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Sensitivity of Yields of Major Rainfed Crops to Climate in India

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I

INNTRODUCTION

There is now adequate evidence about the impending climate change and the consequences thereof. The fourth assessment report of IPCC observed that 'warming of climate system is now unequivocal, as is now evident from the observations of increase in the global average air and ocean temperatures, widespread melting of snow and ice, and rising global sea level' (IPCC, 2007). These changes and their effects are likely to affect global livelihood and environmental systems in various ways. Since climatic factors serve as direct inputs to agriculture, any change in climatic factors is bound to have a significant impact on crop yields and production. This area has attracted the attention of researchers in the recent times as is evident by the growing number of studies on the impact of climate change on agriculture. Studies have shown a significant effect of change in climatic factors on the average crop yield [Dinar *et al*. (1998), Seo and Mendelsohn (2008), Mall *et al*. (2006) and Cline (2007)]. However the impact of climatic factors on mean crop yield has not been investigated much especially in agriculture based developing economies where there is likely to be more serious repercussions in terms of food security, inequality and economic growth. Uncertainties in weather create risky environments for crop production, farming systems and food supply. The way climate change will affect agricultural productivity is expected to vary depending upon the various factors including geography and technology levels. While an overall significant damage of 3.2 per cent is expected in the global agricultural production by the 2080s under business as usual scenario, it is found that the losses may even go up to 15.9 per cent if the carbon fertilisation effect is not realised. The developing countries, predominantly located near the lower altitude, are most likely to incur a much greater loss roughly quantified at 21 per cent (Cline, 2007). In developing countries, climate change will cause yield declines for the most important crops and South Asia will be particularly hard hit (IFPRI, 2009). Many studies in the past have shown that India is likely to witness one of the highest agricultural productivity losses in the world in accordance with the climate change pattern observed and scenarios projected.

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Climate change projections made up to 2100 for India indicate an overall increase in temperature by 2-4^{0}C with no substantial change in precipitation quantity (Kavikumar, 2010). The projected agricultural productivity loss for India by 2080 is about 30 per cent even after taking the expected positive effect of carbon fertilisation on yield into consideration (Cline, 2007). Another study finds that the projected loss of agricultural production in India by 2100 lies between 10 per cent to 40 per cent after taking carbon fertilisation effect into account (Aggarwal, 2008). Many simulation-based crop growth models have been developed to examine the vulnerability of agriculture to climate change (Hoogenboon, 2000) particularly for situations of developed temperate countries. Many studies (Parry *et al*., 1999; Darwin, 2004; Olesen and Bindi, 2002; Adams *et al*., 2003 and Tsvetsinskaya *et al*., 2003 find that region-specific analysis is required to evaluate the agronomic and economic impact of weather changes in more detail.

Within agriculture, it is the rainfed agriculture that will be most impacted by climate change for two reasons. First, rainfed agriculture is practiced in fragile and degraded lands which are thirsty as well as hungry. Second, the people dependent on rainfed agriculture are also less endowed in terms of financial, physical, human and social capital limiting their capacity to adapt to the changing climate. The following are some of the challenges that the changing climate will pose to rainfed agriculture: Temperature is an important weather parameter that will affect productivity of rainfed crops. The last three decades saw a sharp rise in all India mean annual temperature. Though most rainfed crops tolerate high temperatures, rainfed crops grown during *rabi* are vulnerable to changes in minimum temperatures (Venkateswarlu and Rama Rao, 2010). The analysis of data for the period 1901-2005 by IMD suggests that annual mean temperature for the country as a whole has risen to 0.51^{o}C over the period. It may be mentioned that annual mean temperature has been consistently above normal (normal based on period, 1961-1990) since 1993. This warming is primarily due to rise in maximum temperature across the country, over a larger part of the data set. Apart from direct impacts, higher temperatures also increase the water requirements of crops putting more pressure on the availability of water (CRIDA, 2008). The extent to which rainfall and temperature patterns and the intensity of extreme weather events will be altered by climate change remains uncertain, although there is growing evidence that future climate change is likely to increase the temporal and spatial variability of temperature and precipitation in many regions (IPCC, 2007). Therefore, the present study attempts to understand the sensitivity of yields of major rainfed crops namely, bajra, sorghum and maize to climatic factors. More than seasonal rainfall, its distribution is more important for dryland crops grown during *kharif* season. Hence, the study includes the wet day frequency in the analysis. This paper is organised as follows. In the next section, the data set, information about the sources and methodology and technical aspects of the model are discussed which is followed by results and discussion in Section IV. The study concludes and summarises the findings in the final section.

