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Statistical analysis of Indian rainfall and rice productivity anomalies over the last decades

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ABSTRACT: Monsoon fluctuations have a reflective influence on rice productivity, which is the main foodgrain in India. The impact of El Niño on spatial variability of summer monsoon rainfall and thereby *kharif* rice productivity was analysed for the period 1974–2009. It was clear from the analysis that the delayed onset of monsoon along with El Niño has varied influences on rice productivity over different rice growing states as well as over India. Out of eight El Niño years, 6 years received deficit rainfall during monsoon season. But, the quantity of deficit varies from −20.3% in 2002 to −5.5% in 1991. The monthly distribution of monsoon rainfall shows higher frequency of deficit occurred during July and September. Interestingly, all El Niño years, except in 1997, September received deficit in rainfall which indicate the early withdrawal of monsoon. During 8 moderate and strong El Niño years, 5 years the *kharif* rice productivity falls below the technological trend ranging by between −4.3% in 1986 and −13.8% in 2002 over India. There exists a wide spatial variability of normalized *kharif* rice productivity anomaly during moderate El Niño event, with a maximum of −21.9% over Gujarat followed by −15.9% at Maharashtra. However, during the strong El Niño event, there is a maximum of −14.2% at Bihar to −6.6% over Maharashtra. The correlation between normalized monthly rainfall anomaly and rice productivity anomaly during the El Niño years indicated that July rainfall contributed 71% of the variations in rice productivity. Analysis of El Niño impact on spatial rice productivity may be useful for formulating farm-level site specific management planning and policy decisions.

KEY WORDS El Niño; India; monsoon; normalized *kharif* rice productivity anomaly; normalized rainfall anomaly; sea surface temperature; triennium

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1. Introduction

The inter-annual variability of Indian summer monsoon rainfall has been linked to variations of sea surface temperatures (SST) over the equatorial Pacific and Indian Oceans, Eurasian snow cover, etc. (Sikka, 1980; Rasmusson and Carpenter, 1983; Bamzai and Shukla, 1999; Krishna Kumar *et al.*, 1999; Behera and Yamagata, 2001; Terray *et al.*, 2003; Gadgil *et al.*, 2004). The association between El Niño events and Indian monsoon has been studied by many researchers (Barnett, 1983; Mooley and Parthasarathy, 1984a, 1984b; Krishna Kumar *et al.*, 1999; Krishnamurthy and Goswami, 2000; Pai, 2003; Kane, 2005; Rajeevan and Pai, 2006). The Indian Ocean Dipole (IOD) and the El Niño have complimentarily affected the India Summer Monsoon rainfall during the last four decades and El Niño-induced anomalous circulation over the Indian region is either countered or supported by the IOD-induced anomalous meridional circulation cell (Ashok *et al.*, 2001). From the observed record, the El Niño-Southern Oscillation (ENSO)-IOD correlation is positive strong and significant since mid-60s and it may correspond with either strong or weak ENSO-monsoon relationship and with strong or weak IOD-monsoon relationship (Cherchi and Navarra, 2012). The link between ENSO and the monsoon is realized through vertical and horizontal addictions associated with the stationary waves in the upper troposphere set up by the tropical ENSO heating (Xavier *et al.*, 2007). The year-to-year variability in monsoon rainfall causes severe droughts and floods in one or other places in India (Kripalani *et al.*, 2003; Subash *et al.*, 2011). Frequent occurrence of the fluctuating nature of the Indian monsoon affects the agriculture, power generation, water resources and even in financial sectors. The spatio-temporal variability of monsoon rainfall variability leads to large scale droughts/floods in one or other part of India and thereby influence the total foodgrain production (Parthasarathy and Pant, 1985; Parthasarathy *et al.*, 1992a, 1992b; Gadgil *et al.*, 1999) and food security and economic situation of the country (Gadgil and Gadgil, 2006; Chand and Raju, 2009; Krishna Kumar *et al.*, 2010). Rice harvests in India and other parts of Asia are positively correlated with rainfall (Webster *et al.*, 1998; Kumar *et al.*, 2004). On the basis of statistics and simulation techniques confirmed the usefulness of the standard summary measure of the strength of the monsoon, total June–September rainfall for predicting rice yield and it

