varying rate of 0.2–0.5 ^{0}C per decade (Pandey and Patel, 2011). Across the state, the situation was more or less similar but of varying magnitude. The trend analysis of rainfall and temperature for different locations in Gujarat using a 30-year (1961–1990) period of data showed that the trend of temperatures and rainfall was non-significant at Bhavnagar and Vadodara in all the seasons (monsoon, post-monsoon, winter, and summer) and also on an annual basis (Patel *et al.,* 2015). The monsoon rainfall was found to have decreasing trends at Bhavnagar, Bhuj, and Junagadh and an increasing trend at Anand, Vadodara, and Rajkot, all of which were non-significant. Maximum temperature was found to be increasing significantly during the winter, monsoon, and post-monsoon seasons at Bhuj station and during post-monsoon and on an annual basis at Anand. While in Rajkot, it showed a significantly negative trend during the summer season. The minimum temperature was found to increase significantly in different seasons at Junagadh, Rajkot, and Anand while showing a decreasing trend at Bhuj. This clearly suggests that during the 1961–1990 period there was not a uniform climatic trend or variation in any of the climatic parameters.

Climatic extremes

Table 1 shows the extreme events of one-day rainfall, maximum and minimum temperatures recorded in different months at Anand during a 58-year period (1958-2015). The lowest daily rainfall in every month is obviously zero; hence, it is not given. The highest one-day rainfall of 421.0 mm was recorded on July 1, 2005, in continuation of the previous day's (30 June 2005) highest rainfall for the month of June (215.0 mm). October month recorded the highest one-day rainfall of 204.2 mm in 1985, against the normal monthly rainfall of 14.6 mm, which was due to the effect of cyclonic events occurring in October and November. The highest maximum

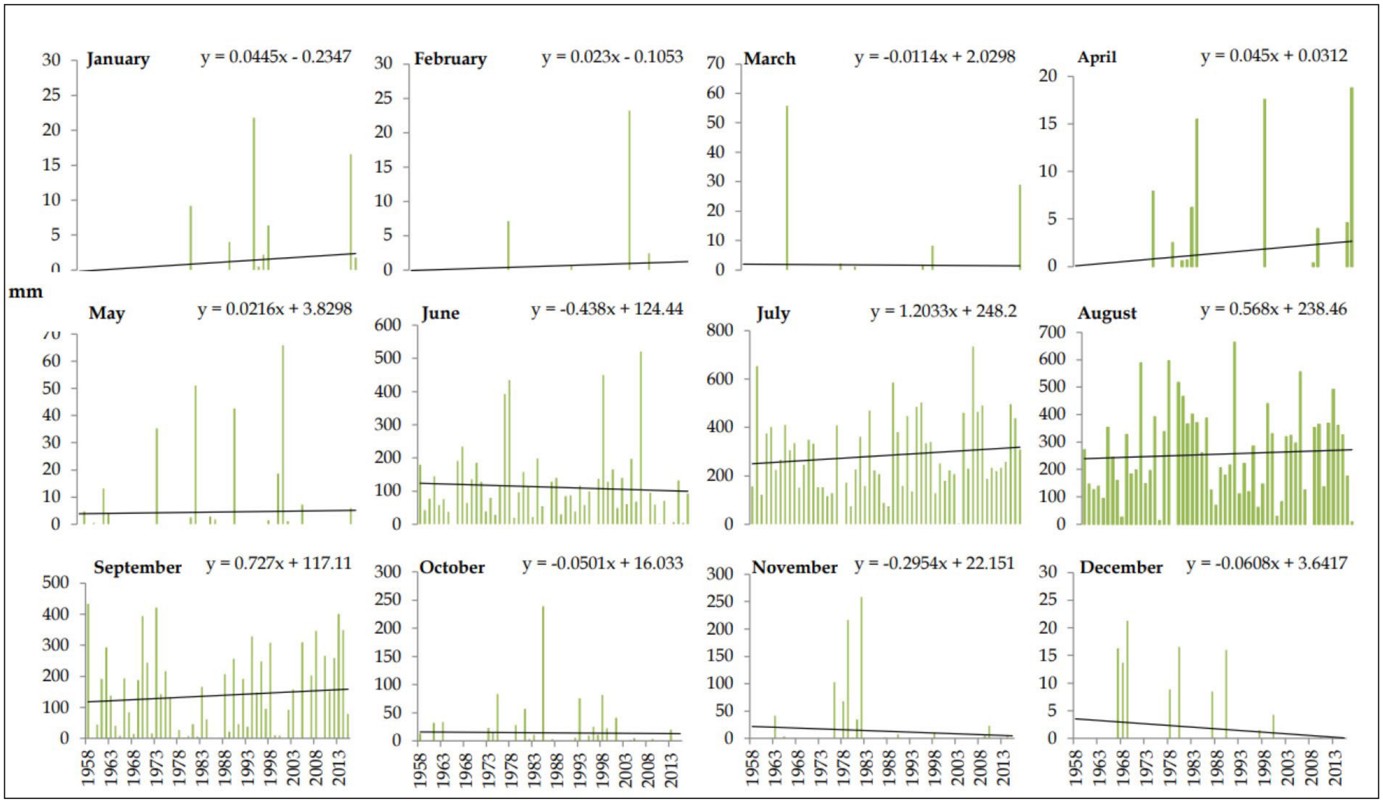

Fig. 2: Variability and trends in monthly rainfall at Anand (1958-2015)

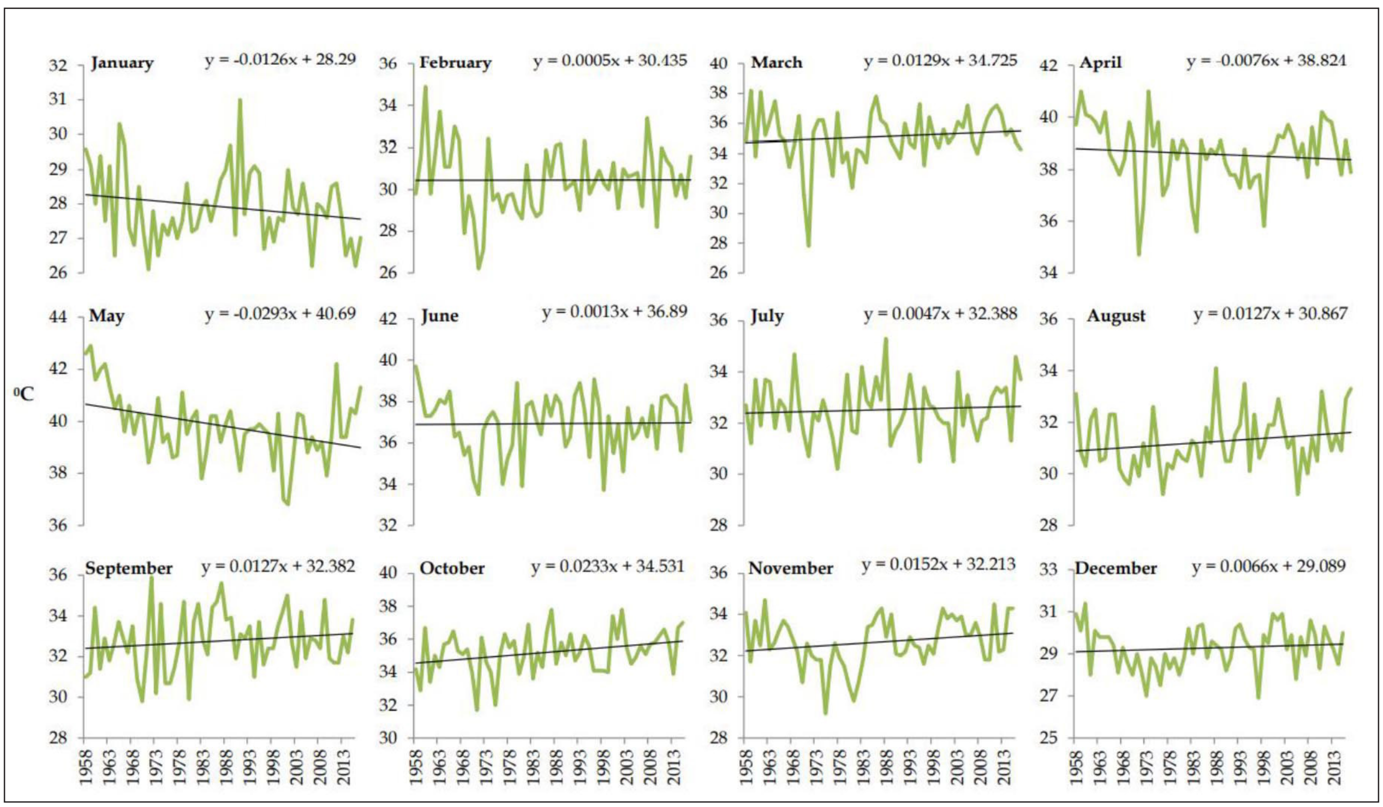

Fig. 3: Variability and trends in mean monthly maximum temperature at Anand (1958-2015)

temperature of 47.2 °C was recorded in May 1960, followed by 45.6 ^{0}C in the month of June 1973 (Table 1). Even September and October months recorded maximum temperatures of more than 41 ^{0}C. The lowest maximum temperature recorded was 15.8 ^{0}C in February 1958, followed by 20.0 ^{0}C in December 1990 and 20.6 ^{0}C in March 1971. The lowest minimum temperature recorded at