II

DATA AND METHODOLOGY

Data used in this study are obtained from two sources. The yield data of the selected crops from 1990 to 2008 were obtained from Centre for Monitoring Indian Economy (CMIE) database and are denoted in kilograms per hectare (kg/ha). CMIE collates the statistics on Indian agriculture from a comprehensive range of sources including government reports. The yield time series data for the three selected crops, viz., bajra, sorghum and maize were compiled for 582 districts of the country. However to examine the weather sensitivity, for each crop only those districts where area sown under the crop was more than 5000 ha and yield data available for at least 10 years were included in the analysis. Consequently the study included 106 districts for soghum, 65 for bajra and 157 for maize crops.

Data on climatic variables are downloaded from CMIE as well as from India Water Portal. The dataset available at the portal is developed using the publicly available Climate Research Unit (CRU) dataset, out of the Tyndall Centre for Climate Change Research, School of Environmental Sciences, University of East Anglia, Norwich, UK (http://indiawaterportal.org/metdata. For this study, we consider district wise monthly maximum temperature during *kharif* season, wet day frequency and total precipitation as the basic climate data. A major strength of this study comes from the use of district level climate and yield data across India, which allows for the examination of both inter-temporal variances in the data with district level characteristics and technology trend controlled.

The crop productivity in rainfed regions is likely to be affected more on account of variation in climatic factors like rainfall, wet-day frequency and temperature as compared to that in irrigated regions. Hence the year wise productivity of crops under study was calculated separately for rainfed as well as irrigated districts for the period from 1990 to 2006. Out of 582 districts, 338 were categorised as rainfed. A district which is either covered under drought prone area programme (DPAP) or desert development programme (DDP) or having less than 30 per cent of its net cultivated area under irrigation was categorised as rainfed district. The year-wise productivity of each crop for rainfed region was estimated by dividing the total production (total quantity produced by 338 rainfed districts together) by total area sown (total of area under the crop in 338 rainfed districts). Productivity of a crop for irrigated region was also derived in a similar fashion.

Analytical Model

Technological progress masks the effects of climate and resource degradation. We removed the effect of technological progress by de-trending the productivity by fitting a time trend equation.[1] The de-trended productivity was then regressed on the three weather variables. This methodology is described here.

Step 1: Assessing Technological Trend: For each crop for each district included in the analysis the following regression model was fitted.

$$Y = a + bt + \theta$$

Where, Y is yield of the crop in year t in the district under study; a is intercept; b is technological trend in the crop assessed from the data in the district under study; t is year and θ is residual. The time trend equation was fitted for each of the 338 districts. Then, the de-trended yields for each district were derived as under

$$\theta = Y - a - bt$$

Step 2: Fitting De-trended Yield Data on to Weather Parameters: De-trended yields of each district were regressed on climatic variables, viz., annual rainfall, wet day frequency and *kharif* monthly maximum temperature (June to October). The multiple linear regression fitted was of the form:

$$\theta = \beta_1 R + \beta_2 W + \beta_3 T + \epsilon$$

Where β_1 is the linear sensitivity of de-trended yield to rainfall R,
β_2 is the linear sensitivity of de-trended yield to wet day frequency W,
β_3 is the linear sensitivity of de-trended yield to Monthly Maximum temperature T.

