Trans. Inst. Indian Geographers
Vol. 33, No. 2, 2011

Regional Impact of Climate Extremes on Foodgrains in India

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Abstract

Agricultural yield in India is significantly affected by monsoon vagary due to strong dependency on it. Extremes such as droughts and floods cause significant losses of crop output, leading to commotion in socioeconomic and ecosystems, enhancing constraints for sustainable development. An assessment of impact of these extremes on foodgrain yield is therefore of paramount importance in formulating policies for sustainable development. This paper explores the historical impacts of climate extremes by examining the long-term changes in cropped area and foodgrain yield at regional level. In secular terms, area and production have increased upto mid-eighties. There is more temporal fluctuation in the production of foodgrain than that in the area under foodgrain. Different regions have depicted differential impact of extremes on various crops. Also impact of extremes in different seasons (Rabi and Kharif) is diverse with respect to crops. Change in yield from that of the previous year depicts significant correlation with summer monsoon rainfall anomaly primarily for rice growing states. Given that rice is most sensitive crop to the extreme climate events, proper and efficient planning is required to ensure sustainability of rice production and enhancing food security in the country.

Introduction

Agriculture is as ancient as human civilization itself and is the essential activity through which humans survive on earth. In developing countries, agriculture is the primary contributor to the nation's economy. Recent estimate in 2008, indicates the contribution of agricultural sector to GDP is 17% (CIA, 2009). Agricultural exports account for 13 to 18% of total annual exports of the country (Ministry of Finance, 2002). However, given that 62% of the cropped area is still dependent on rainfall (MoEF, 2002), Indian agriculture continues to be fundamentally dependent on weather and its vagaries. The Indian summer monsoon circulation influences more than 60% of world population (Webster et al., 1998) due to its large-scale impact on agriculture, water resources, power generation and overall economy (Mooley et al., 1981; Mooley and Parthasarathy, 1983; Parthasarathy et al., 1988). Owing to strong relationship between agricultural performance and climate, in the long run, there will be considerable loss in net revenue due to global warming (Kavi Kumar and Parikh, 2001). Significant influence of monsoon and some of its potential predictors on crop production in India have been established in a recent work (Krishna Kumar et al., 2004).

Eighty percent of the total rainfall over the Indian sub-continent occurs during only four monsoon months (June-September), which is vital to India's agriculture (Parthasarathy et al., 1992). While drought is a recurring problem in some areas of India, floods cause a severe damage to livelihood and agriculture in other areas; one third of the average flood prone area in the country constitutes agricultural land (IPCC, 2007). Climate variability has considerable social and economic consequences in India, where almost three quarters of the population relies directly or indirectly on agriculture for livelihood or employment (Ministry of Agriculture, 2001). The contribution of agriculture to the Gross Domestic Product (GDP) has decreased substantially since independence and led to the expectation that the impact of the monsoon on the overall economy would have also decreased. However, a study of the variation of the GDP and the monsoon has revealed that the impact of severe droughts on GDP has remained between 2 and 5% of GDP throughout (Gadgil and Gadgil, 2006).

Climate extremes are expected to influence crop and livestock production, hydrologic balances, input supplies and other components of agricultural systems. However, the nature of these biophysical effects and the human responses to them are complex and uncertain. For example, crop and livestock yields are directly affected by changes in climatic factors, such as, temperature and precipitation and the frequency and intensity of extreme events like droughts, floods and cyclones. Climate extremes may also change the types, frequencies and intensities of various crop and livestock pests, the availability and timing of irrigation water supplies and the severity of soil erosion. Extreme climate events, such as spells of high temperature, intense cyclones, floods, droughts, disrupt crop production. Heat spells can be particularly detrimental in areas where certain varieties of crops are grown near to their limits of maximum temperature tolerance; for example, rice in southern Asia. Similarly, frequent droughts not only reduce water supplies but also increase the amount of water needed for plant transpiration. Floods damage crops by submerging the plant under water or providing excess water to the root of the plants.

Since agricultural systems are managed ecosystem, the human response is critical to understanding and estimating the effects of climate extremes on production and food supply. Agricultural systems are also dynamic; producers and consumers are continuously responding to changes in crop and livestock yields, food prices, input prices, resource availability and technological change.

