IMPACT ANALYSIS OF CLIMATE CHANGE ON DIFFERENT CROPS IN GUJARAT, INDIA

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ABSTRACT:

The vulnerability to climate change is greater in developing countries like India- which are mostly located in lower, warmer latitudes. Climatic data of different stations of Gujarat have been analyzed to ascertain the climatic change/variability in the state and its likely impact on crop production using crop models. The long period rainfall analysis showed slight increase in annual rainfall by 2.86 mm per year. The rainfall intensity in terms of daily maximum rainfall also showed increasing trend. The rate of maximum temperature increase was between 0.2 to 0.5°C per decade, maximum being in summer season. Similarly, the minimum temperature was found to increase but with slightly lower rate of 0.2 to 0.3°C per decade in different seasons. The calibrated DSSAT-3.5 models were used to simulate the wheat and maize yield under hypothetical weather condition that may be arising due to climate change. The climate scenario simulated for temperatures ($\pm$ 1 to $\pm$ 3°C), radiation ($\pm$ 1 to $\pm$ 3 MJm-2 day-1) and CO2 (440, 550 and 660 ppm against present concentration of 330 ppm) were well within the range of projected climate scenario by IPCC. Results revealed that increase in temperature significantly reduced the wheat yield (-8 to -31 %) while decrease in temperature increased the yield (10 to 26%). The effect of maximum temperature on maize yield had similar effect but the magnitude is marginal (- 4 to 6%) over whole range of temperature ($\pm$3°C) change. The minimum temperature had similar effect on wheat yield with less magnitude of variation (-14 to +19 %), however on maize yield increasing trend was observed with increase in minimum temperature. The effect was higher in wheat crop (-50 to 40%) than maize (-18 to 8%). Increase in CO_2 had beneficial effect on both the crops.

1. INTRODUCTION

The vulnerability to climate change is greater in developing countries like India- which are mostly located in lower, warmer latitudes. Climatic data of different stations of Gujarat have been analyzed to ascertain the climatic change/variability in the state and its likely impact on crop production using crop models. The long period rainfall analysis showed slight increase in annual rainfall by 2.86 mm per year. The rainfall intensity in terms of daily maximum rainfall also showed increasing trend. The rate of maximum temperature increase was between 0.2 to 0.5°C per decade, maximum being in summer season. Similarly, the minimum temperature was found to increase but with slightly lower rate of 0.2 to 0.3°C per decade in different seasons. The calibrated DSSAT-3.5 models were used to simulate the wheat and maize yield under hypothetical weather condition that may be arising due to climate change. The climate scenario simulated for temperatures ($\pm$ 1 to $\pm$ 3°C), radiation ($\pm$ 1 to $\pm$ 3 MJm-2 day-1) and CO2 (440, 550 and 660 ppm against present concentration of 330 ppm) were well within the range of projected climate scenario by IPCC. Results revealed that increase in temperature significantly reduced the wheat yield (-8 to -31 %) while decrease in temperature increased the yield (10 to 26%). The effect of maximum temperature on maize yield had similar effect but the magnitude is marginal (- 4 to 6%) over whole range of temperature ($\pm$3°C) change. The minimum temperature had similar effect on wheat yield with less magnitude of variation (-14 to +19 %), however on maize yield increasing trend was observed with increase in minimum temperature. The effect was higher in wheat crop (-50 to 40%) than maize (-18 to 8%). Increase in CO2 had beneficial effect on both the crops.

In view of the various uncertainties, climatic data of different stations of Gujarat have been analysed to ascertain the climatic change/variability in the state and its likely impact on agriculture using crop models.

1.1 Biophysical Resources

Gujarat is the western-most state of India. It has a long (1600 km) sea coast on the Arabian Sea. The Gulf of Cambay separates the Western peninsula (Saurashatra) from the arid district of Kutch. The hill ranges of Aravalli in the northeast, Saputara in east and Sahyadri in the southeast run along the eastern boundary of the state from the northern district of Banaskantha to its southern end. Topographically, Gujarat state is characterized by a large central alluvial plain and a peninsula, separated by the Gulf of Cambay. Kutch, the largest district, lies north of the peninsula, and on its northern border is the large rann (desert) of Kutch. Of the numerous rivers that flow westward across the plain, the most prominent, the Tapi, Narmada and Mahi, have perennial flow. With the exception of the northern-most part, the plain has assured rainfall. The state's area of 19.60 million ha accounts for about

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6.0% of the total area of India. Its net sown area is 9.58 million ha, which is 6.75% of that of the country. Barren and uncultivated land (2.61 million ha) represents about 13.31% of the landmass of the state.