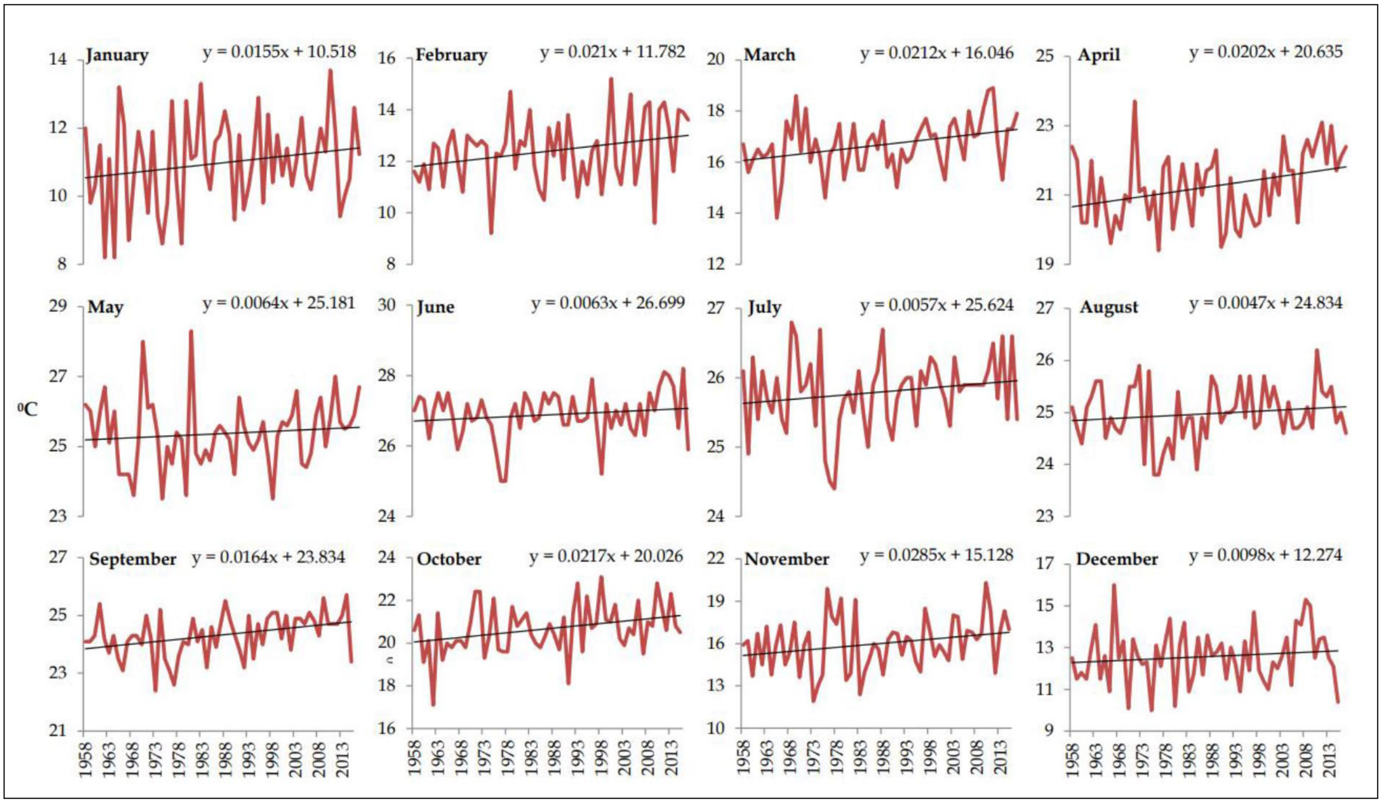

Fig. 4: Variability and trends in mean monthly minimum temperature at Anand (1958-2015)

Table 1: One day extreme rainfall, maximum and minimum temperatures recorded at Anand during 1958-2015

Month	Rainfall (mm)		Max. temp. (^{0}C)		Min. temp. (^{0}C)	
	Highest	Year	Highest	Lowest	Highest	Lowest
January	9.2	2014	36.0 (1991)	21.1 (1973)	27.8 (1969)	1.1 (1964)
February	23.2	2003	38.9 (1960)	15.8 (1958)	22.2 (2010)	2.8 (1968)
March	24.1	1967	43.3 (1959)	20.6 (1971)	26.4 (1985)	6.6 (1965)
April	9.6	1997	43.8 (2002)	27.8 (1971)	28.5 (2010)	10.0 (1967)
May	65.0	2000	47.2 (1960)	30.0 (2004)	29.8 (1990)	16.1 (1960)
June	215.0	2005	45.6 (1973)	25.8 (2001)	30.6 (2007)	17.8 (1962)
July	421.0	2005	41.1 (1979)	24.4 (1965)	30.5 (2010)	12.2 (1984)
August	247.4	1990	39.2 (1987)	24.4 (1973)	29.0 (2009)	17.0 (1984)
September	187.5	1970	43.1 (1965)	25.0 (1966)	27.8 (2014)	15.1 (1984)
October	204.2	1985	41.1 (1987)	24.5 (1996)	28.3 (1963)	11.7 (1964)
November	85.5	1979	37.5 (2001)	21.1 (1978)	25.6 (2014)	5.6 (1974)
December	21.3	1969	35.1 (2008)	20.0 (1990)	19.5 (2008)	2.6 (1983)

Anand was 1.1 ^{0}C in January 1964, followed by 2.6 ^{0}C in December 1983 and 2.8 ^{0}C in February 1968, whereas the highest minimum temperature was 30.6 ^{0}C in June 2007 and 30.5 ^{0}C in July 2010 (Table 1).

Various extreme climate indices analysed using daily available time series data of 1958 to 2011 period for maximum temperature, minimum temperature and rainfall at 32 locations of Gujarat, revealed mixed pattern for most of the temperature and rainfall extreme indices over the Gujarat (Lunagaria *et al*. 2015). However, increase in numbers of warm nights (TR25), decrease in cold days (FD10), increase in minimum of minimum temperature (TNn), decrease in frequency of cool nights (TN10p) and increase in frequency of warm nights (TN90p) revealed state wide uniform pattern, indicating signature of warming in Gujarat (Fig. 5). These warming trend in indices based on minimum temperature reveals trend of less cooling during night period. Rainfall indices also showed no uniformity for any negative or positive trends over Gujarat. Total annual rainfall (PRCPTOT) and extremely wet days (R99p) were found to increase at more numbers of stations. As the rainfall is a parameter having very high variability, very few stations showed statistically significant trends.

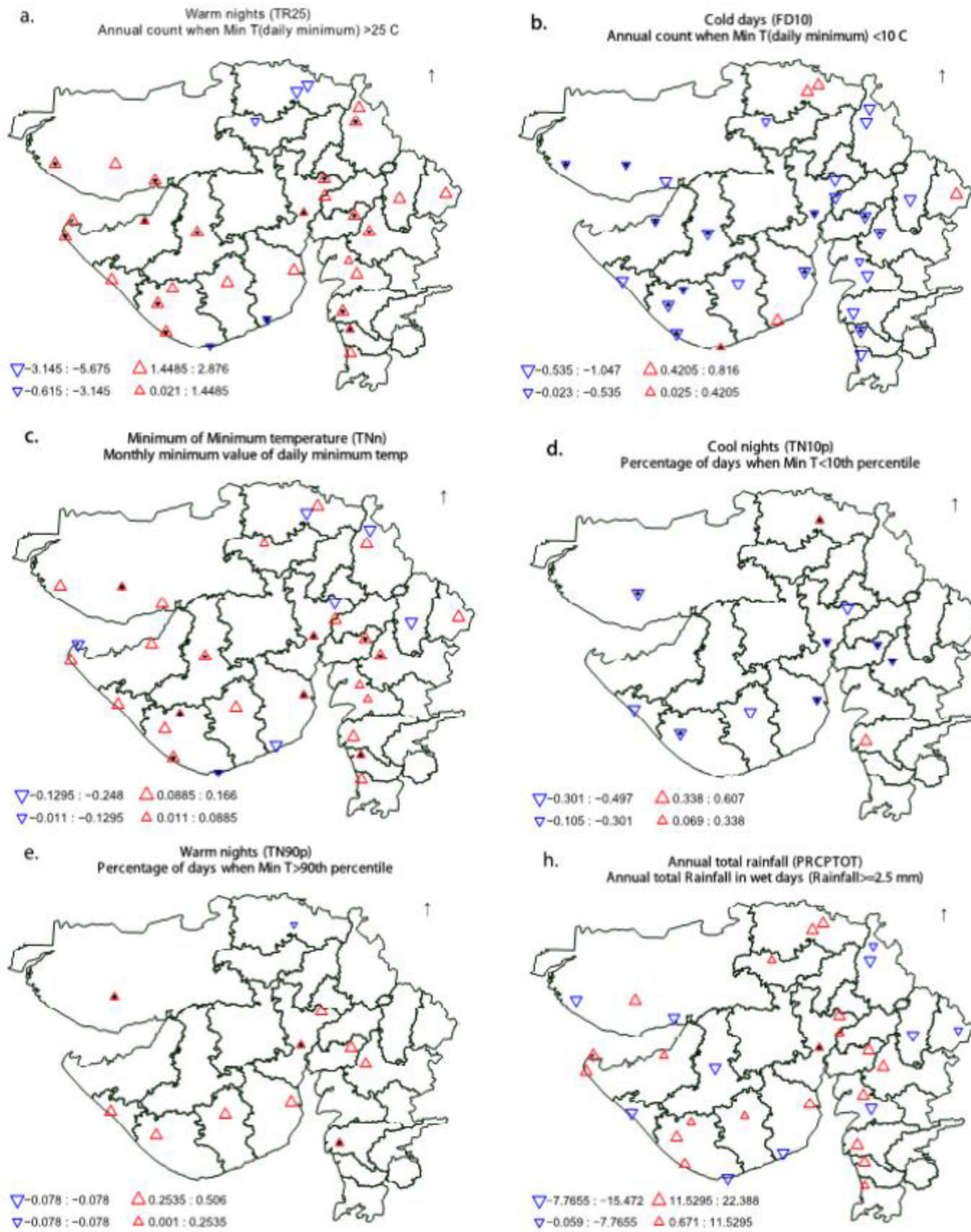

Fig. 5 (a-h): Spatial mapping of climatic extreme indices (trends) over Gujarat. (Triangle indicates positive trend/index value, Inverted triangle indicates negative trend/index value, Asterisk (*) in marker indicates statistically significant value at 0.05 level)

EFFECT OF CLIMATIC VARIATION ON CROP PRODUCTION

The growth, development, and yield of a crop is the combined effect of variation in the climatic parameters encountered by the crop during its life period, in addition to the effects of soils and crop management practices. It is a complex process, however, in order to study the effect of climatic variability on crop growth and yield, the simulation models are the most suitable options. There are several simulation models such as WOFOST, DSSAT, InfoCrop, APSIM, etc. that are being used, after proper validation, to study the impact of climatic variability and climate change by considering weather parameters individually or in combinations with each other and also to test the sensitivity of the models to variation in input parameters. Temperature is the most important parameter affecting the growth and yield of the crops by hastening the growth process, resulting in a shortening of the duration of the crops and a corresponding reduction in the yield. However, the response has been found to vary with the crop and varieties.

