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Original Research Article

Impact of Rainfall and Temperature on the Yield of Major Crops in Gujarat State of India: A Panel Data Analysis (1980-2011)

ABSTRACT

The study has assessed the impact of temperature and rainfall on the yield of major crops in Gujarat State of India, during 1980-2011, using panel data fixed effects model. The panel consisted of district level data on crop yields, rainfall, irrigated area under crops, and minimum and maximum temperature from 1980 to 2011 for 18 districts in Gujarat at their 1980 boundaries. The major crops selected from the State were Rice, Maize, Cotton, Groundnut, Wheat, and Pearl Millet (summer crop), grown in their major regions. The data on rainfall and temperature for the districts were extracted from 1×1 degree high resolution daily gridded data obtained from the Indian Meteorological Department, Government of India. To represent the cumulative rainfall during the crop-growing period, the daily rainfall was summed-up. To represent the average crop-growing period temperature, average of daily minimum and maximum temperature was obtained, and included in the model. To quantify the impact of a single climatic variable on yield, the marginal effects were evaluated at their means. The model was run on STATA software. Analysis revealed that rainfall had a positive effect on most crops, while temperature had a negative impact during the period of study. Pearl Millet may be looked upon as a crop of future. More thrust should be given to the agricultural research and adoption of innovative technologies for sustainable agriculture in future scenario of climate change. The Research and Development involvement should be multi-disciplinary; joint efforts are the need of the hour.

Keywords: Crop yield, Fixed effects model, Gujarat, India, Marginal effects, rainfall, Temperature

1. INTRODUCTION

Climate change is a matter of global concern because of its impending threats to sustainable economic development. Compared to other activities, agriculture is more sensitive to climate change. Productivity of crops has concerns for both, producers and consumers as well [1]. A lower productivity, on one hand doesn't let the producers realize economies of scale, while on the other hand it creates an impediment to achieve the objective of food security, affecting consumers. Several studies have been conducted to analyze the impact of climate change on the yield of crops. Most of these studies either adopted Crop Modelling Approach or Ricardian Approach to achieve the objectives. The fixed effects approach, which off late has been adopted by economists, and is used in this research, has advantages over both approaches in the sense that it takes care of farmer's adaptation that may have happened over time (and which Crop Modelling fails to incorporate) and also the time invariant variables such as soil characteristics (which the Ricardian approach fails to incorporate). In this study, we examine the changes in weather variables viz., temperature and rainfall; and analyze the implications of marginal effect of these two weather variables (temperature and rainfall) on the yield of major crops grown in Gujarat.

2. MATERIAL AND METHODS / EXPERIMENTAL DETAILS / METHODOLOGY

Our panel consisted of district level data on crop yields, rainfall, irrigated area under crops, and minimum and maximum temperature from 1980 to 2011 for 18 districts in Gujarat at their 1980 boundaries. The

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major crops selected from the State were Rice, Maize, Cotton, Groundnut, Wheat, and Pearl Millet (summer crop), grown in their major regions. The data on area and production of the selected crops was obtained from the district crop seasonal abstracts of Government of Gujarat. The data on rainfall and temperature for the districts were extracted from 1×1 degree high resolution daily gridded data obtained from the Indian Meteorological Department, Government of India. To represent the cumulative rainfall during the crop-growing period, the daily rainfall was summed-up. To represent the average crop-growing period temperature, average of daily minimum and maximum temperature was obtained. The fixed effect panel model as used by Birthal *et al* [2], for climate impacts was used for the study and is specified as:

$$\ln y_{it} = D_i + T_t + \beta X_{it} + \gamma Z_{it} + \varepsilon_{it}$$

The subscripts i and t in above equation denote place and time, respectively. The dependent variable y is crop yield, and D and T are Place (districts in this case) and Time fixed effects. The Place fixed effects absorb all unobserved place specific time-invariant factors; for example, soil and water quality. T represents Time fixed effects that absorb the changes in technology, infrastructure, human capital, etc; X and Z are vectors of weather and non-weather variables [2]. The weather variables considered in this study were rainfall, minimum and maximum temperature. To account for non linear relationship between weather variables [3,4], squared term of rainfall was also considered in the above equation. To account for non-weather variables, irrigated area was also included in the equation. To quantify the impact of a single climatic variable on yield, the marginal effects were evaluated at their means. The expected marginal impact of a single climatic variable was estimated as:

$$E\left[\frac{\partial y}{\partial x}\right] = \alpha_{1,i} + 2\alpha_{2,i} * E[\ ]$$

The model was run on STATA software.