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is significantly correlated with rice yield (Auffhammer *et al.*, 2012). Variability in India's agricultural output is largely driven by the year-to-year fluctuations in the strength of the summer monsoon (June–September) rains, which accounts for over 75% of the annual precipitation over India, except Tamil Nadu (Chand and Raju, 2009). Although, severe droughts in India have been associated with El Niño events, El Niño does not always produce droughts (Krishna Kumar *et al.*, 2006; Maity and Kumar, 2006). A linkage between agricultural production and El Niño has been studied by several researchers in India and abroad (Parthasarathy *et al.*, 1988; Cane *et al.*, 1994, Gadgil, 1996; Hansen *et al.*, 1998; Phillips *et al.*, 1998; Zubair, 2002; Selvaraju, 2003; Rao *et al.*, 2011). However, a detailed investigation of the consequences of El Niño on spatial variability of rainfall and quantification of its influence on *kharif* rice productivity are lacking. In this study, we have investigated the statistical analysis of Indian rainfall, effect of El Niño on spatial variability of rainfall and its influence on *kharif* rice productivity over major rice growing states of India.

2. Data and methodology

2.1. Monsoon onset date

The onset of Asian monsoon can be considered as having two phases, one with a rainfall surge over South China Sea and the other with increased rainfall over India (Wang and Lin, 2002). There are a number of techniques to identify the onset of Asian monsoon (Tanaka, 1992; Wang and Wu, 1997; Wang *et al.*, 2004; Zeng and Lu, 2004). In 2006, India Meteorological Department adopted new criteria for declaring the monsoon onset over Kerala (MOK) operationally. These criteria use the information on rainfall and large scale circulation patterns as by Joseph *et al.* (2006). On the basis of this criterion, the dates of MOK during the period 1974–2009, reported by Pai and Rajeevan (2007) and by the India Meteorological Department (www.imd.gov.in) were used for the analysis. The inter-annual variability, standard deviation, coefficient of variation (CV) and trend of date of MOK during the study period were analysed.

2.2. Rainfall data

The monthly rainfall data series during 1974–2009 of 14 important rice growing states, available from the website of Indian Institute of Tropical Meteorology (www.tropmet.ac.in) was used in this study. They have considered 276 rain gauge stations well distributed over these States for preparing this data series, one from each of the districts which is the smallest administrative area and area-weighted mean monthly rainfall of all the meteorological sub-divisions as well as for the whole country by assigning the district area as the weight for each representative rain gauge station. The data for various periods were collected from different sources of publications from Government sources and the India Meteorological Department (Mooley *et al.*, 1981). They have also tested the nature of the frequency distribution of the chi-square statistic with 10 equal probability class-intervals (Cochran, 1952). Mooley and Parthasarathy (1984a, 1984b), Parthasarathy *et al.* (1987, 1990, 1992a, 1992b, 1993, 1994, 1995), Pant and Rupakumar (1997), Mooley *et al.* (1981) provided a more detailed discussion of the methodology adopted for quality, completeness and homogeneity of these data sets.

2.3. Trends methodology

Mann–Kendall (Mann, 1945; Kendall, 1975) is a nonparametric trend test basically involves the ranks obtained by each data in the data series and is a statistical yes/no type hypothesis testing procedure for the existence of trends and does not estimate the slope of trends. The Mann–Kendall nonparametric test, as described by Sneyer (1990), was applied in order to detect trends. The Mann–Kendall test has been widely used by several researchers to detect trends in hydrological time series data (Wilks, 1995; Serrano *et al.*, 1999; Brunetti *et al.*, 2000a, 2000b; Onoz and Bayazit, 2003; Luo *et al.*, 2008; Pal and Al-Tabbaa, 2010). The magnitude of the trends was estimated using Sen Slope (Sen, 1968) and according to Hirsch *et al.* (1982) Sen's method was robust against extreme outliers. The procedures and equations for Mann–Kendall test statistic and Sen's methodology were described by Bandyopadhyay *et al.* (2009) and Subash *et al.* (2011).

