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

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Authors' contributions

This work was carried out in collaboration between all authors. Author RS designed the study, wrote the protocol and wrote the first draft of the manuscript. Author GD managed the literature searches. Authors RS and DJP jointly did the statistical analysis. Author SM managed data collection. All authors read and approved the final manuscript.

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ABSTRACT

Fixed effects panel data approach for multiple year was used to analyse the impact of rainfall and temperature on the yield of major crops in the Western Indian State of Gujarat. During the period of study, the maximum temperature increased by 1.54°C in Saurashtra, while the minimum temperature increased by 5.41°C in Middle Gujarat. Rainfall increased by 401.77 mm in Saursahtra The results of regression of yield on weather and non-weather variables revealed that rainfall had a positive effect on most crops, while temperature had a negative impact confirming that high temperatures could be detrimental to food security in long run. Rice was found most hit of all crops,

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due to rise in temperature. Pearl Millet was the only crop that showed resistance to high temperature, due to its stress tolerant ability. Irrigation was found significant for Cotton, Wheat and Pearl Millet showing the importance of irrigation in these crops. Pearl Millet may be looked upon as a crop of future. As the consumption of rice is high, attention must be given to the crop. On the other hand, consumption of pearl millet must be promoted in diets and more area must be brought under the crop. Assured irrigation in cotton, wheat and pearl millet is necessary to harvest better yield. More area must be brought under irrigation in these crops. Furthermore, innovative technologies in agriculture must be promoted to face the challenges rising out of the changing weather parameters.

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. Rainfall and Temperature both are important climatic inputs in crop growth. A deviation of any of these from the required exposure during the crop growing period has harmful impact on production systems. 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.

The impact of climate change is expected to be more prominent in developing countries. Studies [2] suggest that the temperature is estimated to rise by 1 and 6°C in the next century, causing a shift in hydrological cycles which may result in more rains in Northern Hemisphere and less in subtropical belt, home to most developing countries. The Indian subcontinent may receive higher rainfall during monsoon season while lesser outside monsoon season, leading India to witness more floods and droughts than ever. This will certainly impact the Agricultural production causing wide fluctuations in production levels of several crops leading to scarcity and increasing hunger levels. Mean yield changes of -17 per cent in wheat, -5 per cent in maize, -15 per cent in sorghum and -10 per cent in millet, across Africa, and -16 per cent in maize and -11 per cent in sorghum, across South Asia, were estimated [2] due to climate change. International Food Policy and Research Institute [3] simulated a model run under two climate change scenarios *viz.* with and without CO_2 fertilization. Without CO_2 fertilization, a significant yield decline was observed for most crops, especially irrigated wheat and irrigated rice in developing countries. Countries in South Asia were found most affected. With CO_2 fertilizations, the yield declines were lower.

The State of Gujarat in India has a total geographical area of 19.60 million hectare which is six per cent of the total geographical area of India. Around 51 per cent of 19.60 million hectare is under cultivation. Agriculture in Gujarat contributes to about 18 per cent to the state's GDP and engages more than 50 per cent workforce of the state. The State is divided into eight agro-climatic zones based on rainfall, soil types and cropping pattern. In Gujarat, agriculture is partially dependent on rainfall since most of the kharif crops are rainfed. The rainfall, particularly in Saurashtra and Kutch regions and in the northern Gujarat, is highly erratic. As a result, these regions are often subject to drought. Hence non-availability of proper rainfall is a limiting factor for the growth of kharif crops in Gujarat, while temperature is the main limiting factor to achieve productivity of rabi crops like wheat and mustard. Cotton, Groundnut, Cumin, Rice, Wheat, Pearl Millet, Sesame seed, Green Gram, Pigeon pea, rapeseed and mustard, Coriander, Guarseed, Banana, Mango, Guava, Pomegranate, etc are the major crops in the State.

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. MATERIALS AND METHODS

Panel data regression relying on inter-district variation could lead to the problem of omitted variable bias, which is more prominent in single cross section data (cross section data for single time period). Omitted variable bias occurs when a model created incorrectly leaves out one or more important factors/variables, unobservable in nature, as discussed in the last paragraph of introduction. The "bias' is created when the model compensates for the 'missing variable/factor' by either over or underestimating the effect of one or the other variables/factors included in the model. Thus, the model is most likely estimated, wrongly. In order to remove such harmful effect of omitted variable bias, it is advised to focus on within district (Intra-district) variation using multiple year cross section data. In order to remove the bias by focusing within variation, we assumed that there are no changes in those unobservable factors/variables over time within each district. So the identifying assumption of the model was "Unobservable factors that might simultaneously affect yield, temperature, rainfall, irrigation etc. are time invariant". "Fixed effects regression" is a powerful tool that removes the omitted variable bias as it automatically takes care of unobservable variables/factors in a panel multiple year cross section data. The 'fixed effects regression, exploits within group regression over time.