3. RESULTS AND DISCUSSION

3.1 Trend in Climatic Variables

Table 1 presents the trend analysis of climate variables for selected crops. During the study period, the minimum and maximum temperatures in Saurashtra (for cotton growing season) showed a significant rise, the trend in minimum temperature was quite stronger. The minimum temperature rose by 0.74^{0}C while maximum temperature rose by 0.47^{0}C. The rainfall in this region showed a significant increasing trend; it increased by 333 mm during 1980-2011. In case of Middle Gujarat in rabi season, maximum temperature registered significant rise by 0.89^{0}C, while the minimum temperature rose significantly by 5.41^{0}C (indicating warm winters). The rainfall during rabi season in Middle Gujarat showed a declining trend; rainfall declining by 47.92 mm and was more erratic (CV=142 %). In case of kharif season in Middle Gujarat, only rainfall showed a significant rising trend; rainfall increased by 228 mm during the study period. For, Groundnut in Saurashtra and Kutch region, minimum temperature showed rising trend. Rainfall, too increased significantly. Between February to April, the summer pearl millet crop months in Saurashtra, both minimum and maximum temperature showed significant rising trend; trend being stronger for maximum temperature.

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Table 1: Trend analysis of climatic variables in different regions of Gujarat (1980-2011)

Variables		*Saurashtra (Cotton) June-Feb*	*Saurashtra (Groundnut) Jan-May*	*Saurashtra (Pearl Millet) Feb-April*	*Middle Gujarat (wheat) Oct-March*	*Middle Gujarat (rice and maize) June-Oct*
Minimum Temperature	**Mean**	20.84	25.06	18.8012	16.26	24.15
	SD	0.6953	0.5929	0.9083	0.9573	0.6336
	Trend	0.0232 (.001)	0.0104 (.007)	0.0244 (.001)	0.1691 (.001)	-0.0005 (0.12)
	Change	0.74	0.33	0.78	5.41	-0.01
Maximum Temperature	**Mean**	32.11	33.49	35.21	32.17	33.72
	SD	0.6039	0.3918	1.0657	0.8495	0.7515
	Trend	0.0147 (.002)	0.0008 (0.35)	0.0484 (.005)	0.0277 (.001)	-0.0066 (0.14)
	Change	0.47	0.02	1.54	0.88	-0.21
Rainfall	**Mean**	629.38	617.2645	1.2833	28.7685	832.05
	SD	332.78	333.0431	2.9378	40.7903	300.09
	Trend	11.8379 (.001)	12.5555 (.001)	0.0188 (0.41)	-1.4977 (.005)	7.1242 (.001)
	Change	378.81	401.77	0.60	-47.92	227.97

Total Change in Temp in ^{0}C, Trend: ^{0}C/year, Total Change in Rainfall in mm, Trend: mm/year. Figure within the parentheses shows probability value

3.2 Impact of Climate Change on Crop Yield

Table 2 presents the estimated equations for selected crops of Gujarat. It is to be noted that the place and time fixed effects which were included in the model as control, were significant for all crops, indicating the importance of these characteristics which might have correlation with the climatic variables.

The irrigation coefficient has been found positively significant in Wheat, Cotton, and summer Pearl Millet indicating the importance of irrigation in these crops in their respective seasons. For other crops, the irrigation coefficients were not significant.

We found that a rise in maximum temperature was harmful for all the crops (negative and significant coefficient), except Pearl Millet. On the other hand, a rise in minimum temperature was found having positive effect on the yield; significant for cotton and rice, insignificant for others. Wheat needs cool, dry and clear climate with an optimum temperature ranging between 14-20^{0}C. Excessive heat causes reduction in grain number and reduces duration of the grain-filling period in wheat, ultimately impacting yield. The optimum temperature for rice growth is 20-30^{0}C while in the study period, the temperature in

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the region remained between 24.50^{0}C- 33.72^{0}C. In case of rice, the impact of increased temperature has an accumulative effect on the later phases of plant development; changes in the vegetative and ripening phase alter the grain-filling phase and thus, the grain quality of the rice. High temperature in tropical environments is one of the major environmental stresses limiting rice productivity. The pollen viability in Maize decreases with exposure to above 35^{0}C [5]. High temperatures decreases photosynthetic activity in cotton, causing a severe shortage of carbohydrates, which limits the plant's ability to fill boils. If there is a water stress too, combined with high temperatures, cotton plant suffers small boll size, and leaf damage. In case of groundnut, pod temperature above 35^{0}C significantly reduces the number of mature pods and seed yields [6] .Pearl millet is resistant to higher temperatures, so the impact of increase in maximum temperature on yield of pearl millet was not detrimental. Pearl Millet's seed could survive under high temperatures; however, temperature beyond 50^{0}C could be lethal for the plant