2.4. Rice productivity data

The area, production and productivity of *kharif* rice over different states from 1974 to 2009 was taken from the Directorate of Rice, Ministry of Agriculture, Government of India and is available online at http://www.dacnet.nic.in. Since long-term yield data is not readily available for Jharkhand, Chhattisgarh and Uttarakhand states, the analysis has been done for undivided Bihar, Madhya Pradesh and Uttar Pradesh states. The major and minor rice growing states are depicted in Figure 1 and this study is restricted only in 14 major rice growing states. The production of rice depends on non-meteorological parameters such as type of seeds used, crop area, availability of irrigation facilities, fertilizers, pesticides and also on the government incentives to the farming sector during the year as well as the previous year and meteorological parameters such as rainfall, temperature, relative humidity and solar energy. The total non-meteorological parameters, i.e. the total technological inputs to the farming sector have been growing steadily and are difficult to quantify. Therefore, to know the pattern of trends and to quantify the growth rate of total technological inputs to the agricultural sector the actual yield was fitted into linear model.

To normalize the yield and rainfall data, the following indices were used.

The Normalized Rice Productivity Anomaly (NRPA) was taken as the percentage of the technological trend

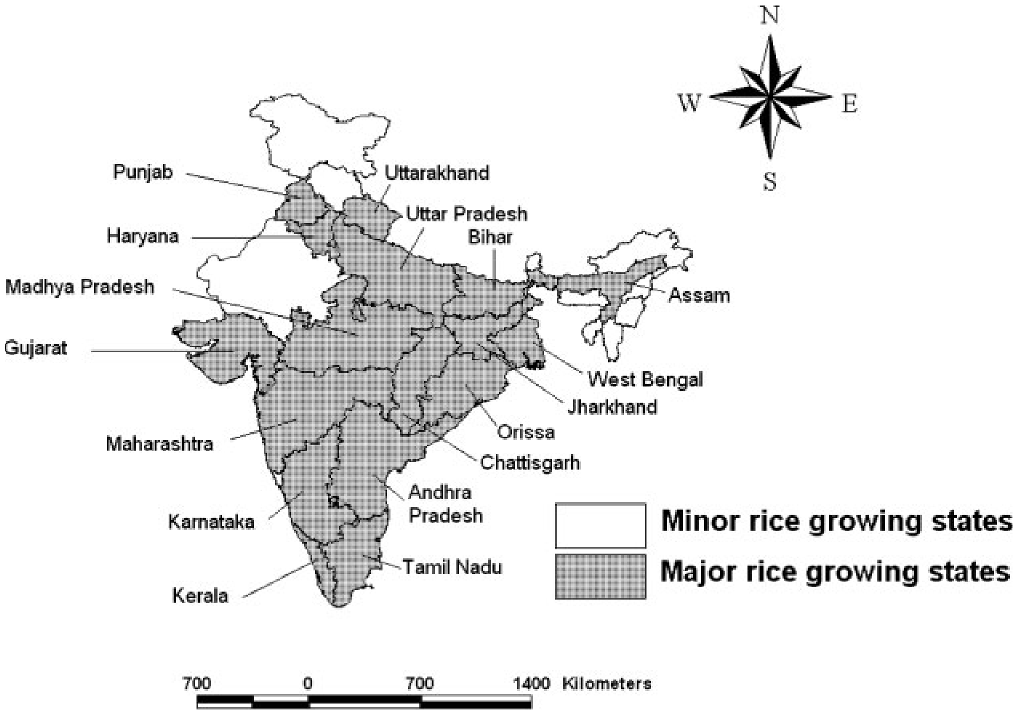

Figure 1. Location of major rice growing states of India.

productivity to the actual product. The NRPA for the ith year is

$$\mathrm{NRPA}i = \frac{(P_i - TP_i) * 100}{TP_i} \tag{1}$$

where NRPA_i is the normalized rice productivity anomaly for the ith year, P_i is the actual productivity for the ith year and TP_i is the technological trend productivity for the ith year.

The Monthly Rainfall Anomalies (MRA) during June to September was computed by taking the monthly rainfall in terms of percentage deviation from its mean. The monthly rainfall anomaly for any month is expressed as

$$Ra_i = \frac{(R_i - R) * 100}{R} \tag{2}$$

where Ra_i is the monthly rainfall anomaly for the ith year, R_i is the monthly rainfall for the ith year and R is the mean monthly rainfall.