Gujarat is divided into eight agroclimatic zone based on rainfall, soils and cropping pattern. The distribution of cropping systems is determined largely by the climatic gradient and distribution of soils. Three types of tropical climate prevail across the state. An arid climate is seen in the extreme north and northwest, comprising Kutch, and western portions of Banaskantha, Patan and Jamnagar. The Surat, Narmada, Navsari, Valsad and Dangs districts in the extreme south have a sub-humid climate with good vegetative cover. The remaining parts of the state have a semi arid climate, relatively sparse vegetative cover, frequent droughts and susceptibility to soil erosion.

The monsoon normally sets in mid-June and withdraws by mid-September. The annual average rainfall of the state is 821 mm which is not reliable neither representative. Average annual rainfall ranges from as high as 1900 mm in the sub-humid southeast to as low as 320 mm in the arid north. The distribution of rainfall, particularly wet and dry spell characteristics, has largely determined the traditional evolution of cropping patterns and agricultural practices. Much of the southern portion of the state experiences excess rainfall frequently. The northern and northwestern parts of Gujarat receive less precipitation and experience frequent failures of monsoon.

2. MATERIAL AND METHODS

Fifty years (1958-2007) of rainfall and temperature data of Anand, Gujarat, India were used to analyse the variability at different time scales while district wise rainfall data were use to study the spatial variability of rainfall in the state. The impact analysis of climate change on wheat and maize yield was assessed using CERES-wheat and CERES-maize models, which were calibrated and validated using experimental data conducted at Anand (Anon., 2007; Patel, 2004; Patel et al 2007). CERES models were subjected to simulate the wheat yield under hypothetical weather condition that may be arising due to climate change (Pandey et al 2007). The climate scenario simulated for temperatures (± 1 to $\pm 3°C$), radiation (± 1 to ± 3 MJm^{-2} day^{-1}) and CO_2 (440, 550 and 660 ppm) against present concentration of 330 ppm) were well within the range of projected climate scenario by IPCC (IPCC, 2007). In the case of wheat crop two management conditions (Full irrigation and limited irrigation) were considered while for maize crop two cultivars (Ganga Safed-2 and GM-3) were selected. Looking to the interaction effect of climatic parameters the yield was simulated due to change in individual parameters as well as in combination with other one or two.

3. RESULTS AND DISCUSSIONS

3.1 Climate Change/Variability

3.1.1 Rainfall variability: Gujarat state receives about 95% of its annual rainfall through the influence of SW monsoon during June to September period. The subdivision wise rainfall analysis revealed that Saurashtra and Kutch subdivision have mean annual

rainfall of 428 mm with coefficient of variation of 44% and decreasing trend of –5% per 100 years while Gujarat sub division has mean annual rainfall of 863 mm with coefficient of variation of 32% and decreasing trend of –5% per 100 years.

Temporal and spatial variability of rainfall analysis suggested occurrence of floods and drought side by side (Pandey et al 1999). Kutch having less rainfall (<350 mm) had highest annual rainfall variability (57%) while the Dangs having highest rainfall (1792 mm) had lowest rainfall variability (29%). On monthly basis, the coefficient of variability is still higher, being >100% in Kutch even in monsoon months. Among four months of monsoon months, July contributes 35-45% of annual rainfall. Kutch is having 80% chances of getting low rainfall (<500 mm), the Dang and Valsad have 70% chances of getting higher rainfall (>1500 mm). Kutch district and parts of Banaskantha, Patan, Surendranagar, Rajkot and Jamnagar districts were found prone to experience moderate to severe droughts in more than 30 % of the years (Pandey et al 1999).