Step 3: Multivariate Cluster Analysis of Sensitivities of Districts: In order to enable a more meaningful and easy interpretation of the findings, the districts were grouped into more homogeneous districts by subjecting the district-wise sensitivity estimates to multivariate cluster analysis. For each crop, 4-6 clusters with varying extent of sensitivity were delineated. Before subjecting the data to cluster analysis the three sensitivity variables were standardised using z score method ([(x-mean)/SD]). All the hierarchical clustering algorithms such as Farthest neighbour, Nearest neighbour and Ward's methods were tried with standardised data and finally Ward's method was found to be yielding the manageable number of clusters at relatively lower intra-cluster variation. The distance measure used in the analysis was Squared Euclidian distance. The analysis facilitated to interpret three sensitivity variables together in terms of variability in sensitivities. One cluster of districts with –ve sensitivities (highly sensitive) and another cluster of districts with medium sensitivity and one cluster of districts with +ve sensitivities (highly sensitive) and so on.

III

RESULTS AND DISCUSSION

Productivity Trends

Indian agriculture continues to be dominated by rainfed agriculture with nearly 55 per cent of net cultivated area not having any access to irrigation. It has been estimated that even after full irrigation potential of the country is realised, half of the cultivated area will continue to be under rainfed farming (Katyal *et al*., 1996). Thus examining the factors affecting crop yield in rainfed regions becomes more important. The productivity trends of major rainfed food crops, viz., bajra, sorghum and maize over the period of 17 years (1990-2006) calculated separately for rainfed and non-rainfed (irrigated) districts shows large variability in crop yields over the year. The yield of all the three crops viz., bajra, sorghum and maize drastically varied over the time. However, there appears to be productivity gains in the long run particularly in case of bajra and maize in both rainfed as well as irrigated areas. The productivity trends show wide gap between rainfed and irrigated regions in the case of both bajra and maize. In case of sorghum, the crop yield in rainfed as well as irrigated areas did not differ much. It may be due to the reason that the sorghum is mostly grown as a rainfed crop even in irrigated areas and also in marginal lands. It may be noticed that the productivity trends in irrigated areas are also behaving similar to rainfed areas in all the crops. Similar behaviour of crop productivity trends in rainfed and irrigated areas indicates the importance of weather variables in irrigated regions also.

Impact of Climatic Factors on Crop Yields

The crop yields even in the rainfed areas are also influenced by factors other than weather variables like technology, market and managemental factors. Fitting technological trend and consequently deriving de-trended yields for further functional analysis takes care of the factors other than weather variables. District wise and crop wise regression functions fitted by using de-trended yields as dependent variables and weather variables as independent, demonstrate that weather variables like rainfall, wet day frequency and maximum temperature influenced the yields of rainfed crops.

In the case of bajra cluster wise sensitivity coefficients presented in Table 1 show that the crop yields were highly and positively influenced by wet day frequency (number of rainy days) in clusters I, II, III and VI. The distribution of rainfall was a major factor influencing bajra yield. Similarly, the bajra yield was quite sensitive to the amount of rainfall and was positively associated indicating that yield will increase with the increase in rainfall and vice versa. The sensitivity coefficient of rainfall was positive and highest in cluster IV with a wide variability in actual annual rainfall (295-1268 mm). The observed negative relationship of yield with rainfall in cluster