Theoretically, some of the factors, which affect the variability of agricultural yields, can be roughly grouped into three categories based on nature of their variation over time:

1. Secular changes - these include factors that involve application of technology and management principles already proved; for example, mechanization, varieties, irrigation and farmers' know-how where the growth is smooth. They also include factors where growth is more abrupt, taking place after some innovation, which by itself is uncertain but after which growth exists for several years in succession. Secular changes are human induced and result of social, environmental and technological factors.
2. Irregular or abrupt changes - these include extreme factors of various origins which influence management

decisions; for example, policy related to subsidy on fertilisers which would influence farmers' decision on the amount of fertiliser to be applied. It is also true of infrastructure, the growth of which is not necessarily smooth.

3. Quasi-periodic changes- showing some cyclicity which is not easily predictable; for example, weather extremes. These changes are most likely to be climate related or climate induced.

This paper sharpens understanding of link between climatic extremes and agriculture. Climate extremes impact agricultural output (yield or production) through its effects on yields and areas planted. As indicated above, yields are affected by continuously changing technological and management trends, discontinuously changing innovations and randomly changing weather. Planted areas vary according to labour availability, level of mechanization and expected return (prices). Harvested areas are often strongly linked to environmental conditions, including poor weather during the cycle; very low yields make the harvest rather uneconomic in some areas and no harvest is possible in areas of withered crops. Damage to infrastructure due to extreme weather conditions also adversely affects harvested areas by making them inappropriately located with respect to both sources of inputs as well as destinations of outputs. These complexities make the estimation of loss due to weather extremes a really difficult exercise.

The paper is organised as follows: Next section deals with the description of data and methodology used in the study. Subsequent section describes the results and their discussion, and, finally, the paper outlines major findings with conclusions and future scope for research.

Data and Methodology

The major cropping seasons in India are Kharif and Rabi. The Kharif season crops (rice, sorghum, maize, pigeonpea and blackgram) are grown during the summer monsoon (June–September) period and harvested in the autumn or early winter months. The Kharif crop production is greater than 50% of the total annual foodgrain production and constitutes the principal source of food supply. The Rabi cropping (wheat and chickpea) season starts after the summer monsoon and continues up to the spring or early summer months. The rainfall, which occurs towards the end of the summer monsoon, provides soil moisture for the Rabi crop, which is sown during the post-monsoon season. Thus, the summer monsoon is mainly responsible for both Kharif and Rabi foodgrain production in India (Parthasarathy et al., 1988). A small region southern peninsular India, Tamil Nadu, also benefits from the northeast monsoon (October–December) rainfall for Rabi foodgrain production.

The data related to annual production of total foodgrains and area under it over the country for the agricultural years (1 June to 31 May) have been downloaded from www.indiastat.com. The total foodgrains consist of (a) cereals (rice, wheat, jowar, bajra, maize and barley) and (b) pulses (chickpea, pigeonpea, greengram and blackgram). The cereals form the core staple food, and pulses are the protein supplement for the large vegetarian population. All India Summer Monsoon Rainfall (AISMR) series has been downloaded from Indian Institute of Tropical Meteorology (IITM), Pune web page (http://www.tropmet.res.in). Also, Regional Monsoon Rainfall (RMR) data for the country compiled by IITM for five selected regions viz. North West, West Central, Central North East, North East and Peninsular India have been used to look into the impact of regional monsoon rainfall anomaly on regional agriculture yield. These regions are based on monsoonal homogeneity and cover almost the entire country except the hills of the north and the north- east as also the islands of the Andaman-Nicobar group and Lakshdweep. The impact of regional monsoon on the foodgrain production of different states has been assessed making use of these data. Regression analysis for the production and area figures has been performed to get trend in these variables. Moving averages of these variables have been calculated to appreciate long term fluctuations.

In order to get an idea about the yearly fluctuation in production time series with respect to its maximum, the loss has been calculated using the following methodology:

1. National level production of all the foodgrains has been taken for 54 years, from 1950-2003.
2. For each year Y, the maximum production value P_m in the 7-year interval from Y-3 to Y+3 has been noted.
3. The difference between the production P of year Y and P_m is computed and expressed as a percentage "loss"; i. e. $(P_m-P)/P_m$ x 100%.

The approach assumes that no marked technological progress takes place during the seven year period. Similar analysis has been carried out for change in planted area. Correlation coefficients between production data and rainfall have been calculated to know the extent of association between them.