The annual rainfall analysis at revealed that Anand showed slight increase in annual rainfall by 2.86 mm (Fig.1). Although, the months of July and August are the months of receiving higher rainfall, the analysis at Anand showed that many a times June and September received higher rainfall than that of July and August. The rainfall intensity in terms of daily maximum rainfall also showed increasing trend at Anand.
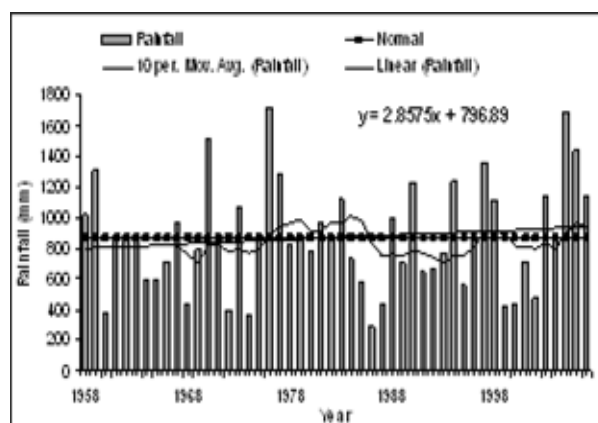

Figure 1. Annual Rainfall Variability and Trend at Anand

3.1.2 Temperature: The maximum temperature at Anand was found to increase in all the three seasons (summer, monsoon and winter). The rate of increase was between 0.2 to 0.5 ^0C per decade, maximum being in summer season (Fig.2). Similarly, the minimum temperature was found to increase but with slightly lower rate of 0.2 to 0.3 ^0C per decade in different seasons (Fig. 3).

3.2 Impact Analysis

3.2.1 Impact on wheat yield: The rate of increase of maximum as well as minimum temperature was lowest during monsoon season and highest during summer season. Thus the higher temperature during summer season may further aggravate the summer season.

3.2.1.1 Individual effects of temperature, solar radiation and CO_2 concentration: The simulated grain yield of wheat by CERES-wheat model under incremental units of maximum temperature (1 to 3°C) showed gradual decrease in yield ranging from 3546 to 2646 kg ha^{-1} (8 to 31 %) under irrigated condition (Table 1). Under limited irrigation condition, yield reduction was recorded to the extent of 2841 to 2398 kgha^{-1} (9 to 23 %).