The effect of rainfall was found positive and significant on all kharif crops. The quadratic term of rainfall was found negative and significant for cotton, groundnut, and maize, indicating that excess rainfall leads to damage and reduction in yield, presumably due to an increased probability of flooding. For rice too, it was negative and significant, which means that higher rainfall leads to increase in yield but at a decreasing rate [7]. Rainfall was found to have negative and insignificant impact on wheat, which is a rabi crop and is grown with irrigation. It was found to have positive and significant impact on Pearl Millet. The amount and distribution of rainfall are important factors in determining the Yield of Pearl Millet in the study area as it is entirely a rainfed crop. In case of poor rains, the crop is deprived of required moisture supply, which affects seeding emergence and yield of pearl millet. Regression models, however, give combined effect of variables on dependent variables; however, the individual effect of each of the independent variables is hard to interpret. To resolve this, the marginal effect of each of the individual climatic variables on yield, was evaluated at their mean values.

Table 2: Regression results with fixed effect panel data analysis of Major crops of Gujarat (1980-2011)

	Crops					
Variables	**Cotton**	**Wheat**	**Rice**	**Maize**	**Ground nut**	**Pearl Millet**
Minimum temperature	1.1862 (.001)	0.0327 (.27)	0.1862 (.04)	0.07219 (.45)	0.1651 (.45,)	0.0487 (.17)
Maximum temperature	-0.9175 (.001)	-0.0560 (.03)	-0.1338 (.04)	-0.2261 (.007)	-0.5740 (.002)	0.0359 (.19)
Rainfall	0.0008 (.01)	-0.0002 (.82)	0.0030 (.002)	0.0037 (.005)	0.0021 (.001)	0.0436 (.017)
Rainfall square	-3.61e-07 (.03)	-5.67e-06 (.32)	-1.22e-06 (.001)	-2.10e-06 (.001)	-4.81e-07 (.001)	-0.0020 (.119)
Irrigation	0.0004 (.03)	0.0004 (.009)	0.0002 (.37)	0.0024 (.16)	0.0013 (.18)	0.0002 (.004)
Constant	10.4082 (.001)	5.1499 (.001)	5.4442 (.007)	11.4603 (.006)	20.3240 (.001)	5.3430 (.001)

Figure within the parentheses shows probability value

3.3 Marginal Effect

Table 3 presents the marginal effect of climate change, i.e. the effect on yield due to rise in 1^{0}C in temperature and 1mm rainfall. A 1 ℃ rise in the maximum temperature in *rabi* season reduces the yield of wheat crop significantly by around 10 per cent, while a similar rise in minimum temperature leads to a

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significant increase in the yield by 6 per cent. Patel & Shekh [8] also stated on the basis of sensitivity analysis of CERES-Wheat that elevated maximum temperature decreased wheat yield significantly. Mishra *et al* [9], in a study found the same. Wheat is not significantly influenced by rainfall as the quantum of rainfall is less and is erratic in rabi season; the crop is grown in irrigated conditions.

A 1^0C rise in the maximum temperature leads to decline in the yield of cotton by 7 per cent (insignificant), however a similar rise leads to a significant increase by 43 per cent. Elevated CO2 levels in the atmosphere of up to 650 ppm and temperature of 40º C was found to be optimum for cotton plant growth [10] By and large, though, research in India indicates that the impact of climate change on cotton production and productivity will be favourable [11] given we find a solution to combat pests and diseases. Marginal effect of rainfall on cotton was negligible, however, excessive rainfall is detrimental to cotton yield. Thakare *et al* [12] concluded that erratic monsoon or delayed monsoon hampers crop physiology and yield.

Table 3: Marginal effect of climate change on Major crops of Gujarat 1980-2011

	Crops					
Variables	**Cotton**	**Wheat**	**Rice**	**Maize**	**Ground nut**	**Pearl Millet**
Minimum temperature	0.4331 (.001)	0.0675 (.01)	-0.0451 (.07)	-0.0838 (.07)	-.0523 (.05)	0.0545 (.01)
Maximum temperature	-0.0738 (.50)	-0.1011 (.02)	-0.1330 (.001)	-0.0978 (.002)	-0.0957 (.002)	0.0542 (.005)
Rainfall	0.0011 (.001)	-0.0010 (.16)	0.0011 (.001)	0.0002 (.08)	0.0020 (.004)	0.0270 (.04)

Figure within the parentheses shows probability value

A 1^0C rise in maximum temperature causes rice yield to significantly decline by 13 per cent, while a similar rise in minimum temperature causes a decline in yield , but in this case not a significant one. The results are also supported by other studies. Welch *et al* [13] found higher minimum temperatures reduced grain yield in rice, while higher maximum temperature raised yields; because in their study area, the maximum temperature rarely reached the critical maximum temperature for rice that hampers yield. However, the simulation results for the scenario of future temperatures increases revealed that, with the maximum temperature nearing the upper threshold limit, the yield of rice tends to decline. The negative impact of increasing maximum temperature on yield of rice has also been supported by other studies [14, 15, 16, 2, 17, 18].