Wheat

Wheat is an important cereal crop in the state, grown during the winter season (November to March). Pandey and Patel (2011) reported that an increase in maximum temperature by 2^{0}C during the crop growing season resulted in a reduction of wheat yield by -19% at Anand, whereas a decrease in maximum temperature by the same magnitude caused an increase in the grain yield of wheat by +17%. The effect of night-time temperature had a similar effect, but was slightly less within the range of ±10%. Mishra *et al.* (2015), using the WOFOST model, reported a variable response among the wheat varieties. Due to the increase in maximum temperature by 2^0C, the yield reduction was about -8% in cultivar GW 366 and -20% in cultivar GW322. Cultivar GW366 was found to be most sensitive to the night temperature, as the yield reduction was the highest (-17%) in this cultivar in comparison to other varieties tested. The effect of an increase in solar radiation or sunshine duration was found to be beneficial to wheat crops. The increase in CO_2 concentration resulted in an increase in wheat yield production. at a CO_2 level of 440 ppm resulted in +21% increase in the grain yield of wheat. However, if the temperature was also increased along with the CO_2 concentration, then the beneficial effect of a higher CO_2 concentration was nullified to a great extent due to the adverse effect of a higher temperature (Pandey and Patel, 2011).

Maize

Maize is another important cereal crop in the state, grown both during the *kharif* and *rabi* crop seasons. The response of the *rabi* maize crop to climatic variations was quite different from that of the wheat crop (Pandey and Patel, 2011), while that of the *kharif* maize crop was similar to that of winter wheat. An increase or decrease in the maximum temperature by 1^0C was found to have a favorable effect on maize yield. By 2^0C increase in maximum temperature, the reduction in maize yield was only -0.2%. The response to changes in the minimum temperature was always favorable; however, the magnitude was less than +10%. The increase in CO_2 concentration was also not beneficial to the maize crop (less than 3% at 440 ppm), which may be due to the maize crop being a C4 plant.

Rice

An increase in maximum and minimum temperatures was found to have a negative effect on the yield of rice at Nawagam, Gujarat, while a decrease in temperature resulted in an increase in the yield of different cultivars of rice. The magnitude of the response was found to vary with the cultivars (Shamim *et al.* 2010). An increase in maximum temperature of 2^0C resulted in a decrease in yield from -7.8% in cultivar Narmada to -19.9% in GR-104, while 2^0C decrease in maximum temperature caused an increase in yield from +11.3% in Narmada to +16.4% in GR-104. Among all the four varieties tested, GR-104 was found to be the most sensitive to variations in maximum temperature. Similar effects were also observed with the variation in minimum temperature. The variation in sunshine duration and solar radiation significantly affected the rice yield. Increase in sunshine by one hour caused an increase in yield by 7% to 10% in different cultivars, while decrease in duration by one hour resulted in a decrease in yield by -7% to -22% (Shamim *et al.* 2010).

Groundnut

Groundnut is an important oilseed crop in the state, grown mainly during the *kharif* season; however, it is also grown in the summer, when irrigation facilities are available, resulting in higher production in comparison to *kharif* groundnut. The analysis carried out by Mote *et al*. (2018) on summer groundnut revealed that with an increase in maximum temperature by 2^0C, there was a drastic reduction (-30% to -40%) in the pod yield of different cultivars of summer groundnut. The decrease in the maximum temperature by 2^0C resulted in an increase in pod yield of 20-35%. The effect of the minimum temperature was quite small in comparison to the maximum temperature. An increase in minimum temperature by 2^0C caused yield reductions of -8% to -15%, while a decrease in temperature resulted 5-11% increase in the pod yield of groundnut cultivars. An increase in CO_2 concentration increased the pod yield substantially, however, this increase in yield may be nullified with an increase in temperature of 2^0C. For groundnut grown during *kharif* season, the rainfall distribution is more important. Sane amount of rainfall with erratic distribution may cause poor yield. Groundnut sown with the onset of monsoon has produced higher pod yield than delayed crop (Pandey *et al*. 2016).

Pigeon pea

Pigeon pea is a medium- to long-duration pulse crop grown during the *kharif* season in Gujarat. The crop's seed yield was significantly influenced by the date of sowing.Patil *et al*. (2018a) have reported that the delay in sowing caused a reduction in the seed yield by about 50%, from 1825 kg ha^{-1} in the June 20 sown crop to 904 kg ha^{-1} in the August 14 sown crop. Cultivar AGT2 produced the highest yield among the three cultivars tested. The change in maximum and minimum temperatures by 2^0C caused seed yield variation of 10% or less among different sowing dates and varieties. An increase in maximum temperature of 2^0C caused a decrease in yield of -8.7% in early sown crops and a decrease of -6.6% in late sown crops, while a decrease in maximum temperature caused an increase in yield of -8.0% in early sown crops and a decrease of -6.1% in late sown crops. The response of pigeon peas to variation in minimum temperature was similar to that of maximum temperature, with slightly less ranging between -7.4% and 7.8% (Patil *et al.,* 2018a). The intra-seasonal analysis revealed that the fluctuation in temperature during the October month had the highest influence and that of the June month had the least influence on the seed yield of pigeon pea. The seed yield of pigeon pea was directly related to the amount of rainfall received during the crop season.

Potato

Potato is an important vegetable crop in Gujarat, grown during the winter season. Tubers planted during the first fortnight of November were found to have produced a significantly higher tuber yield than the tubers planted during October (Patil *et al*., 2018b). Varietal differences were found to be significantly influenced by climatic variation. The effect of temperature variation during different months of the potato crop growing season was found to have differential effects due to planting dates. An increase in maximum temperature by 2^0C in different months (November, December, January, and February) caused a decrease in the tube yield by -4.6% to -10.6%, while a decrease in temperature caused a slight increase in the yield, varying between 2.2% and 12.6% across the dates of planting. Lowering of the maximum temperature during November has the highest favorable effect, while temperature fluctuation during February has the least favorable effect (Patil *et al.,* 2018b). However, the late sown crop was more influenced by the temperature fluctuation in February than that of other months. The effect of the minimum temperature was more or less similar to that of the maximum temperature, but slightly on the higher side.

Cotton

Gujarat's most important cash crop is cotton. Desi as well as hybrid cotton varieties are widely grown in the state. With the introduction of Bt-cotton varieties in the state, the farmers income increased by many folds. The effect of climatic variation on the seed cotton yield of hybrid cotton cultivars has been reported by Patil *et al.* (2019). The results revealed that the increase in maximum as well as minimum temperature caused a decrease in seed cotton yield, the magnitude varied with the cultivars, as well as the period and extent of the increase in temperature. With an increase in maximum and minimum temperatures by +2^{0}C in different months, the decrease in the seed cotton yield was between -3.3% and -9.9%; the maximum effect was with the November temperature, and the least effect was with the July temperature. A similar effect was observed with the minimum temperature. The effect of rainfall was also found to vary with the month and amount of rainfall. The fluctuation in rainfall during the month of September has the greatest effect on seed cotton yield in comparison to July and August rainfall. A 10% increase in rainfall in September resulted in an 8-10% increase in yield, while a 10% decrease in rainfall may result in a -13 to -15% decrease in yield.Patil *et al.* (2019).

Sugarcane

Sugarcane is a long-duration crop mostly grown in south Gujarat, but it is also grown in some areas of middle Gujarat and south Saurashtra. Parmar *et al*. (2019) calibrated and validated the CANEGRO model for sugarcane cultivars at Navsari, which was used to study the effect of rainfall and temperature variation on sugarcane yield. Pandey (2020) reported that the response of sugarcane to a change in temperature was in general similar to other crops, however, the magnitude of yield variation was less than the other crops. An increase in maximum and minimum temperatures by +2^{0}C in different months, caused a decrease in the sugarcane yield of only -2.4% to -6.3%, while a decrease in maximum temperature by the same amount resulted in an increase in yield by more or less percentage. Temperature variation during April month was found to have the most influence on sugarcane production. A similar effect of lesser magnitude was noticed with the fluctuations in the minimum temperature.

CLIMATE PROJECTIONS UNDER A2 SCENARIO AND ITS IMPACT ON CROPS

The regional climate model PRECIS (**P**roviding **RE**gional **C**limates for **I**mpacts **Studies),** developed at Hadley Center, United Kingdom, had been used to generate climate under different climate change scenarios. The climatic parameters generated by the model have been widely used for climate change impact studies. Under the Network Project on Climate Change (NPCC) at the Department of Agricultural Meteorology in Anand, the climate projections under the A2 scenario of the IPCC (2007) were obtained from the Indian Institute of Tropical Meteorology, Pune, for a baseline period of 1961–1990 and a projected period of 2071–2100. These data were downscaled to the nearest grid point for different stations in Gujarat. Lunagaria *et al.* (2011) compared the PRECIS output for the baseline period (1961–1990) with observed data from Anand for the same period and reported that the model output for rainfall and minimum temperature was very close to the observed data, whereas there was some under- and overestimation in the monthly distribution of maximum temperature that needed to be corrected before using such output data.