In general, increase in maximum temperature from 1 to 3°C significantly reduced the wheat yield. The reduction in yield was mainly due to reduction in duration of anthesis and grain filling with rise in ambient temperature and vice versa. Similarly in case of gradual down scale of maximum temperature in the range of -1 to -3 °C, totally reverse trend was observed. Similar trend was also noticed in case of increase and decrease in minimum temperature. The magnitude of effect of minimum temperature was quite less (-14 to +19 %) than those due to maximum temperature (-31 to +26 %). This showed that wheat yield was found to be highly sensitive to change in temperature under irrigated as well as under limited irrigation conditions.
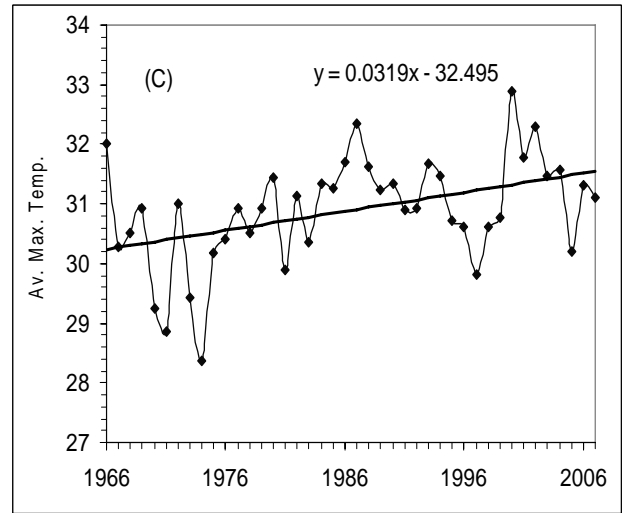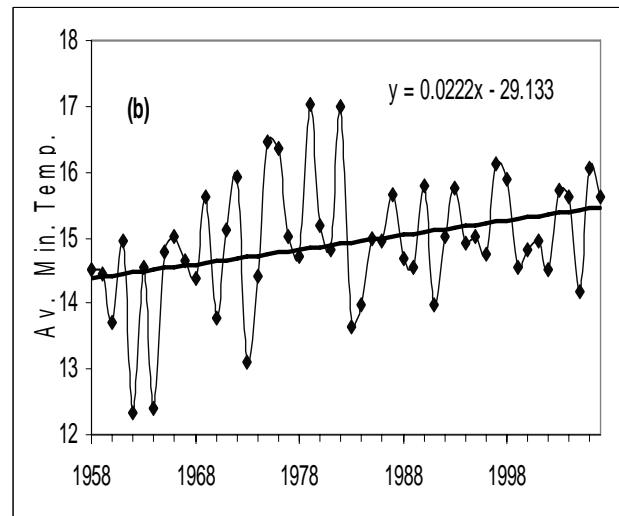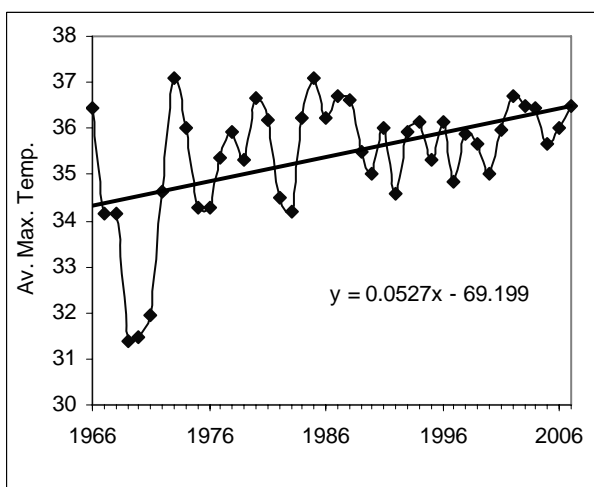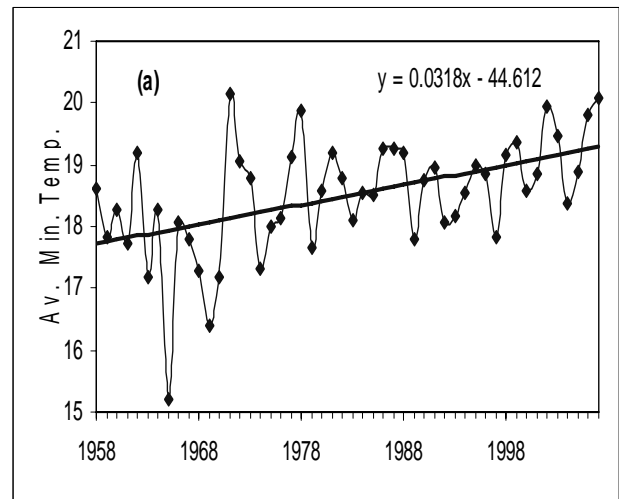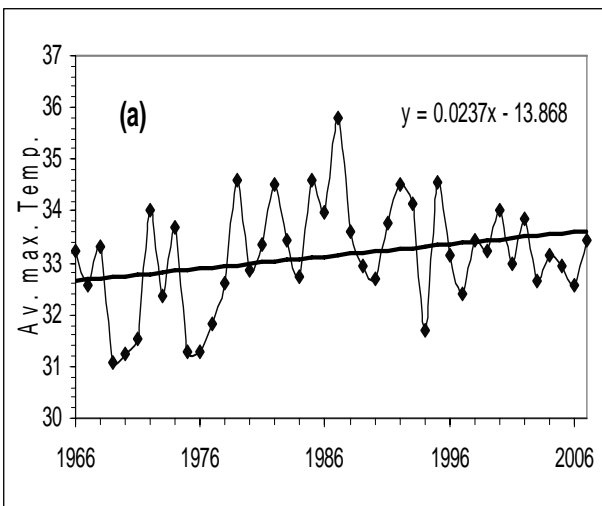

Figure 2. Trends of Maximum Temperature During (a) Monsoon (b) Summer and (C) Winter Season at Anands
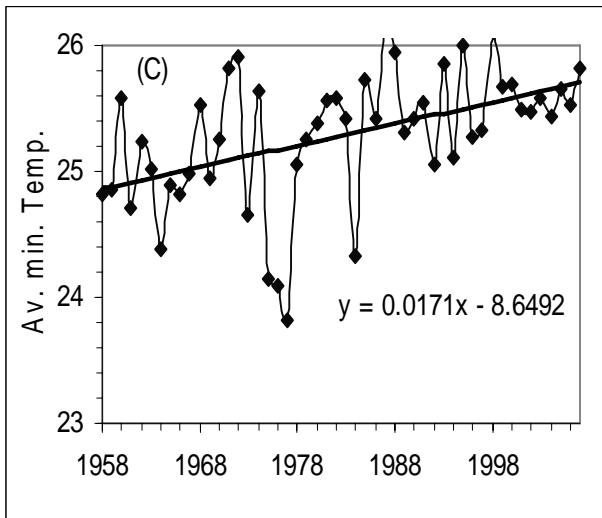
Figure 3. Trends of Minimum Temperature During (a) Monsoon (b) Summer and (C) Winter Season at Anand