Results and Discussion

3.1 Trends in Foodgrain Production and Planted Area

There has been a rise in foodgrain production from about 50 million tonnes in 1950 to about 175 million tonnes in 2003. This is primarily due to increase in area under foodgrains and improvement in agricultural technology and policy. There is sharp fall in some years followed by rise (Fig. 1a). The sharp falls in the production are accounted for by bad monsoon. On an average, rice contributed 40% of the total foodgrain production consistently and is the single largest contributor to the production (Fig. 2a). The contribution of wheat has increased by threefold, while pulses have declined. The coverage of area under irrigated wheat crop has increased significantly and other crops have depicted a very slow increase over time (Fig. 2b).

Fluctuations are eliminated in moving average (7 year) line which shows nearly monotonous trend (Figs. 1a & 1b). However, moving average line is not straight suggesting that increase in the production is not uniform over years. The regression line shows a marked increasing trend in the production of foodgrains (Fig. 1a & 1b). The increase in the production is the result of increase in area and improvement in agricultural and allied technologies.

There is overall increase in area under foodgrains production from 1950 to 2003 (Fig. 1b). There has been a peak in early 1980s; since then there is a decline in the area under foodgrains. Some years have experienced a sharp fall in the area, which is accounted for bad monsoon conditions. Fluctuations in area planted disappear when one takes 7 year moving average (Fig. 1b).

Fig. 1a All India Foodgrain Production

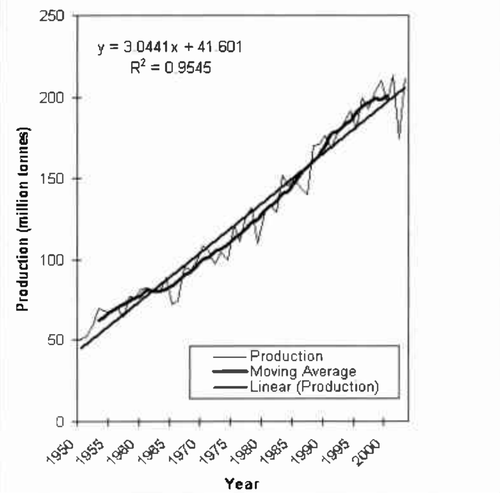


Fig. 1b All India Planted Area under Foodgrain

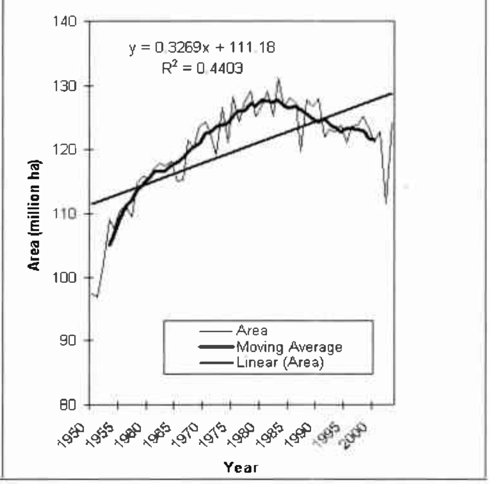


Fig. 2a Percentage Contribution of Major Crops to Total Foodgrain Production

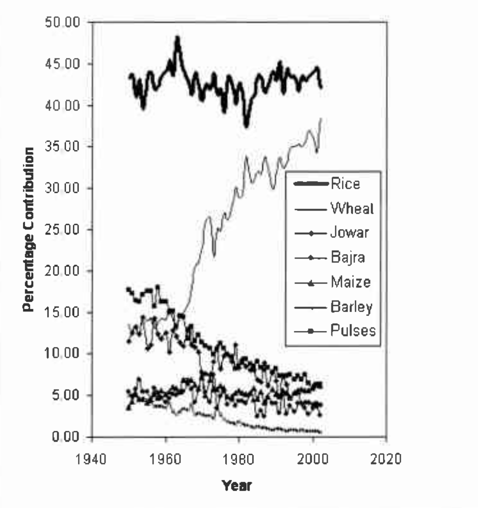
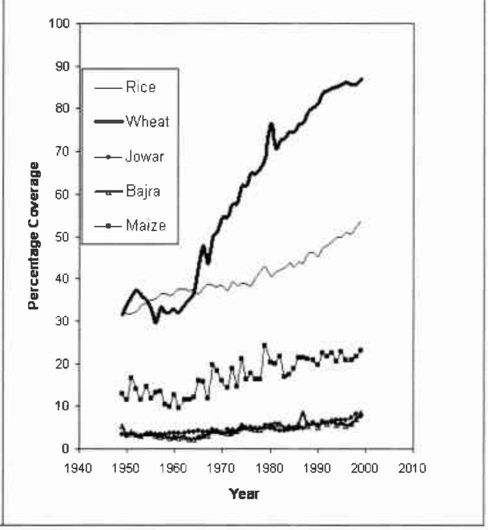