Therefore, to establish the relationship between crop yield and weather variables, our panel consisted of district level data on crop yields, cumulative rainfall, irrigated area under crops, and average minimum and average maximum temperature from 1980 to 2011 for 18 districts in Gujarat at their 1980 boundaries. The data was collected for the crop growing period only. The major crops selected from the State were Rice, Maize, Cotton, Groundnut, Wheat, and Pearl Millet (summer crop), grown in their major regions. The major region for Rice, Wheat and Maize is Middle Gujarat while for Cotton, Pearl Millet and Groundnut is Saurashtra region of the State. 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. [4], 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 per hectare, and D and T are Place (districts in this case) and Time fixed effects, respectively. The Place (district) fixed effects absorb all unobserved place specific time-invariant factors; for example, soil and water quality that influence crop yield. 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 [4], respectively. The weather variables considered in this study were cumulative rainfall, and the average minimum and maximum temperature for the crop growing period. To account for non linear relationship between weather variables [5,6], 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. It was observed that irrigation is an exogenous non weather variable that represents farmers' response to climate change. β and γ are parameters on weather and irrigation variables, respectively and ε is error term. Equation was estimated as log linear to reduce excessive variation in the dependent variable 'y'.

According to Birthal et al. [4], in the presence of non-linear and interaction effects, the interpretation of regression coefficients is not straightforward. Therefore, to quantify the true effect of a single climatic variable on yield, the marginal effects should be evaluated at their means. Its significance in the study is to find out the effect of one unit increase in mean temperature (minimum and maximum) or mean rainfall on crop yield. The expected marginal impact of a single climatic variable (derivative of the yield with respect to the weather variable, evaluated at the mean of weather variable) on yield was estimated as:

$$E[\partial \prod / \partial X_i] = \alpha_{1,i} + 2\alpha_{2,i} * E[X_i]$$

Where $E[X_i]$ is the expected value of weather variable, $\alpha_1 and \alpha_2$ are constant and coefficient, respectively.

Trend Analysis: To estimate trends in temperature and rainfall, natural log value of these two variables were regressed on time with district fixed effects as controls for time invariant factors [4].

The model was run on STATA software, version 12.1.

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°C while maximum temperature rose by 0.47°C. The rainfall in this region showed a significant increasing trend; it increased by 378 mm during 1980-2011. In case of Middle Gujarat in rabi season, maximum temperature registered significant rise by 0.89°C while the minimum temperature rose significantly by 5.41°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. 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 for groundnut in Saurashtra and Kutch. 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.

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.

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	18.80	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 °C, Trend: °C /year, Total Change in Rainfall in mm, Trend: mm/year. Figure within the parentheses shows probability value

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

The irrigation coefficient has been found positively significant in Wheat, Cotton, and summer Pearl Millet indicating the importance of irrigation for 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°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°C while in the study period, the temperature in the region remained between 24.50°C - 33.72°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°C [7]. 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°C significantly reduces the number of mature pods and seed yields [8]. 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°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 [9]. 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. The reported intercept or constant is the average value of fixed effects (time invariant factors) in the model. The significant value of the constant shows the strength of the model, and that the fixed effects were taken proper care by the model and the omitted variable bias was removed.

Regression models, however, give combined effect of variables on dependent variables; 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.

3.3 Marginal Effect

Table 3 presents the marginal effect of climate change, i.e. the effect on yield due to rise in by 1°C in temperature and 1mm rainfall. A 1°C 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 significant increase in the yield by 6 per cent. Patel & Shekh [10] also stated on the basis of sensitivity analysis of CERES-Wheat that elevated maximum temperature decreased wheat yield significantly. Mishra *et al* [11], in a study have 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°C 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 CO_2 levels in the atmosphere of up to 650 ppm and temperature of 40°C was found to be optimum for cotton plant growth [12] By and large, though, research in India indicates that the impact of climate change on cotton production and productivity will be favourable [13] 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. [14] concluded that erratic monsoon or delayed monsoon hampers crop physiology and yield.

A 1°C 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. [15] 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 [16-18,4,19,20].

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 [21]. The marginal effect of rainfall on yield was negligible and insignificant. It was found that 1°C 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. [22] 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°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°C rise in maximum temperature results in decline in yield by 9 percent, while, a similar rise in minimum temperature shows a decline in yield by 8 per cent. Studies [23,24] have suggested that the average yield of groundnut decreases in absence of good rainfall and prolonged dry spells during

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 the crop growth period in India. Similar results were obtained for China [25] and several parts of Africa [26]. In an another study by Rao et al. [27], it was found that the increase in seasonal minimum temperature beyond 22°C 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°C 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 [28], Hussein *et al*. [29] supported the same argument.

4. CONCLUSIONS

The impact of temperature and rainfall is significant on the production sub system of crops.. According to the Food and Agriculture Organization of the United Nations [30], repeated floods between 2004 and 2013 led to crop and livestock production losses in India. The FAO also found that in Ethiopia, drought in 2003 resulted in decline of maize yields by 26 per cent maize yields dropped by 26 percent, while in Brazil, 2007 drought resulted in decline of coffee yield by up to 10 percent, impacting international prices. Fluctuations in weather variables beyond threshold level play havoc on crop yields threatening food and nutritional security of people round the globe, and increase rural poverty, bringing macroeconomic shifts. This study shows that the marginal effects of increase in maximum temperature are significantly negative for most of the crops, highest for rice 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 [31] 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 [32]. Input management is another area to look upon. Patel et al. [33] 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. However, 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. Rice needs special attention as it is the special foods to a large chunk of population and high yield losses are expected due to change in weather parameters. 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.

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COMPETING INTERESTS

Authors have declared that no competing interests exist.

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