The increase in solar radiation from 1 to 3 $MJm^{-2} day^{-1}$ resulted in increase in yield of wheat from 18 to 40 percent while reduction in solar radiation by –1 to –3 $MJm^{-2} day^{-1}$ caused decrease in wheat yield to the tune of –18 to –50 per cent. However, under limited irrigation conditions the yield was found to decrease both under elevated as well as reduced solar radiation. This showed that under limited irrigation condition the higher solar radiation receipt may have adverse effect through heating and thereby reduction in yield. It may be noted that under lower solar radiation regime, the yields under both conditions are same. The overall response of varying radiation to grain yield of wheat showed that the model was more sensitive to radiation than it was to temperature.

The effects of elevated carbon dioxide on simulated grain yield of wheat showed that due to gradual increase in CO_2 concentration from 440 to 660 ppm, the yield levels increased to the tune of 21 to 68 per cent under irrigated condition. Under limited irrigated condition similar response were observed with slightly lower magnitude (19 to 57 %). This showed that under climate change scenario, CO_2 enhancement proved beneficial for higher productivity. The increase in yield under increase in concentration in CO_2, may be due to most plants growing in experimental environments with increased levels of atmospheric CO_2, exhibit increased rates of net photosynthesis and reduced stomatal opening. Partial stomatal closure leads to reduced transpiration per unit leaf area and, combined with enhanced photosynthesis, often improves water-use efficiency.

3.2.1.2 Combined effect of temperature and solar radiation: Under optimal condition, the effect of increase in temperatures was found to be nullified by similar increase in solar radiation ($MJm^{-2} day^{-1}$), as it is evident from the effect on yield (+2 to -4 %), while decreasing temperature and radiation had negative effect (-3 to -25 %) on grain yield (Table 2).

Para Meters	Simulated Grain Yield ($kgha^{-1}$)		% Change in Yield	
MaxT (°C)	Full Irrigation	Limited Irrigation	Full Irrigation	Limited Irrigation
3	2646	2398	-31	-23
2	3091	2668	-19	-14
1	3546	2841	-8	-9
-1	4206	3190	10	3
-2	4485	3358	17	8
-3	4817	3641	26	17
MinT (°C)				
3	3288	2874	-14	-8
2	3460	2948	-10	-5
1	3692	3039	-4	-2
-1	4118	3140	7	1
-2	4226	3195	10	3
-3	4581	3234	19	4
Solar radiation (MJ $m^{-2} day^{-1}$)				
3	5387	2454	40	-21
2	5111	2709	33	-13
1	4523	3085	18	-1
-1	3156	2985	-18	-4
-2	2503	2503	-35	-20
-3	1903	1903	-50	-39
CO_2 concentration (Base value 330 ppm)				
440	4630	3695	21	19
550	5687	4327	48	39
660	6465	4876	68	57

Table 1: Simulated Wheat Yield due to Varying Temperature, Solar Radiation and CO_2 Concentration Under Irrigated and Limited Irrigation Conditions

Temper-atures (°C) and SAR (MJ $m^{-2} day^{-1}$)	Simulated Grain Yield ($kgha^{-1}$)		% Change in Yield	
	Full Irrigation	Limited Irrigation	Full Irrigation	Limited Irrigation
3	3670	2083	-4	-33
2	3790	2486	-1	-20
1	3917	2799	2	-10
-1	3738	3292	-3	6
-2	3453	3273	-10	5
-3	2892	2892	-25	-7

Table 2: Simulated Wheat Yield due to Combined Effect of Temperature and Solar Radiation Under Irrigated and Limited Irrigation Conditions

This showed that the favourable effect of lower temperature was suppressed by negative effect of lower solar radiation regimes. Under limited irrigated condition, the decrease in yield up to 33 per cent was observed due to increase in both temperature and radiation by 3 units, while lowering of temperature and radiation had marginal effect (+6 to -7 %) on wheat yield. It can further be revealed that due to lowering of temperature and radiation by 3

units the wheat yields under fully irrigated condition was same as that of under limited irrigated condition.