Climate projections

Patel *et al.* (2015) compared the 1961–1990 base line climate with the projected (2071-2100) climate at six stations in Gujarat (Anand, Vadodara, Bhuj, Junagadh, Rajkot, and Bhavnagar) and reported that all three parameters (rainfall, maximum temperature, and minimum temperature) were found to increase during the projected period. Rainfall during the projected period was found to increase less in Anand (37%) and Vadodara (15%) and more (52–81%) in the Saurashtra region. Bhuj was expected to receive 101% more rainfall during the projected period. The maximum temperature was projected to increase by 2.8^{0}C to 7.7 ^{0}C at different stations, the lowest being at Bhuj and the highest being at Anand. At other stations, it is projected to increase between 3.6^{0}C and 4.1^{0}C. In the case of the minimum temperature, the increase is expected to be between 3.8^{0}C and 5.2^{0}C, the highest being at Anand and the lowest being at Bhavnagar. A similar increase in rainfall (43%), maximum and minimum temperatures (4.2^{0}C) for Dahod station was reported by Choudhary *et al*. (2015). However, Yadav *et al.* (2012) reported that there was a large year-to-year variation in rainfall during the projected period (-20% to +56%) at Anand, while in the case of maximum and minimum temperatures, the variation was less but had an increasing trend.

Impact on crops and adaptation strategies

Using downscaled PRECIS climate projection data for the 2071-2100 period, validated crop simulation models like InfoCrop and DSSAT were used to simulate the growth and yield of different crops and compared them with that of the 1961–1990 baseline period. Patel *et al*. (2012) reported that under the projected climate (2071-2100), the simulated anthesis, physiological maturity, LAI, biomass, and grain yield of wheat would be reduced. There was less change (-5%) in the duration of the crop) but a drastic reduction (-40% to -70%) in LAI, biomass, and grain yield of wheat simulated by the InfoCrop model at Anand. Varietal differences as well as changes in sowing dates were also found to vary in their response to the projected climate.

Patel *et al*. (2012) also analyzed the impact of projected climate on the maize crop grown during the *kharif* and *rabi* seasons at Dahod and reported that the reduction in duration of anthesis, maturity crop, and LAI was about -25% to -27% in *kharif* maize and about -15% in *rabi* maize. The reduction in biomass and grain yield was much higher (-30% to -40%) in *kharif* maize in comparison to *rabi* maize (-8% to -10%). Thus, the *rabi* maize would be less impacted by the climate change. Choudhary *et al*. (2015) applied adaptation measures like additional irrigation, fertilizers, and

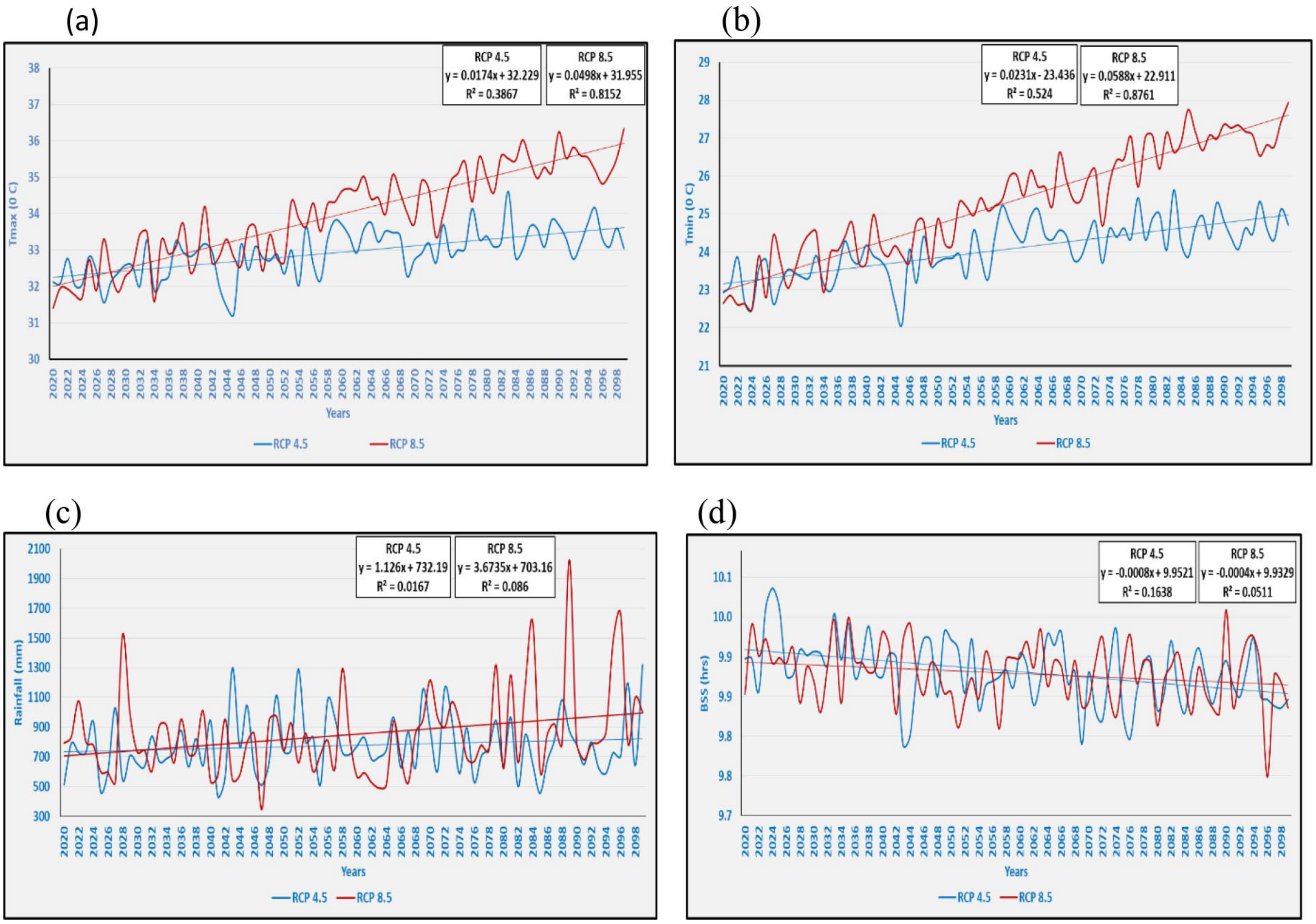

Fig. 6: Projected (a) maximum temperature, (b) minimum temperature, (c) annual rainfall and (d) sunshine hours under RCP 4.5 and RCP 8.5 in Ahmedabad

organic manures and reported that an 8–18% higher yield could be obtained, which would not be sufficient to meet the challenges arising due to climate change.

Yadav *et al.* (2013) used the CERES-Millet model to simulate the impact of the projected climate during 2071-2100 under the A2 scenario on the pearl millet crop and compare it with that of the baseline (1961–1990) at different locations (Junagadh, Rajkot, Bhavnagar, and Bhuj) in Saurashtra and the Kutch regions of Gujarat. They reported that the duration of pearl millet grown during *kharif* seasons reduced by -5% to -16% at the different locations across the two varieties and two sowing windows, with the least effect being at Junagadh (-9% or less) and the maximum being at Rajkot (-12% to -16%). The LAI was projected to be reduced by -10% to -18% across the locations, while the biomass would be reduced by a little less (-5% to -15%). The grain yield was projected to be reduced by -7% to -18% across the locations, varieties, and sowing windows. They also worked out the performance of pearl millet grown during the summer season and reported that the response was similar, but the magnitude of reduction was quite less in comparison to *kharif* pearl millet. The yield reduction was reported to be less than 10% across the locations. They also applied adaptation strategies such as changing the variety, changing the dates of sowing, and applying additional irrigation and fertilizer. They reported that by adapting all the measures, yield could be improved by 10%, but that would not be sufficient to cope with the adverse effects of climate change.

Parmar *et al.* (2023) evaluated the impact of the projected climate (2071-2100) under the A2 scenario on the groundnut crop in Rajkot using the CROPGRO-peanut model and compared it with that of the 1961–1990 baseline. Results indicated the phenological duration, LAI, haulm yield, and pod yield were found to be reduced in comparison to that of the baseline period; however, the percent reduction was maximum (-25% to -42%) in the LAI simulation, followed by pod yield, which is expected to decrease between -28% and -32% across the variety and sowing window. The phenological duration was projected to reduce by less than 10%. They also attempted to see how adaptation measures, such as early sowing and applying organic manure, affected yield, and found that early sowing with one irrigation increased yield by 16%, and using organic fertilizers instead of chemical fertilizer increased yield by 11%. However, even applying adaptation strategies may not be enough to cope with the adverse effects of climate change during the 2071-2100 period.