TABLE 1. WEATHER SENSITIVITY COEFFICIENTS OF DISTRICT LEVEL FUNCTIONAL ANALYSIS FOR BAJRA PRODUCTIVITY

Cluster (1)	Frequency (2)	Variables (3)	Range of actual value of weather parameters (4)	Average of 25th and 75th percentile of weather sensitivity coefficients (5)	Range of coefficients (6)	(7)	Districts in each cluster (8)
I	19	Annual rainfall	292-824	0.14	-0.02	0.31	Rajasthan- Sawai Madhopur, Nagaur, Jaisalmer, Barmer, Jalore, Sirohi, Pali, Ajmer; Gujarat- Sabarkanta, Ahmedabad; Maharashtra- Buldhana, Pune, Satara; Andhra Pradesh- Mahabubnagar, Kurnool; Tamil Nadu- Thiruvannamalai, Villupuram; Jammu & Kashmir- Jammu; Haryana- Mahendragarh
		Annual wet day frequency	16-93	11.85	5.22	18.48	
		Kharif Maximum monthly temperature	31-40	-11.03	-15.37	-6.70	
II	11	Annual rainfall	426-1487	-0.61	-0.76	-0.47	Haryana- Hissar, Bhiwani, Rewari; Madhya Pradesh- Bhind; Gujarat- Banaskantha, Panchmahal, Vadodara; Maharashtra- Nasik; Andhra Pradesh – Prakasam; Karnataka- Bidar; Tamil Nadu- Dindigul
		ann_wdf	19-71	27.39	17.08	37.70	
		Kha_max_temp	29-40	-16.63	-27.96	-5.31	
III	6	Annual rainfall	322-1098	0.43	0.09	0.78	Rajasthan-Hanumangarh, Churu; Gujarat- Amreli; Karnataka-Chitradurga; Tamil Nadu- Virudhunagar, Thoothukudi
		ann_wdf	23-62	26.09	15.26	36.92	
		Kha_max_temp	27-41	-40.85	-58.50	-23.20	
IV	14	Annual rainfall	295-1268	1.02	0.81	1.24	Rajasthan- Bikaner, Jodhpur, Tonk; Uttar Pradesh- Jalaun; Madhya Pradesh- Dhar; Gujarat- Bhavanagar; Maharashtra- Dhule, Jalgaon, Yavatmal, Jalna, Aurangabad, Beed, Osmanabad, Sangli
		ann_wdf	19-57	-18.00	-30.37	-5.64	
		Kha_max_temp	32-41	2.57	-10.72	15.86	
V	12	Annual rainfall	488-1642	0.22	0.13	0.31	Rajasthan- Jhunjunu, Bharatpur, Jaipur; Uttar Pradesh-Mirzapur Madhya Pradesh-Jhabua Maharashtra- Ahmednagar, Latur, Solapur; Andhra Pradesh-Nalgonda; Karnataka- Belgaum, Gulbarga
		ann_wdf	27-73	-9.62	-13.80	-5.45	
		Kha_max_temp	31-40	8.06	2.80	13.32	
VI	3	Annual rainfall	346-619	-0.86	-1.72	0.00	Gujarat- Kutch, Surendranagar, Rajkot
		ann_wdf	16-25	36.11	72.22	0.00	
		Kha_max_temp	30-34	-32.70	-65.39	0.00	

II may be due to untimely rains affecting the crop or to the fact that the crop is grown under irrigated conditions in some districts, especially for seed production. Sensitivity coefficients show that bajra yield was highly sensitive to *kharif* maximum temperature negatively except in cluster V. Since the districts falling in cluster V like Jhunjhunu, Bharatpur, Ahmednagar, Nalgonda, etc. are relatively agriculturally progressive and might have higher adoption of improved technologies including drought tolerant varieties, the productivity in these districts might be higher in the base year itself (1990) not allowing the technological trend to reflect the influence of technology. In terms of comparison among clusters, the cluster I and III were more vulnerable to change in climatic factors. In these clusters the bajra yield was influenced by all the three factors, where the coefficient of rainfall and wet day frequency was positive indicating the adverse impact on yield in case of decrease in their magnitude, and negative coefficient for *kharif* monthly maximum temperature indicating adverse impact on yield with its rise.

Maize is a major rainfed crop and has huge untapped potential (Dass *et al*., 2010). In the past few years it has been replacing crops like sorghum, castor, *rabi* paddy, etc., particularly in rainfed regions. District wise analysis of weather sensitivity of maize productivity was carried for 156 districts and the results are presented in Table 2. Sensitivity coefficients indicate that the productivity of maize was quite sensitive to change in *kharif* maximum temperature and wet day frequency (number of rainy days) in most of the districts. It is pertinent to note that besides rise in temperature levels over the past 100 years, the frequency of extreme weather events like dry spells, extreme temperatures, high intensity rainfall, etc. during the recent decades is increasing (CRIDA, 2008) and thus has implications for crop like maize. The sensitivity coefficient for wet day frequency was positive in cluster I and III covering more than 136 districts indicating that any decrease in the number of rainy days will negatively affect the maize yield in these districts.