3.2.1.3 Combined effect of temperature, solar radiation and CO_2 concentration: Model simulation was also carried out for combined effect of temperature, solar radiation and different levels of CO_2 concentration (440, 550 and 660 ppm) under fully irrigated and under limited irrigated conditions (Table 3).

The results revealed that at CO_2 concentration of 440 ppm, the wheat yield was found to generally increase (-2 to 23 %) with either increase or decrease of temperature and radiation up to 3 units under optimal condition. Under limited irrigated condition, however, the favourable effects were observed only under down scaling of the temperature and radiation regimes, the total effect being -23 to 26 per cent. At higher CO_2 concentration of 550 ppm, the net effect on yield was favourable (23 to 51 %) irrespective of whether temperature and radiation increased or decreased under full irrigation condition, while under limited irrigation condition, the negative effect (-12 %) was observed at higher temperature and radiation (+ 3 units) regimes. Under doubling of CO_2 concentration (660 ppm) scenario, increase in yield levels are quite high (42 to 70 % under full irrigation condition and -3 to +75 % under limited irrigation condition) due to changes in both temperature and radiation by $\pm$ 3 units.

Temperatures (°C) and SAR (MJ $m^{-2}day^{-1}$) and CO_2	Simulated Grain Yield ($kgha^{-1}$)		% Change in yield	
	Full Irrigation	Limited Irrigation	Full Irrigation	Limited Irrigation
440 ppm				
3	4369	2410	14	-23
2	4699	2896	22	-7
1	4726	3287	23	6
-1	4550	3920	19	26
-2	4255	3929	11	26
-3	3776	3776	-2	21
550 ppm				
3	5125	2730	34	-12
2	5593	3307	46	6
1	5778	3784	51	22
-1	5452	4602	42	48
-2	5161	4642	35	49
-3	4707	4695	23	51
660 ppm				
3	5781	3015	51	-3
2	6332	3476	65	12
1	6541	4226	70	36
-1	6229	5201	62	67
-2	5950	5262	55	69
-3	5537	5439	44	75

Table 3: Simulated Wheat Yield due to Interaction Effect of Temperature, Solar Radiation and CO_2 Concentration Under Irrigated and Limited Irrigation Conditions

The interaction effect of temperature, radiation and CO_2 concentration revealed that the response under irrigated condition was quite different than that under limited irrigated condition. Under fully irrigated condition the highest benefits are obtained at

higher level of CO_2 concentration combined with 1 unit increase in temperature and radiation. The percentage change in yield decreased both ways i.e. either increasing or decreasing the parameters from the mean values. The percentage change in yield under limited irrigation condition was found to have increasing trend with decreasing (+3 to -3 units) temperature and radiation at higher levels of CO_2 concentration.

3.2.2 Impact on maize yield: CERES-maize model was used to study the impact of climate change on maize production for two cultivars (Ganga Safed-2 and GM-3) commonly grown in the state.

3.2.2.1 Effects of temperatures, solar radiation and CO_2 concentration: Results on effects of minimum and maximum temperatures, solar radiation and CO_2 concentration on simulated grain yield of maize (Table 4) revealed that as the maximum temperature increases the yield decrease and vise versa. In case of increase or decrease of minimum temperature yield was found to increase, however, there is drastic decrease in yield if minimum temperature falls by more than 3 °C. Thus the minimum and maximum temperature influences the maize crop differently. Higher solar radiation receipt was found to increase the yield of maize while lower radiation may have adverse effect. Higher CO_2 concentration was found to have favourable effect on maize yield. Doubling of CO_2 may increase its yield by 8-9% (Table 4).

Parameters	Simulated Grain Yield ($kgha^{-1}$)		% Change in Yield	
	Ganga Safed-2	GM-3	Ganga Safed-2	GM-3
MaxT (°C)				
3	3518	3444	-4.3	-4.3
2	3658	3499	-0.5	-2.8
1	3717	3552	1.1	-1.3
-1	3776	3697	2.7	2.8
-2	3868	3708	5.3	3.1
-3	3927	3773	6.9	4.9
MinT (°C)				
3	3785	3615	3.0	0.5
2	3856	3687	4.9	2.5
1	3999	3631	8.8	0.9
-1	3767	3688	2.5	2.5
-2	3697	3620	0.6	0.6
-3	3537	3418	-3.8	-5.0
Solar radiation (MJ $m^{-2}day^{-1}$)				
3	3862	3778	5.1	5.0
2	3794	3714	3.2	3.2
1	3977	3892	8.2	8.2
-1	3510	3373	-4.5	-6.3
-2	3284	3217	-10.6	-10.6
-3	3013	2954	-18.0	-17.9
CO_2 concentration (Base value 330 ppm)				
440	3781	3701	2.9	2.9
550	3873	3790	5.4	5.3
660	3993	3907	8.7	8.6