Thus, amongst all the crops studied, the impact of climate change would be maximum in the wheat crop, followed by *kharif* maize, paddy, *kharif* groundnut, and *kharif* pearl millet, and it would

(a) (b)

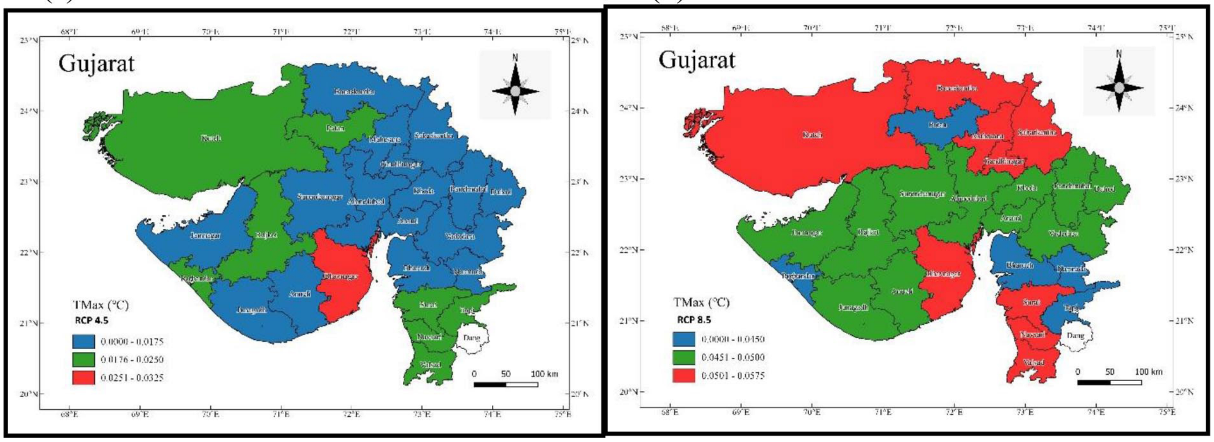

Fig. 7: Trends of projected maximum temperature in Gujarat under (a) RCP 4.5 and (b) RCP 8.5

be less in *rabi* maize and summer pearl millet (Patel *et al*., 2015).

CLIMATE PROJECTIONS UNDER RCP4.5 and RCP 8.5 AND ITS IMPACT ON CROPS

Climate projections under RCP 4.5 and RCP 8.5

The IPCC (2014), in its Fifth Assessment Report (AR5), defines the four pathways for climate modelling. These Representative Concentration Pathways (RCP) are based on greenhouse gas concentrations labelled RCP 2.6, RCP 4.5, RCP 6.0, and RCP 8.5 after the possible radiative forcing at the end of the century in 2100. For climate change impact studies in Gujarat state, the climate change projections made by the RCM model: (RegCM4-4CCCma-CanESM2) developed by the Canadian Centre for Climate Modelling and Analysis, Canada, for regional climate studies, were obtained from the Indian Institute of Tropical Meteorology, Pune. The climate change data on maximum temperature, minimum temperature, rainfall, and bright sunshine hours under two climate scenarios, RCP 4.5 and RCP 8.5, were downloaded from the website http://cccr-dx.tropmet.res.in:8000/cccrindia/, and the data were extracted using tools developed by the Centre for Climate Change Research of IITM, Pune, for the period from 2006 to 2100 for different locations covering all the districts of the Gujarat (Pandey 2020).

The projected annual rainfall, maximum temperature, minimum temperature, and sunshine hours were plotted, and trendlines were fitted under RCP 4.5 and RCP 8.5 for all the districts of Gujarat. Fig. 6 shows one such graph for the Ahmedabad district. The maximum temperature and minimum temperature have increasing trends with a large annual variation. The rate of increase was higher under RCP 8.5 in comparison to that under RCP 4.5. Under RCP 4.5, the maximum temperature is projected to increase at a rate of 0.17 ^{0}C per decade, while under RCP 8.5 the rate is 0.50 ^{0}C per decade (Fig. 6a). The minimum temperature was found to increase at the rate of 0.23 ^{0}C per decade under RCP 4.5 and at the rate of 0.59 ^{0}C per decade under RCP 8.5 (Fig, 6b). Under RCP 4.5, both the maximum and minimum temperatures were found to increase until 2050–2060; thereafter, thereafter remained more or less constant with regular annual variations. The annual rainfall was also found to increase during the projected period at the rate of 11.6 mm per decade under RCP 4.5 and 36.7 mm per decade under RCP 8.5. Annual rainfall varied greatly from year to year under RCP 8.5, ranging from 350 mm in 2047 to 2050 mm in 2087, whereas it varied less under RCP 4.5 (Fig, 6c). The sunshine duration has been projected to decrease under both the RCPs, however, the rate of decrease was very small (-0.004 to -0.008 hours per day per decade), and the rate was higher under RCP 4.5 than that of RCP 8.5 (Fig, 6d). Annually, the decreasing trend was 1.46 hours per decade under RCP 8.5 and 2.52 hours per decade under RCP 4.5.

Similar analysis has been done for all the districts of the state and the rate of changes are presented on the map of Gujarat wherein the rates have been grouped into 3 categories depicted by 3 colours (Figs. 7, 8, 9 and 10).

Trends in maximum temperature: The rate of increase was always higher under RCP 8.5 than that of RCP 4.5 in all the districts. Under RCP 4.5, the maximum temperature is projected to increase up to it is projected to be more or less constant, fluctuating over the years. By the end of the century, the maximum temperature is projected to increase by 1.3^{0}C to 2.0^{0}C at different locations under RCP 4.5 and by 3.4^{0}C to 4.5^{0}C under RCP 8.5. Under RCP 4.5, the rate of increase of the maximum temperature varied from 0.0159^{0}C to 0.0255^{0}C per year, with the highest being in Bhavnagar district and the lowest in Amreli district. The map of the trend of maximum temperature (Fig. 7a) shows that the majority of districts in Gujarat fall under the low category of rate of increase of maximum temperature (0.0175^{0}C per year), while some districts in south Gujarat, Saurashtra, and Kutch show a medium-to-high rate of increase in maximum temperature under RCP 4.5.

Under RCP 8.5, the rate of increase of the maximum temperature varied from 0.0429^{0}C per year in Somnath district to 0.0562^{0}C per year in Navsari district. The spatial distribution of the rate of increase of maximum temperature under RCP 8.5 (Fig. 7b) shows that most parts of middle Gujarat and Saurashtra regions fall under a moderate range of temperature increase (0.0451 to 0.050^{0}C per year), while some districts in south Gujarat, north Gujarat, and Kutch district are expected to experience a higher rate of increase (>0.050^{0}C per year) in maximum temperature under RCP 8.5.

Trends in minimum temperature: The spatial distribution of rates

(a) (b)

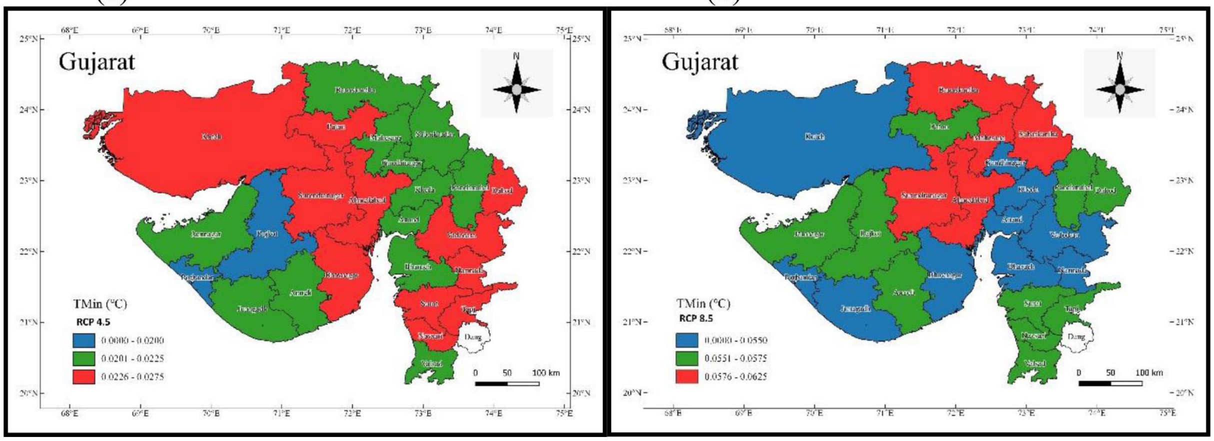

Fig. 8: Trends of projected minimum temperature in Gujarat under (a) RCP 4.5 and (b) RCP 8.5

(a) (b)

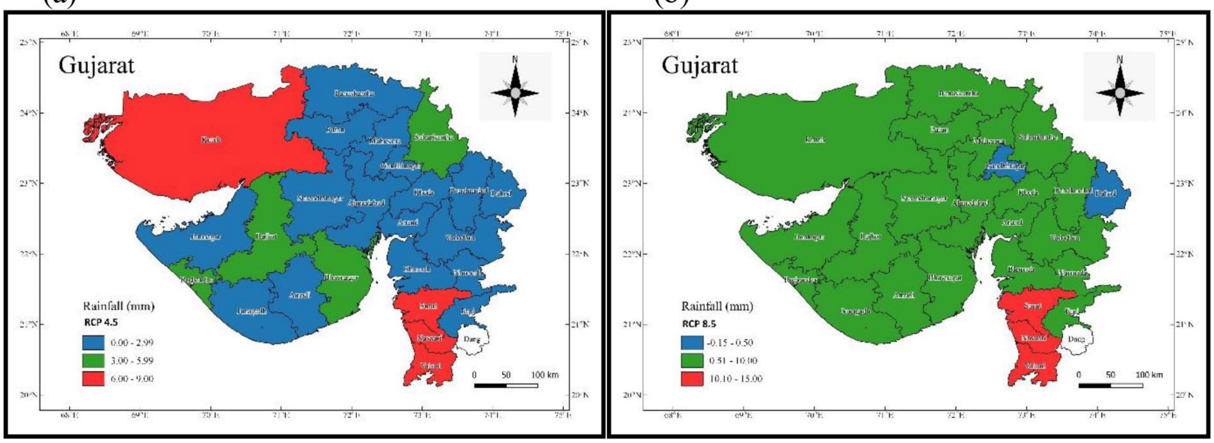

Fig. 9: Trends of projected rainfall in Gujarat under (a) RCP 4.5 and (b) RCP 8.5

of increase of the minimum temperature is presented in Fig. 8. By the end of the century, the minimum temperature is projected to increase by 1.5^0C to 2.1^0C at different locations under RCP 4.5 and by 3.5^0C to 4.84^0C under RCP 8.5. Under RCP 4.5, the rate of increase of the minimum temperature varied from 0.0192^0C to 0.0265^0C per year, with the highest increase being projected in Bhavnagar district and the lowest in Somnath and Porbandar districts. The spatial distribution of trend of minimum temperature (Fig. 8a) shows that the districts of the south-eastern parts of Gujarat (Dahod, Vadodara, Narmada, Tapi, and Surat) as well as the central west part comprising of Bhavnagar, Ahmedabad, Surendranagar, Patan, and Kutch districts fall under the high category of rate of increase of minimum temperature (>0.0226^0C per year), while remaining most of the districts show a medium rate of increase in minimum temperature under RCP 4.5.