Fig. 2b Percentage Coverage of Major Crops under Irrigation



Moving average does not run straight, which suggests that increase in the area is not uniform over the years.

After early 1980s, there is a fall in the area under foodgrains. This is due to many factors including encroachment of agricultural area by the cities or switching over to crops other than foodgrains; there is also a shift from extensive to intensive farming. The linear trend line shows a slight

Table 1 : Correlation Coefficient between AISMR Anomaly and Yield of Foodgrains in Different States of India (**Note**: Bold values are significant at 5% level.)

	Loss in Area (%)	**Area Residuals**	**Loss in Production (%)**	**Production Residuals**	**AISMR (cm)**	**Departure in AISMR**
Loss in Area (%)	1.00					
Area Residuals	-0.54	1.00				
Loss in Production (%)	0.73	-0.23	1.00			
Production Residuals	-0.58	-0.16	-0.82	1.00		
AISMR (cm)	-0.68	0.21	-0.71	0.74	1.00	
Departure in AISMR	-0.70	0.22	-0.72	0.75	0.99	1.00

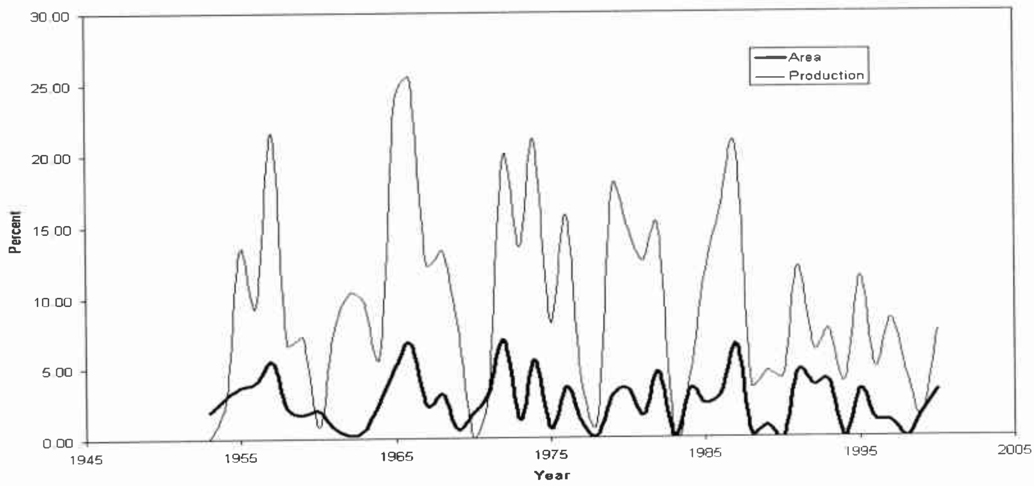
increase in the area under foodgrain (Fig. 1b). Between 1950 and 1960, there are negative residuals followed by positive residuals till late 1980s and then again negative residuals till 2003. The observed increase in planted area is due to impact of green revolution between 1960s and late 1980s.

3.2 Decline in Foodgrain Production and Planted Area

It is evident that loss of foodgrain production varies from 0 to about 25% (Fig. 3). Loss in area under foodgrains varies from 0 to only about 7% (Fig. 3). This depicts that production undergoes larger fluctuation than that in area. This is primarily due to the fact that the former is an ex post phenomenon while the latter is ex ante. The farmer is not in a position to take a decision in advance to reduce the area under cultivation and production is left to subsequent behaviour of monsoon rain, other factors remaining the same. It is not only the reduction in area that affects production but also lowering of productivity due to failure of monsoon rain. A comparison of the loss in area and production shows that there is a general coincidence between losses in the two (Fig. 3). However, it is not perfect as indicated by the value of r =0.73 (Table 1).