Sensitivity coefficients of rainfall were positive in cluster II and it was positive in the number of districts in cluster I indicating the impact of rainfall variability on maize yield. At the same time in cluster I, the coefficient was negative in the districts which are irrigated and have higher level of rainfall. Similarly, in cluster III, the coefficient of rainfall was negative where many of the districts have higher rainfall and better access to irrigation. Therefore, for better maize yield, besides rainwater harvesting and in *situ* moisture conservation practices in low rainfall regions, provision for draining out excess rainwater during high intensity rains is equally important. The sensitivity coefficients of *kharif* maximum temperature were negative in cluster I and III indicating that reduction in maize yields is imminent in the respective regions as a result of increase in temperature due to future threat of climate change. It needs further investigation as to how increased temperature affects the yield whether through increased evapo-transpiration or other factors.

TABLE 2. WEATHER SENSITIVITY COEFFICIENTS OF DISTRICT LEVEL FUNCTIONAL ANALYSIS FOR MAIZE PRODUCTIVITY

Cluster (1)	Frequency (2)	Variables (3)	Range of actual value of weather parameters (4)	Average of 25th and 75th percentile of weather sensitivity coefficients (5)	Range of coefficients (6)	Range of coefficients (7)	Districts in each cluster (8)
I	121	Annual rainfall	664-1289	-0.25	-0.91	0.40	Andhra Pradesh: Mahabubnagar, Karimnagar, Krishna, Khammam, Prakasam, Adilabad, Visakhapatnam, Warangal, West Godavari, Nizamabad, Rangareddy; Arunachal Pradesh: Lohit; Assam: Karbi-Anglong; Bihar: Vaishali, Gopalganj, Purnea, Katihar, Samastipur, Champaran(East), Saharsa, Bhagalpur, Monghyr, Champaran(West), Madhupura, Darbhanga, Nalanda, Begusarai, Patna, Banka; Gujarat: Bharuch, Panchmahal, Sabarkanta, Kheda, Vadodara; Haryana: Yamunanagar, Ambala, Panchkula; Himachal Pradesh: Sirmaur, Solan, Kangra, Kulu, Una, Mandi, Simla, Hamirpur, Chamba; Jammu & Kashmir: Baramulla, Jammu, Pulwama, Udhampur, Doda, Rajouri, Kapuara, Kathua, Budgam; Karnataka: Kolar, Belgaum, Hassan; Madhya Pradesh: Ratlam, Jhabua, Indore, Vidisha, Guna, Ujjain, Seoni, Dewas, Shivpuri, Dhar, Sidhi, Sehore, Betul, Rajgarh, Shajapur; Maharashtra: Kolhapur, Jalgaon, Dhule, Solapur; Orissa: Keonjhar; Punjab: Rupnagar, Gurdaspur, Kapurthala, Patiala, Amritsar; Rajasthan: Rajsamand, Sirohi, Bhilwara, Jaipur, Udaipur, Alwar, Pali, Dungarpur, Chittorgarh, Bundi, Banswara, Ajmer, Baran, Kota, Jhalawar, Tonk; Tamil Nadu: Coimbatore; Uttar Pradesh: Jaunpur, Sultanpur, Barabanki, Kanpur (Dehat), Unnao, Lalitpur, Ballia, Sitapur, Mainpuri, Hardoi, Shahjahanpur, Sonbhadra, Kheri, Kanpur City, Etah, Saharanpur, Budaun, Firozabad; Uttarakhand: Dehardun; West Bengal: Darjeeling, Purulia.
		Wet day frequency	32-72	4.76	-12.90	22.42	
		kharif_max_temp	31-40	-0.94	-17.87	15.99	

(Contd.)

TABLE 2. (CONCLD.)