Under RCP 8.5, the rate of increase of the minimum temperature varied from 0.04390°C per year in Somnath district to 0.06050°C per year in Banaskantha district. The spatial distribution of rate of increase of minimum temperature under RCP 8.5 (Fig. 8b) shows that most parts of middle Gujarat and some districts of Saurashtra and Kutch regions fall under a low range of temperature increase (less than 0.0550 ^{0}C per year), while the districts of north Gujarat (Banaskantha, Mehsana, Sabarkantha, Ahmedabad, and Surendranagar) are expected to experience a higher rate of increase in minimum temperature (>0.0576 ^{0}C per year) under RCP 8.5 (Fig. 8b).

Trends in rainfall: On average, the rainfall was found to have an increasing trend at all the stations and under both RCP 4.5 and RCP 8.5. Although the increasing trend is very marginal, its year-to-year variability was found to be high during the second half of the century. By the end of the century, the annual rainfall is projected to increase from 8.9 mm to 704.2 mm under RCP 4.5, with the lowest increase in Narmada district and the highest in Kutch district. The rate of increase in rainfall varied from 1.1 mm to 88.0 mm per decade. The spatial distribution of the rate of increase of projected rainfall (Fig. 9a) shows that under RCP 4.5, in most of the districts of Gujarat, the rate of increase is less than 2.99 mm per year, while south Gujarat (Surat, Navsari, and Valsad districts) and Kutch are expected to receive higher rainfall (>6.00 mm per year).

Under RCP 8.5, increasing trends are noticed at all the stations except the Dahod district, which shows a decreasing trend in rainfall (-1.31 mm per decade). The increasing trend in other districts varied from 5.8 to 142.8 mm per decade. By the end of the century, under RCP 8.5, the rainfall is projected to increase by 46.4 to 1142.5mm in different districts. The spatial distribution of the

Table 2: Precent change in seed cotton yield in different districts of Gujarat under RCP 4.5 and RCP 8.5

Districts	Percent change in the seed cotton yield over 2020							
	RCP 4.5				RCP 8.5			
	2040	2060	2080	2099	2040	2060	2080	2099
Ahmedabad	4.1	-18.1	-48.7	-53.0	-11.8	-22.6	-51.5	-57.1
Amreli	18.6	18.3	-18.8	-49.8	16.3	1.2	-24.9	-49.9
Anand	-21.5	-36.3	-53.6	-61.9	-20.1	-37.0	-58.2	-71.7
Banaskantha	11.5	0.0	-11.5	-33.3	-3.8	-11.8	-30.5	-54.3
Bharuch	-9.5	6.4	-37.1	-49.6	-26.3	-25.3	-47.7	-60.8
Bhavnagar	18.5	-19.0	-45.6	-66.8	-2.8	-35.3	-66.8	-81.9
Jamnagar	-17.9	-31.6	-43.8	-69.2	-48.5	-53.5	-71.3	-84.3
Junagadh	50.8	20.1	4.5	-26.5	-5.2	-14.2	-21.1	-69.9
Kheda	-32.0	-1.5	-55.9	-62.0	-51.5	-37.0	-63.5	-78.5
Kutch	18.5	-5.2	-42.4	-52.7	-9.6	-36.2	-53.8	-68.5
Mehsana	23.2	-16.5	-39.0	-44.8	-25.1	-11.0	-30.9	-45.6
Panchmahal	37.6	-10.2	4.0	-42.4	-26.3	6.5	-24.1	-45.0
Porbandar	-0.3	31.8	-12.1	-36.2	-25.3	6.2	-23.2	-43.3
Rajkot	2.5	28.1	-36.9	-39.1	-25.3	-46.4	-46.9	-59.5
Sabarkantha	21.2	-33.2	-17.6	-42.6	-30.7	-56.1	-50.4	-61.7
Surendranagar	47.0	-16.9	-41.3	-49.7	-9.0	-30.6	-49.2	-59.8
Vadodara	13.4	-6.5	-39.2	-60.6	10.3	6.9	-25.7	-51.7

(a) (b)

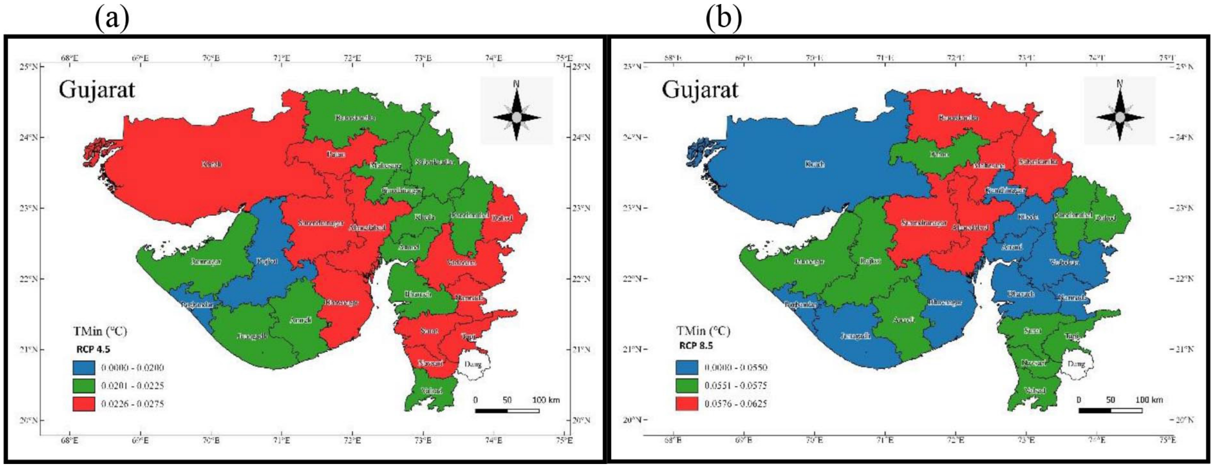

Fig. 10: Trends of projected sunshine hours in Gujarat under (a) RCP 4.5 and (b) RCP 8.5

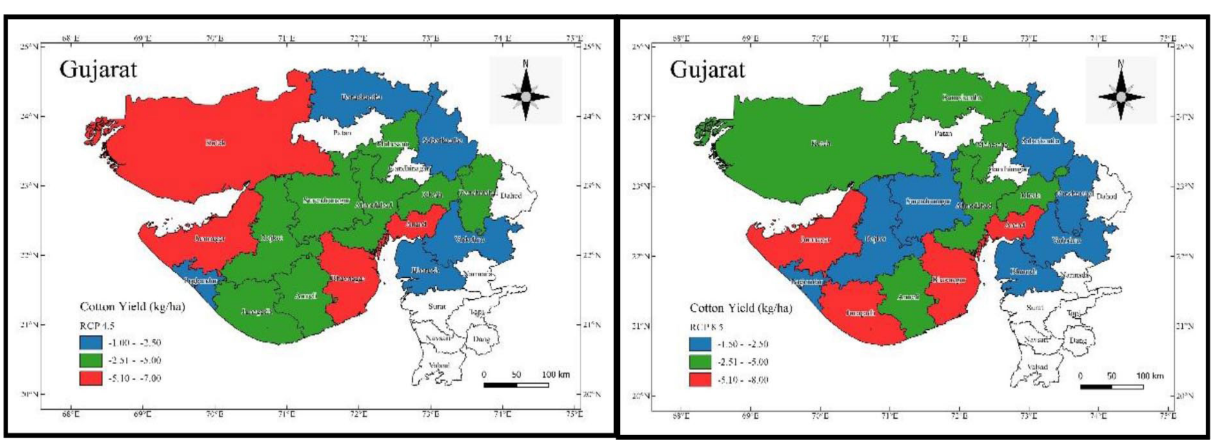

Fig.11: The rate of decrease in seed cotton yield during projected period (2020-2099) under RCP 4.5 and RCP 8.5

Table 3: Precent change in seed yield of pigeonpea in different districts of Gujarat under RCP 4.5 and RCP 8.5

Districts	Percent change in the seed yield of pigeonpea over 2020							
	RCP 4.5				RCP 8.5			
	2040	2060	2080	2099	2040	2060	2080	2099
Banaskantha	-7.0	-29.5	-25.7	-46.5	-16.2	-38.4	-36.9	-59.7
Bharuch	-13.7	-27.5	-25.7	-43.8	-16.9	-38.0	-38.8	-57.0
Dahod	-4.9	-27.9	-27.6	-47.3	-14.0	-38.6	-36.8	-59.2
Panchmahal	-8.0	-30.0	-30.8	-48.4	-16.2	-41.1	-38.4	-61.7
Sabarkantha	-10.5	-31.9	-31.8	-52.0	-15.3	-38.5	-36.0	-59.3
Surat	-7.0	-29.5	-25.7	-46.5	-16.2	-38.4	-36.9	-59.7
Vadodara	-7.7	-28.4	-29.1	-47.9	-15.2	-38.0	-37.3	-61.7

Table 4: Precent change in tube yield of potato in different districts of Gujarat under RCP 4.5 and RCP 8.5