The percent loss in foodgrain production in India is negatively related with AISMR; this is confirmed quantitatively by value of r = -0.71 (Table 1). This is quite explicable as failure of rains is related to failure in production. The percentage loss in planted area under foodgrains is also negatively related with AISMR and is confirmed quantitatively by r = -0.68 (Table 1). This is quite explicable as failure of rains results in failure of the farmer in planting the intended area. The same trend is indicated when production and area losses are regressed against moving departure of AISMR from normal and one finds slight improvement in the values of r (Table 1). Moving departure from normal has been calculated by taking normal of sliding window of seven years. Hereafter for simplicity the moving

Fig. 2 : Precent Loss in Area and Production of Foodgrains in India



departure of AISMR from normal is termed as 'departure of AISMR from normal'. This suggests that area and production are more related to departure in rainfall rather than rainfall amount by itself.

There is only a slight quantitative improvement in correlation coefficient when the production and area residuals are regressed against the percent departure of AISMR from normal; moreover, the relation turns out to be positive (Table 1). It suggests that residuals in area and production are directly influenced by the departure of rainfall as is clear from the values of r (Table 1). This is primarily due to the fact that there is higher dependency of residuals with the departure from normal rainfall

It is noteworthy that the relationships between production residuals, on the one hand, and, losses in area under foodgrains and production of foodgrains, on the other, are negative (Table 1). Higher residual values for production are suggestive of higher production and vice versa. The higher value for losses, on the other hand, reflects on lower production or area. The residual values are, therefore, bound to be related negatively to production and planted area losses. The relationship to the latter is weak.

3.3 Regional Impact

Climatic extremes do not affect all the regions equally because of the vastness of our country and variability in their nature. In fact, whenever there is flood situation in one region, the other is affected by drought; the remaining experience normal conditions. In addition to AISMR, the Regional Monsoon Rainfall (RMR) might be a good indicator to study the impact at regional level. The regional impact has, therefore, been analysed in terms of AISMR and RMR anomalies on agricultural yield of different states of India. The following are the important findings: The impact of AISMR anomaly on yield of foodgrains for different states has been analysed by working out correlation co-efficient. It is evident that yield of foodgrains in states of India is not significantly related

Table 2 : Correlation Matrix for the Production, Area and AISMR Variables

State	Yield	Change in Yield (%)	Residual of Yield
Andhra Pradesh	0.07	**0.43**	0.15
Bihar	-0.06	0.17	0.07
Gujarat	0.29	**0.65**	**0.64**
Haryana	0.23	0.10	0.26
Himachal Pradesh	-0.22	0.05	-0.13
Karnataka	-0.19	-0.03	0.08
Kerala	-0.13	0.20	0.08
Maharashtra	0.00	0.04	0.33
Madhya Pradesh	0.35	**0.43**	**0.53**
Orissa	-0.20	0.23	0.10
Punjab	-0.08	0.13	0.06
Rajasthan	0.20	0.32	**0.48**
Tamil Nadu	-0.03	**0.45**	0.33
Uttar Pradesh	-0.07	0.10	0.16
West Bengal	-0.08	0.14	0.23

to AISMR anomalies (Table 2). This is explicable on the basis that the AISMR anomalies are not equally spread over all the states of India. However, the percentage change in the yield over that of the previous year has depicted significant relationship with AISMR anomalies for some states. Andhra Pradesh, Gujarat, Madhya Pradesh and Tamil Nadu have shown significant relation between percentage change in the foodgrain yield and AISMR anomalies. This is probably because these states are rice growing states and rice is the most vulnerable crop to rainfall extremes, being highly water intensive.

The statewise residuals of foodgrain yield have also been computed to test the relationship between them and AISMR anomalies for different states of India. The correlation coefficient between residual of agricultural yield and AISMR anomalies have been found significant for a few states (Table 2). Gujarat, Madhya Pradesh and Rajasthan have shown significant correlation between residual of agricultural yield and AISMR anomalies. Since this type of analysis eliminates influence of other maturation effects, it suggests that these three states have failed to take mitigative measures when compared to the other states.