Cluster	Frequency	Variables	Range of actual value of weather parameters	Average of 25th and 75th percentile of weather sensitivity coefficients	Range of coefficients		Districts in each cluster
(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)
II	20	Annual rainfall	672-1438	2.03	1.23	2.83	Andhra Pradesh: Medak, East Godavari; Jammu & Kashmir: Poonch; Bihar: Gaya, Supaul, Muzafarpur; Madhya Pradesh: Chhindwara; Maharashtra: Ahmednagar, Jalna, Aurangabad, Pune, Buldhana, Sangli, Satara, Nasik; Orissa: Nawarangpur, Gajapati; Punjab: Jalandhar, Hoshiarpur; Tamil Nadu: Virudhunagar.
		Wet day frequency	32-78	-98.56	-138.31	-58.81	
		kharif_max_temp	31-40	75.68	42.40	108.97	
III	15	Annual rainfall	807-1879	-2.29	-3.78	-0.81	Andhra Pradesh: Guntur; Bihar: Saran, Khagaria, Araria, Jamui, Siwan; Gujarat: Banaskantha; Karnataka: Tumkur, Bangalore (Rural), Chitradurga; Maharashtra: Osmanabad, Beed; Tamil Nadu: Dindigual, Theni; West Bengal: Malda.
		Wet day frequency	43-85	155.21	98.42	212.00	
		kharif_max_temp	29-38	-194.72	-265.30	-124.14	

Similarly, weather sensitivity analysis for sorghum was carried out for 106 districts. After removing one outlier which was Kolhapur district of Maharashtra, the remaining 105 equations were clustered into three groups based on similarities of sensitivity coefficients (Table 3). As sorghum is known to be tolerant to drought conditions, sensitivity coefficient of rainfall was positive mainly in cluster II and for some districts in cluster I indicating that decrease in rainfall will adversely affect sorghum yield in these districts. However, the sorghum yields were highly sensitive to change in the distribution of rainfall in terms of wet day frequency. The coefficients of wet day frequency were positive in cluster I and III in all for 68 districts. The number of rainy days per annum has been decreasing all over the country during the past two decades resulting in frequent and longer dry spells. Hence, there is need for interventions to cope with moisture stress during dry spells. The cluster of districts where the magnitude of positive coefficient of wet day frequency is large is more sensitive and need appropriate adaptation and coping strategies. Similar to the other two crops of bajra and maize, the sensitivity coefficient of *kharif* maximum temperature were negative for sorghum also in cluster I and III covering major sorghum producing districts.

IV

SUMMING UP AND IMPLICATIONS

The analysis of productivity trends of bajra, maize and sorghum crops clearly shows that there is wide gap between productivity in rainfed and irrigated regions except in case of sorghum, which is least irrigated. However, the similar behaviour of productivity trends in rainfed as well as irrigated regions in all the three selected crops clearly indicates that weather variables have major influence on the productivity of these crops in the irrigated regions also. The debate on the extent of climate change and its impact on agricultural production is still continuing, however, it is becoming increasingly evident that the climatic variations and extreme weather events like longer and frequent dry spells, reduced number of rainy days, high intensity rainfall in a single day, extreme temperature events, etc., observed in the recent decades are impacting agriculture. The analysis carried out for the crops of bajra, maize and sorghum shows that the increase in rainfall and number of rainy days would result in yield increment in most of the districts and vice-versa. *Kharif* maximum temperature was found to influence the yields negatively in most of the districts. The cluster analysis has helped in categorising the districts based on similarity in weather sensitivity. In the cluster of districts where the sensitivity coefficient of rainfall is very high and positive, the interventions on rainwater harvesting through farm ponds, percolation pond, and its use for supplemental irrigation are likely to result in a considerable increase in productivity. For such districts, there is also need to strengthen weather based agro-advisories and prepare contingency crop plans. The seed of contingency crops may be arranged in advance