Districts	Percent change in the tuber yield of potato over 2020							
	RCP 4.5				RCP 8.5			
	2040	2060	2080	2099	2040	2060	2080	2099
Anand	-9.1	-28.3	-26.2	-46.3	-15.8	-37.5	-36.1	-58.3
Banaskantha	-14.4	-41.0	-35.9	-55.3	-21.6	-47.5	-50.6	-70.7
Kheda	-4.2	-29.2	-25.0	-45.8	-16.7	-33.3	-37.5	-58.3
Mehsana	-8.7	-23.9	-31.4	-44.8	-13.6	-32.6	-32.4	-57.6
Sabarkantha	-14.1	-24.9	-34.1	-51.9	-14.7	-37.8	-43.7	-69.7

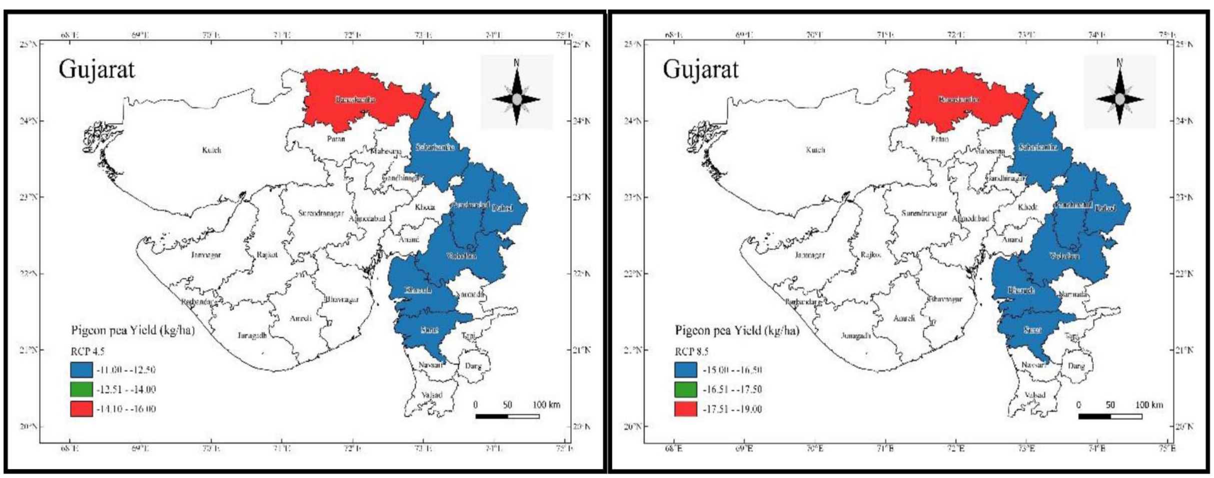

Fig.12: The rate of decrease in seed yield of pigeonpea during projected period (2020-2099) under RCP 4.5 and RCP 8.5

rate of increase of rainfall (Fig. 9b) shows that under RCP 8.5, three districts of south Gujarat (Surat, Navsari, and Valsad) are expected to receive higher rainfall than the Saurashtra region.

Trends in sunshine duration: Unlike temperature and rainfall, the duration of sunshine hours is projected to decrease under both the climate scenarios, as depicted in the case of Ahmedabad district. The decrease may be due to higher rainfall projected, which may cause increased cloudiness, resulting in a decrease in sunshine hours. The rate of decrease is very nominal, ranging between -0.255 and -0.401 hours per year under RCP 4.5 and between -0.146 and -0.475 hours per year under RCP 8.5. By the end of the century, the decrease in duration is projected to be hardly more than -20.4 to -32.1 hrs per year under RCP 4.5 and -11.7 to -0.10 hrs per year under RCP 8.5.

The spatial distribution of the rate of decrease in sunshine duration under RCP 4.5 and RCP 8.5 is presented in Fig. 10 (a and b). It may be seen that under RCP 4.5, the rate of decrease was least in Anand and Amreli districts, while it was higher in three districts of south Gujarat (Bharuch, Valsad, and Tapi), two districts of middle Gujarat (Kheda and Dahod), three districts of north Gujarat (Gandhinagar, Mehsana, and Sabarkantha), and two districts of Saurashtra (Bhavnagar and Surendranagar). Under RCP 8.5, three districts of south Gujarat have a high rate of decrease in sunshine duration (Fig. 10b).

Table 5: Precent change in cane yield of sugarcane in different districts of Gujarat under RCP 4.5 and RCP 8.5

Districts	Percent change in cane yield of sugarcane over 2020							
	RCP 4.5				RCP 8.5			
	2040	2060	2080	2099	2040	2060	2080	2099
Bharuch	-12.4	-25.4	-36.9	-55.8	-8.1	-33.9	-38.5	-61.5
Navsari	-12.0	-24.6	-35.7	-53.9	-7.7	-32.2	-36.6	-58.4
Surat	-11.8	-25.9	-36.4	-56.6	-16.8	-33.9	-41.2	-60.6
Tapi	0.6	-29.3	-32.4	-57.8	-4.5	-31.7	-35.1	-69.0
Valsad	-11.3	-24.0	-28.2	-58.4	-7.0	-29.4	-39.4	-60.8

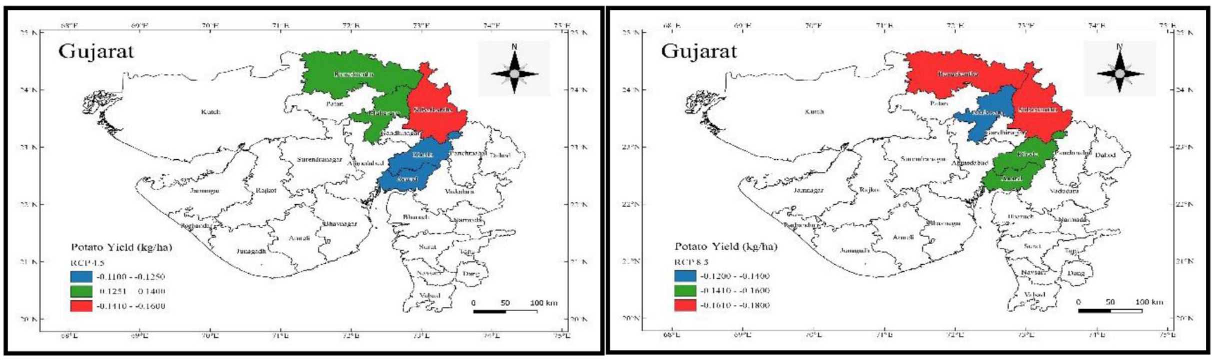

Fig.13: The rate of decrease in tuber yield of potato during projected period (2020-2099) under RCP 4.5 and RCP 8.5

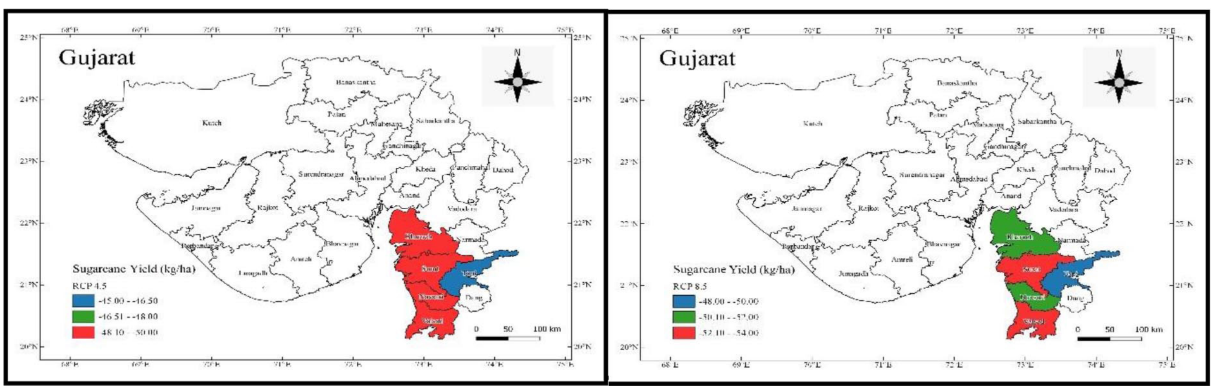

Fig. 14: The rate of decrease in cane yield of sugarcane during projected period (2020-2099) under RCP 4.5 and RCP 8.5

Impact of climate projections (RCP 4.5 and RCP 8.5) on crops

The climate change projection data under RCP 4.5 and RCP 8.5 were used to simulate the yields of cotton, pigeonpea, potato and sugarcane in the districts where these crops are majorly grown. Cotton is grown in 17 districts covering most parts of Gujarat and Saurashtra, pigeonpea in 7 districts (Banaskantha, Sabarkantha, Panchmahal, Dahod, Vadodara, Bharuch and Surat), potato in 5 districts (Banaskantha, Sabarkantha, Mehsana, Kheda and Anand) and sugarcane in 5 districts of south Gujarat. The rate of change in simulated yield for different crops are depicted in Figs. (11,12, 13 & 14). The percent change in yield over the yield of 2020 in selected years of 2040, 2060, 2080 and 2099 are also presented in the Tables 2 to 5.

Cotton: Fig.11 shows the rate of decrease in seed cotton yield in different districts under RCP 4.5 and RCP 8.5. The seed cotton yield is projected to decrease during 2020 to 2099 period at the rate of -1.0 to -7.00 kg per kg per year under RCP 4.5 and at the rate of -1.5 to -8.00 kg per kg per year under RCP 8.5 in different districts. However, the low rate of decrease are the districts in which initially increase in the yield are projected (Table 3). At the end of the century a drastic reduction in the yield is projected that ranges from -26.5% (Junagadh) to -69.2% (Jamnagar) under RCP 4.5 and from -43.3% (Porbandar) to -84.3% (Jamnagar) under RCP 8.5 (Table 3).