Correlation coefficients have also been computed for change in yield (percentage change in yield from that of the previous year) of major crops, viz. rice, wheat, bajra, jowar and maize for different states and AISMR anomalies (Table 3). It is evident that most of the states depict significant positive correlation at 5% level for the yield of rice. This is primarily because rice is a Kharif crop. In case of wheat, only Madhya Pradesh and Orissa show significant correlation; of these Orissa depicts inverse relationship. While the former is to be explained in terms of poor mitigating efforts, the latter is explained by absence of wheat as a major crop in Orissa. In the case of bajra, Rajasthan alone shows significant positive correlation, as it is the most important state growing the crop. For jowar and maize, Gujarat alone brings out positive correlation significant at 5% level. Thus the impact of AISMR anomalies is spatially extensive on the yield of rice.

Correlation coefficients between the yields of foodgrains, change in such yields for states over that of the previous year and residual of yields with the regional monsoon rainfall (RMR) anomaly, forhomogeneous monsoon region (Fig. 4) in which the state falls, have been computed. It is evident that most of the states do not show any significant correlation between the yield and regional monsoon rainfall anomaly (Table 4). Only Gujarat shows significant positive

Table 3: Statewise Correlation Coefficient between Change in Yield and AISMR anomalies for Different Crops

State	Rice	Wheat	Bajra	Jowar	Maize
Andhra Pradesh	**0.636**	0.101	0.144	-0.269	0.256
Bihar	0.245	0.058	NA	NA	-0.381
Gujarat	**0.575**	0.238	0.394	**0.567**	**0.473**
Haryana	**0.451**	0.156	0.392	0.105	0.354
Himachal Pradesh	**0.596**	0.238	NA	NA	0.075
Karnataka	0.158	0.331	0.167	0.129	0.164
Kerala	0.273	NA	NA	NA	NA
Maharashtra	**0.464**	0.378	-0.087	-0.062	NA
Madhya Pradesh	**0.466**	**0.484**	-0.002	-0.138	0.228
Orissa	**0.408**	**-0.402**	0.082	-0.016	0.057
Punjab	**0.507**	-0.107	-0.055	-0.384	0.003
Rajasthan	**0.610**	0.386	**0.508**	-0.044	0.308
Tamil Nadu	**0.537**	NA	0.395	-0.038	0.018
Uttar Pradesh	0.306	0.348	0.177	-0.063	-0.093
West Bengal	0.029	0.024	NA	NA	0.068

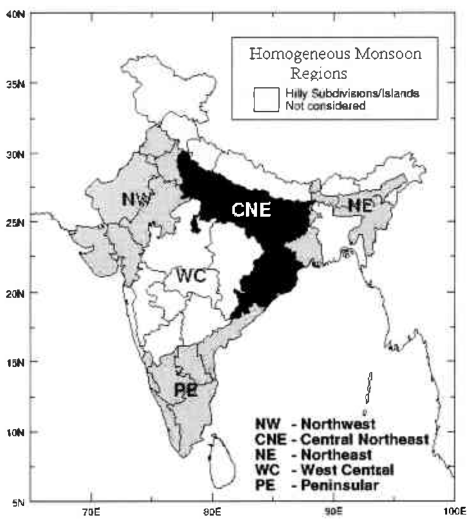


Fig. 4 : Homogeneous monsoon regions of India

correlation, indicating its vulnerability to fluctuations in rainfall. Andhra Pradesh, Gujarat and Madhya Pradesh depict significant correlation between change in the yield and regional monsoon rainfall anomaly. The number of states showing significant correlation increases to four when residual of the yield is correlated with regional monsoon rainfall anomaly. Such states reflect on their physical vulnerability to regional rainfall anomalies; for example, Gujarat, Haryana, Madhya Pradesh and Rajasthan, that have a significant drought prone segment.

Similar analysis has been carried out for major crops. Correlation coefficients between change in their yield with respect to previous year and regional monsoon rainfall (RMR) anomaly for different states of India have been worked out (Table 5). It is

Table 4 : Correlation Coefficient between RMR Anomaly and Yield, Change in yield and Residual of yield of Foodgrains for Different States of India