TABLE 3. WEATHER SENSITIVITY COEFFICIENTS OF DISTRICT LEVEL FUNCTIONAL ANALYSIS FOR SORGHUM PRODUCTIVITY

Cluster (1)	Frequency (2)	Variables (3)	Range of actual value of weather parameters (4)	Average of 25th and 75th percentile of weather sensitivity coefficients (5)	Range of coefficients (6)	Range of coefficients (7)	Districts in each cluster (8)
1.	62	Annual rainfall	589-1291	-0.045	-0.27	0.18	Haryana- Jhajjar; Rajasthan -Sawai Madhopur, Jaipur, Nagaur, Jodhpur, Sirohi, Pali, Ajmer, Tonk, Rajsamand, Udaipur, Kota, Baran, Jhalawar; Uttar Pradesh- Sitapur, Jalaun, Jhansi, Hamirpur, Mahoba; Madhya Pradesh- Bhind, Shivpuri, Guna, Panna, Damoh, Ratlam, Shajapur, Rajgarh, Betul, Seoni; Gujarat- Ahmedabad, Rajkot, Amreli, Bhavanagar, Vadodara, Bharuch Maharashtra- Dhule, Nagpur, Aurangabad, Nasik, Pune, Satara; Andhra Pradesh- Adilabad, Medak, Rangareddy, Mahabubnagar, Nalgonda, Khammam, Prakasam, Cuddapah; Karnataka- Raichur, Koppal, Gadag, Bellary, Chikmagalur; Tamil Nadu- Vellore, Dharmapuri, Namakkal, Coimbatore, Karur, Thiruchirapalli, Perambalur, Virudhunagar
		ann_wdf	28-77	9.955	2.14	17.77	
		Kha_max_temp	30-40	-11.745	-21.16	-2.33	
2.	37	Annual rainfall	688-1519	0.595	0.36	0.83	Rajasthan –Bharatpur; Uttar Pradesh- Lalitpur; Madhya Pradesh- Rewa, Sidhi, Dewas, Jhabua, Dhar, Chhindwara; Gujarat- Banaskantha; Maharashtra- Jalgaon, Buldhana, Akola, Amravati, Wardha, Gadchiroli, Chandrapur, Yavatmal, Nanded, Parbhani, Jalna, Ahmednagar, Beed, Latur, Osmanabad, Solapur, Sangli; Andhra Pradesh- Kurnool, Anantapur; Karnataka- Belgaum, Bagalkot, Bijapur, Gulbarga, Bidar, Mysore, Chamarajanagar; Tamil Nadu- Dindigual, Thoothukudi;
		ann_wdf	38-71	-23.835	-32.43	-15.24	
		Kha_max_temp	28-38	15.885	5.91	25.86	
3.	6	Annual rainfall	833-2386	-0.725	-1.41	-0.04	Karnataka- Dharwad, Haveri, Chitradurga, Tumkur, Hassan; Tamil Nadu- Salem
		ann_wdf	46-96	75.91	31.91	119.91	
		Kha_max_temp	28-30	-186.2	-270.72	-101.68	

through participatory approach like community seed bank with support from relevant government schemes. Similarly, in the cluster of districts where sensitivity coefficient of wet day frequency is high and positive, the interventions to reduce moisture stress through supplemental irrigation, mulching and *in situ* moisture conservation practices like conservation furrow, ridge and furrow system of sowing, etc. are likely to result in increase of crop yield. The sensitivity coefficients of *kharif* maximum temperature which were negative for most of the clusters in all the three crops showing negative impact of increase in temperature on crop yields needs to be further examined. The farmers in the districts which have very high negative coefficient for *kharif* temperature may need to shift to suitable varieties. For all the three crops the sensitivity coefficients of rainfall were also negative for some of the districts. That may be due to high intensity or untimely rainfall affecting the crop yields. In such situation, the natural resource management (NRM) interventions like ridge and furrow system of sowing, conservation furrow, etc. will not only help in *in-situ* moisture conservation but also in draining out the excess rain water. The interventions like farm ponds, percolation ponds, water recharge structures, *in situ* moisture conservation practices as part of adaptation to climate change could be taken up under Mahatma Gandhi National Rural Employment Guarantee Scheme in a big way. However such works at the field level must be supervised by trained manpower in order to ensure technical soundness of NRM interventions.

NOTE

1. In order to assess the technological trend, we had first tried with independent variables like area under HYV, fertiliser use, extent of irrigation, pesticide use, etc. in the model, but the model explained less variation with low value of R^2. Since there are large numbers of technological and managemental variables that influence the crop yields and which are not possible to include in the function on account of non availability of data. However, the model fitted with time as independent variable was tuned out to be better fit and was finally used in the analysis.

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