Climate limits the production area of maize and lack of rainfall (drought) or too much of it (flood) can result in 100 per cent loss of maize output [19]. The marginal effect of rainfall on yield was negligible and insignificant. It was found that 1^0C rise in maximum temperature leads to a decline in yield by 9 per cent, while a similar rise in minimum temperature leads to a decline in yield by 8 per cent for the crop varieties grown in Middle Gujarat region of the state. The results are supported by Patel *et al* [20] who also found for Dahod region in Middle Gujarat that the gradual increase of minimum temperature showed gradual yield reduction for maize cultivar Ganga Safed-2, while cultivar GM-3 did not show any specific trend. They also found that incremental units of maximum temperature (1 to 3 ^{0}C) showed gradual decrease in yield ranging from 3717 to 3518 kg ha-1 (1.1,-0.5 and -4.3 % of base yield) for cultivar Ganga Safed-2.

Groundnut is grown mainly as rainfed crop; the Marginal effect of rainfall on yield was positive and significant for groundnut. A 1^0C rise in maximum temperature results in decline in yield by 9 percent,

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while, a similar rise in minimum temperature shows a decline in yield by 8 per cent. Studies [21,22] have suggested that the average yield of groundnut decreases in absence of good rainfall and prolonged dry spells during the crop growth period in India. Similar results were obtained for China [23] and several parts of Africa [24]. In an another study by Rao *et al*. [25], it was found that the increase in seasonal minimum temperature beyond 22℃ resulted in decline in average productivity by 26.2 per cent. In their study, they also found that the yield of groundnut has shown a decreasing tendency with increase in maximum temperature, minimum temperature and as well as with mean daily temperature, irrespective of rainfall regimes during the growing season in arid and semi-arid regions of Andhra Pradesh in India, again indicating that groundnut is highly susceptible to poor rainfall and rise in temperature beyond optimum high and low.

In the case of Pearl Millet, the marginal effect of rainfall on yield was positive and significant, but negligible during the study period. In summer, Pearl Millet is grown with irrigation and the yields are higher than the kharif grown crop. Pearl Millet is extremely resistant to drought and thrives well in high temperature. The same was reflected in marginal effect analysis of Pearl Millet; a 1^0C rise in maximum and minimum temperature leads to a significant increase in yield by almost similar quantum (5 per cent). Looks like pearl millet remains, the only crop that has promise of food security for the growing world population under the changing climate. Mustapha and Arshad [26], Hussein *et al*. [27] supported the same argument.

4. CONCLUSIONS

The impact of temperature and rainfall is significant on the production sub system of crops. Fluctuations in weather variables beyond threshold level play havoc on crop yields. The study shows that the marginal effects of increase in maximum temperature are significantly negative for most of the crops and may pose a threat to food security in the long run. Several researches have projected shortage of food between 2050-2100, wherein the yields of crop may decline highly and significantly, in response to climate change, under no mitigation strategies. Changes in planting dates, crop varieties, intercropping etc or adopting innovative technologies like precision farming, micro-irrigation, nanotechnology, may help in increasing yields and at the same time help in mitigating the effects of climate change in long run. Aggarwal [28] reported if farmers plant earlier than usual, climate induced damages to wheat can be reduced by 60-75 percent. Biotechnology has an important role here. Studies suggest that drought tolerant varieties can reduce production risk by 30-50 percent [29]. Input management is another area to look upon. Patel *et al*. [30] showed that by applying supplementary irrigation at tasseling and silking stage to kharif maize, nearly 27-32 percent increase in yield can be achieved over no irrigation. Further, the authors suggested shifting crop to rabi season under climate change scenario as high yields could be achieved than kharif season. This study shows that crop of the future in Gujarat could be Pearl Millet, which shows resistant to high temperatures and the yield responds positively to marginal increase in both minimum and maximum temperature. Howsoever, we do not suggest one crop for all. That means we need to promote crops which have potential to survive harsh situations and coarse cereals seem one option. Cotton may be looked upon as a promising crop, however, the pest and disease incidence increases at high temperatures. More thrust should be given to the agricultural research and adoption of innovative technologies for sustainable agriculture in future scenario of climate change. The Research and Development involvement should be multi disciplinary; joint efforts are the need of the hou

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