State	Yield	Change in Yield (%)	Residual of Yield
Andhra Pradesh	0.246	**0.448**	0.333
Bihar	0.011	0.138	0.105
Gujarat	**0.394**	**0.497**	**0.632**
Haryana	0.383	0.101	**0.396**
Himachal Pradesh	-0.072	0.117	-0.073
Karnataka	-0.134	0.077	-0.031
Kerala	-0.141	-0.031	-0.028
Maharashtra	-0.072	-0.034	0.247
Madhya Pradesh	0.278	**0.403**	**0.467**
Orissa	-0.046	0.299	0.080
Punjab	0.037	-0.016	0.089
Rajasthan	0.296	0.223	**0.470**
Tamil Nadu	0.009	0.298	0.352
Uttar Pradesh	-0.003	0.229	0.194
West Bengal	-0.050	0.346	0.011

evident that most of the states do not depict significant correlation between change in yield of various crops and regional monsoon rainfall anomaly. Rice is the only crop that shows significant correlation for states like Gujarat, Madhya Pradesh, Rajasthan, Punjab and Uttar Pradesh. Most of these areas grow rice despite rather unfavourable rainfall conditions. Wheat crop has shown significant correlation between regional monsoon rainfall anomalies and the change in the yield for only Madhya Pradesh. Only Rajasthan depicts the significant correlation between regional monsoon rainfall anomalies and change in bajra yield over previous year. Significant positive correlation has been observed between regional monsoon rainfall anomalies and change in jowar yield over previous year for only Gujarat. A significant negative correlation has been noticed between regional monsoon anomalies and change in maize yield over previous year only for Uttar Pradesh. It is evident that rice crop is most sensitive to the regional monsoon and needs proper management in its cultivation for food security and sustainable development.

Conclusion

From the foregoing analysis it is clear that both area and production of foodgrains have shown fluctuations from year to year. In secular terms, both of them increased upto mid-eighties; this shows emphasis on extension till that time; increase in production was at least partly related to increase in area. Thereafter, while area under foodgrains declined, production continued to increase suggesting improvement in

Table 5: Correlation Coefficient between Change in Yield of Major Crops and RMR Anomaly

State	Rice	Wheat	Bajra	Jowar	Maize
Andhra Pradesh	0.394	0.043	-0.113	-0.266	0.052
Bihar	0.355	0.323	NA	NA	-0.348
Gujarat	**0.521**	0.125	0.204	**0.604**	0.184
Haryana	0.330	-0.148	0.326	0.003	0.279
Himachal Pradesh	-0.192	0.035	NA	NA	-0.126
Karnataka	0.199	0.004	-0.074	0.137	-0.129
Kerala	-0.057	NA	NA	NA	NA
Maharashtra	0.133	0.270	-0.354	0.011	NA
Madhya Pradesh	**0.464**	**0.491**	0.008	-0.126	0.270
Orissa	0.298	-0.149	-0.112	-0.024	0.276
Punjab	**0.495**	-0.296	0.017	-0.368	-0.052
Rajasthan	**0.429**	0.226	**0.530**	-0.086	0.254
Tamil Nadu	0.230	NA	0.060	-0.073	-0.180
Uttar Pradesh	**0.654**	0.351	0.274	0.294	**-0.444**
West Bengal	0.286	0.219	NA	NA	-0.084

technology and policy. Decline in planted area and production shows periodicity. Fluctuation in area is less compared to that in production as the climatic extremes cannot be anticipated at the time of plantation but they show their impact at the time of harvest. Loss in planted area and foodgrain production are negatively related to AISMR and its anomaly; the correlation with the latter is stronger than that with the former. Production residuals show significant positive correlation with AISMR and its anomaly. Area residuals, on the other hand, show statistically insignificant correlation with the same. Production residuals are negatively related to losses in area under foodgrains and production of foodgrains.

Yield of foodgrains in individual state is not significantly related to AISMR anomalies for the simple reason that such anomalies are not equally spread over the whole of India. However, change in yield over the previous year depicts significant relationship with AISMR anomaly for some states; these states are primarily rice growing and the crop is highly vulnerable to rainfall extremes, particularly droughts. Statewise foodgrain yield residuals show significant relation with AISMR anomaly for a few states, which have failed to take mitigating measures. The relationship between change in yield and AISMR anomaly is significant in case of rice, which is most water intensive. In the case of other crops, the relationship is not very strong and only a few states stand out. Kharif crops are more vulnerable than Rabi crops; adequate planning for minimising the impact of climate extremes, especially on kharif crops, is essential. Rice, one of the important staple foods which occupies a major component of the Indian diet, is the most sensitive to climate extremes, and necessitates better planning and management to meet future demand. Enhancement of irrigation facility, forecasting of climate extremes well in advance and technological development for suitable variety of crops to minimise the negative impacts of these extremes are required for food security and sustainable development.

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