Table 4: Effect of Maximum and Minimum Temperature, Solar Radiation and CO_2 Concentration Maize Cultivars

3.2.2.2 Combined effect of temperature and radiation: The combined effect of minimum and maximum temperature revealed that if both temperatures are increased or decreased by more than 1°C, maize yield was found to decrease (Table 5).

MaxT and MinT (°C)	Simulated Grain Yield (kgha^{-1})		% Change in Yield	
	Ganga Safed-2	GM-3	Ganga Safed-2	GM-3
3	3528	3369	-4.0	-6.4
2	3665	3587	-0.3	-0.3
1	3677	3604	0.1	0.2
-1	3798	3661	3.3	1.8
-2	3529	3454	-4.0	-4.0
-3	3351	3279	-8.8	-8.9

Table 5: Combined Effect of Maximum and Minimum Temperature for Maize Cultivars

If the increase in temperature is accompanied by increase in solar radiation the favourable effect was noticed only up to 2 units of increment in the parameters. Otherwise the negative effect was observed either by increasing the parameters by more than 2 units or decreasing them (Table 6).

MaxT and MinT (°C) and SAR (MJm^{-2}d^{-1})	Simulated Grain Yield (kgha^{-1})		% Change from Base Yield	
	Ganga Safed-2	GM-3	Ganga Safed-2	GM-3
3	3630	3552	-1.2	-1.3
2	3903	3725	6.2	3.5
1	3908	3832	6.3	6.5
-1	3600	3578	-2.0	-0.6
-2	3420	3349	-6.9	-6.9

Table 6: Combined Effect of Temperature and Solar Radiation Maize Cultivars

CONCLUSION

Gujarat being western-most state of India and having long seacoast has high variability in terms of biophysical parameters. Extreme arid climate to sub-humid climates are experienced in the state. The distribution of cropping systems is determined largely by the climatic gradient and distribution of soils. The temporal variability in rainfall indicated variable trend in different regions of the state. In middle Gujarat increasing trend is observed in rainfall as well as maximum and minimum temperatures during different seasons. Impact of climate change study revealed that increase in temperature significantly reduced the wheat yield while decrease in temperature increased the yield. The effect of maximum temperature on yield was more than that of minimum temperature. The higher radiation receipt and lower radiation receipt caused decrease in yield under optimal condition whereas, negative effect was seen under sub-optimal condition due to either increase or decreasing radiation. The combined effect of temperature and solar radiation were very marginal at the lower side of yield. More or less similar effects with less magnitude were observed for maize crop also.

REFERENCES

Anonymous., 2007. Determination of spatial irrigation requirement and production potentials for major crops over Narmada canal command areas using crop models and GIS. Project Completion report (2004-2007), Department of Agricultural Meteorology, BA College of Agriculture, AAU, Anand, pp. 1-62.

IPCC., 2007. Climate Change 2007. The Physical science basis, Fourth Assessment Report.

Pandey, V., Patel H.R., Patel V.J., 2007. Impact assessment of climate change on wheat yield in Gujarat using CERES-wheat model. *J. Agrometeorol.,* 9(2), pp. 149–157.

Pandey, V., Shekh A.M., Parmar R. S., 1999. Occurrence of droughts and floods over Gujarat. *J. Agrometeorol.,* 1(2), pp. 177-181.

Patel, H.R. 2004. Simulation modeling of Wheat (cv. GW-496) yield using CERES-wheat model in varied environmental and moisture regimes of middle Gujarat agro-climatic region. Ph.D. Thesis submitted to the Anand Agricultural University, Anand.

Patel, V.J., Patel H.R., Pandey V., 2007. Evaluation of CERES-wheat model for estimation of wheat yield in middle Gujarat. *Asian J. Envi. Sci.* 2(1&2). Pp. 89–93.