Pigeonpea: The seed yield of pigeon pea is found to decrease at the rate of -11.0 to -16.0 kg per ha per year under RCP 4.5 and at the rate of -15.0.0 to -19.0 kg per ha per year in different districts under RCP 8.5 (Fig. 12). The rate of decrease was maximum in Banaskantha By end of the century the projected yields would be reduced by -43% to -48% under RCP 4.5 and by -57% to -61% under RCP 8.5 (Table 3).

Potato: The tuber yield of potato is projected to decrease at the rate of ranging from -0.118 to -0.155 t ha^{-1} yr^{-1} under RCP 4.5 and from -0.130 to -0.177 t ha^{-1} yr^{-1} under RCP 8.5. The highest rate of decrease in noticed in Sabarkantha and Banaskantha districts. By end of the century, the potato yield projected to decrease by -55% and -71% in Banaskantha under RCP 4.5 and RCP 8.5 (Table 4).

Sugarcane: Sugarcane is grown mostly in five districts of south Gujarat. The sugarcane yield is projected to decrease at the rate of ranging from -45.1 to -49.7 kg ha^{-1} yr^{-1} under RCP4.5 and from -48.4 to -53.56 kg ha^{-1} yr^{-1} under RCP 8.5 (Fig. 14). By end of the century, the sugarcane yield projected to be reduced by -53.9 % to -58.4% in different districts under RCP 4.5 and by -58.4 % to -69.0% in different districts of Gujarat under RCP 8.5 (Table 5).

CONCLUSION

Due to large spatial and temporal variations in rainfall and temperature in Gujarat combined with different soil types, a large variation in crops and cropping patterns is observed in the state. Analysis of past climatic records showed that rainfall and temperature increased in Gujarat, but trends were not at significant levels. However, nighttime temperatures significantly increased across the locations. The effect of inter- and intra-seasonal climate variation on different crops suggested that the increase in temperature had adverse effects on almost all the crops, the extent of which varied with the crops, varieties, and seasons, while increases in rainfall and sunshine had favourable effects. Temperatures and rainfall have been projected to increase; the increased rainfall may cause increased cloudiness, resulting in fewer sunshine hours. Kutch district, receiving the lowest rainfall in the state, is likely to receive 200% more rainfall by the end of the century as projected under RCP 4.5, whereas Dahod, in the easternmost part of the state, is the only district expected to receive less rainfall under RCP 8.5. The districts of south Gujarat in the heavy rainfall agroclimatic zone are expected to get higher rainfall in comparison to other parts of the state under both RCPs. The impact of the projected climate on crops suggested decreasing trends in the yield, with a higher rate of decrease under RCP 8.5. Among the cereal crops, the yield reduction due to climate change will be highest in the wheat crop and lowest in the winter maize crop. Under RCP 4.5, up to 2040, the beneficial and/or least effects were observed in most of the crops. The adaptation measures could minimize the yield reduction by 10–20 percent, which may not be sufficient to meet the drastic reduction projected after 2060, suggesting the need to evolve new varieties to meet the challenges arising due to climate change.

Funding: No funding is involved for this work.

Conflict of interest: There is no conflict of interest

Data availability: Review article from author's published articles and reports

Author's contribution: Sole author, conceptualisation, writing and reviewing

Disclaimer: The contents, opinions, and views expressed in the research article published in the Journal of Agrometeorology are the views of the authors and do not necessarily reflect the views of the organizations they belong to.

Publisher's Note: The periodical remains neutral with regard to jurisdictional claims in published maps and institutional affiliations.

REFERENCES

Choudhary, Divesh, H.R. Patel and V. Pandey (2015). Evaluation of adaptation strategies under A2 climate change scenario using InfoCrop model for *kharif* maize in middle Gujarat region. *J. Agrometeorol.,* 17(1): 98-101. https://doi.org/10.54386/jam.v17i1.982

IPCC (2007*). Climate Change 2007:* Synthesis Report. Contribution of Working Groups I, II and III to the Fourth Assessment Report of the Intergovernmental Panel on Climate Change [Core Writing Team, Pachauri, R.K and Reisinger, A. (eds.)]. IPCC, Geneva, Switzerland, 104 pp.

IPCC (2014). *Climate Change 2014:* Synthesis Report. Contribution of Working Groups I, II and III to the Fifth Assessment Report of the Intergovernmental Panel on Climate Change [Core Writing Team, R.K. Pachauri and L.A. Meyer (eds.)]. IPCC, Geneva, Switzerland, 151 pp.

Lunagaria, MM, H R Patel, AV Shah, SB Yadav, BI Karande and Vyas Pandey (2011). Validation of PRECIS baseline (1961-1990) simulation for middle Gujarat agroclimatic zone. *J. Agrometeorol.,* 13(2): 92-96. https://doi.org/10.54386/jam.v13i2.1348

Lunagaria, M M, H P Dabhi and Vyas Pandey (2015). Trends in the temperature and rainfall extremes during climatic past of Gujarat. *J. Agrometeorol.,* 17(1): 118-123. https://doi.org/10.54386/jam.v17i1.986

Lunagaria, M M., H R Patel, N J Chaudhari, VUM Rao, P Vijaykumar, Vyas Pandey (2018). Agroclimatic Atlas of Gujarat, Department of Agricultural Meteorology, Anand Agricultural University, Anand Gujarat

Mishra, Sudhir Kumar, A.M. Shekh, V. Pandey, S.B. Yadav and H.R. Patel (2015). Sensitivity analysis of four wheat cultivars to varying photoperiod and temperature at different phenological stages using WOFOST model. *J. Agrometeorol.,*17(1): 74-79. https://doi.org/10.54386/jam.v17i1.978

Mote, B. M., Vyas Pandey and D. D. Patil (2018). Effects of change in temperature and CO_2 concentration on summer groundnut in middle Gujarat- A simulation study. *J. Agrometeorol.,* 20(3): 219-222. https://doi.org/10.54386/jam.v20i3.548

Pandey, Vyas (2020). Project Completion Report (2017-2020) of ICAR-Emeritus Scientist Scheme. ICAR Ref. No. Agril Edn./9/29/2016/ES/HRD dated 3rd January 2017, Department of Agricultural Meteorology, Anand Agricultural University, Anand, pp 161.

Pandey, Vyas and H R Patel (2011). Climate Change and its Impact on Wheat and Maize Yield in Gujarat. *In*. Challenges and

Opportunities in Agrometeorology (eds) S D Attri, L S Rathore, MVK Sivakumar; SK Dash, Springer. Pp321-334.

Pandey, Vyas, B.I.Karande and B.M.Mote (2016). Impact and Management of Extreme Weather Events in Groundnut Production in India. *Indian J. Natural Sci.*, 7(39):11824-11833. ISSN: 0976 – 0997

Parmar, P.K., S.C. Mali, A.K. Arvadiya, D.P. Patel, S.V. Vihol and Vyas Pandey (2019). Calibration and validation of CANEGRO model for sugarcane in south Gujarat region. *J. Agrometeorol.,* 21(3): 338-391. https://doi.org/10.54386/jam.v21i3.268

Parmar, P. K., M. J. Vasani, H. R. Patel, S. B. Yadav, V. Pandey (2023). Impact Assessment of Climate Change on Groundnut in North-Saurashtra Agro-Climatic Zone of Gujarat. *Mausam,* 74(1): 213-216. https://doi.org/10.54302/mausam.v74i1.6466

Patel, H. R., M.M. Lunagaria, B.I. Karande, Vyas Pandey, S.B. Yadav, A. V. Shah, V.U.M. Rao and S. Nareshkumar (2012). Impact of projected climate change on wheat and maize in middle Gujarat agro-climatic zone. *J. Agrometeorol., 14(2): 134-137.* https://doi.org/10.54386/jam.v14i2.1409

Patel, H R, M M Lunagaria, B I Karande, S B Yadav, A V Shah, V K Sood and Vyas Pandey (2015). Climate change and its impact on major crops of Gujarat. *J. Agrometeorol.,*17(2): 190-193. https://doi.org/10.54386/jam.v17i2.1003

Patil, D. D., Vyas Pandey, Ramesh Gurjar and H. P. Patel. (2018a). Effect of intra-seasonal variation in temperature and rainfall on seed yield of pigeon pea cultivars using CROPGRO model. *J. Agrometeorol.,* 20(4): 286-292. https://doi.org/10.54386/jam.v20i4.567

Patil, D. D., Vyas Pandey, R R Acharya and L N Baria (2018b). Effect of intra-seasonal variation in temperature on tuber yield of potato in middle Gujarat using SUBSTOR model. *J. Agrometeorol.,* 20(1): 22-27. https://doi.org/10.54386/jam.v20i1.497

Patil, D. D., Vyas Pandey, Vipul Kapadia and A. C. Sadhu (2019). Sensitivity analysis of CROPGRO- cotton model to intra-seasonal climatic variability in middle Gujarat. *J. Agrometeorol.,* 21(2): 148-153. https://doi.org/10.54386/jam.v21i2.224

Shamim, M., A M Shekh, Vyas Pandey, H R Patel and M M Lunagaria (2010). Sensitivity of CERES-Rice model to different environmental parameters on productivity of aromatic rice in middle Gujarat. *J. Agrometeorol.,* 12(2): 213-216. https://doi.org/10.54386/jam.v12i2.1308

Yadav, S B., H R Patel, A Kumar and V Pandey (2012). Impact assessment of climate change on wheat yield in middle Gujarat region. *Int. J. Agric. Sci. Techn*., 1(1): 5-13.

Yadav, S.B., H.R. Patel, M.M. Lunagaria, B.I. Karande, P K Parmar, N J Chaudhary and Vyas Pandey (2013). Impact assessment of projected climate change on pearlmillet in Gujarat. *Proc. National Seminar on "Climate Change Impact on Water Resources System"* held at PIET, Vadodara 27-29 Nov. 2013. (Ed)D T Shete, pp: 33-38.