2.5. El Niño identification

Oceanic Niño Index (ONI) has become the accepted criteria that NOAA uses for identifying El Niño (warm) and La Niña (cool) events in the tropical Pacific (Jan Null, 2011). It is the running 3-month mean SST anomaly for the Niño 3.4 region (i.e. 5°N–5°S, 120°–170°W). Events are defined as 5 consecutive months at or above the $+0.5^\circ$ anomaly for warm (El Niño) events and at or below the -0.5 anomaly for cold (La Niña) events. The threshold is further broken down into weak (with a 0.5 to <1.0 SST anomaly), moderate (1.0 to <1.5) and strong (≥ 1.5) events. For the purpose of this study for an event to be categorized as weak, moderate or strong it must have equaled or exceeded the threshold for at least 3 months. The time series of the 3-month Nino Region 3.4 average ONI is given in Figure 2. Accordingly the El Niño years were classified during the study period (Table 1). There were four moderate and four strong El Niño events, out of 36 years study period.

3. Results and discussion

3.1. Observed variability in onset of monsoon and El Niño

The time series of date of monsoon onset over India during the period 1974–2009 is shown in Figure 3. The average date of monsoon onset over India was 2nd June with a standard deviation (SD) of about 7 days. During this period, the extreme dates of onset of monsoon over Kerala were 18 May 1990 and 13 June 2003. The CV of 42.9% showed higher inter-annual variability and about 31% of the years (11 years) the date of monsoon onset took place under earlier/late (±1 SD) category. Interestingly, no definite trend has been observed for the date of monsoon onset over India during the study period. Similarly, no specific trends of the relationship between El Niño and date of monsoon onset have been found during the study period. However, Xavier *et al.* (2007) reported that El Niño years shrinking the monsoon season by delaying the onset and advancing the withdrawal during study period 1950–2003 and also explained the physical mechanism behind the delay of onset of monsoon under El Niño year. The reason for this contradictory nature of the results may be due to the difference in the period considered. In our study,

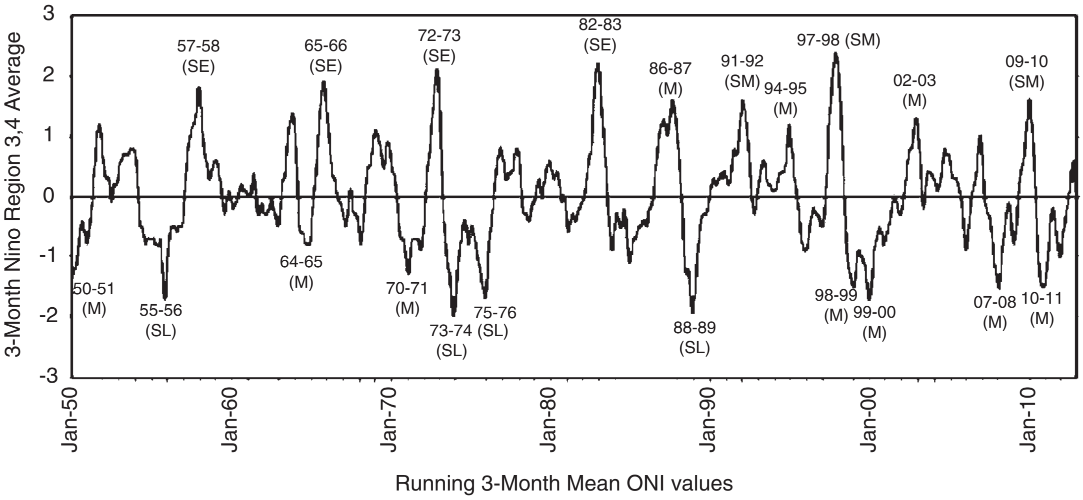

Figure 2. The time series of the 3-month Nino Region 3.4 average ONI. Adopted from http://www.cpc.noaa.gov/products/analysis_monitoring/ensostuff/ens.

Table 1. Years associated with El Niño and La Niña based on the sea surface temperature in the NINO3.4 region of the equatorial Eastern Pacific Ocean.

El Niño			La Niña		
Weak	Moderate	Strong	Weak	Moderate	Strong
1951	**1986**	1957	1950	1954	1955
1963	**1987**	1965	1956	1964	1973
1968	**1994**	1972	1962	1970	1975
1969	**2002**	**1982**	1967	1998	1988
1976		**1991**	1971	1999	
1977		**1997**	1974	2007	
2004		**2009**	1984	2010	
2006			1995		
			2000		

Figures in bold indicate the ENSO events during the study period 1974–2009.

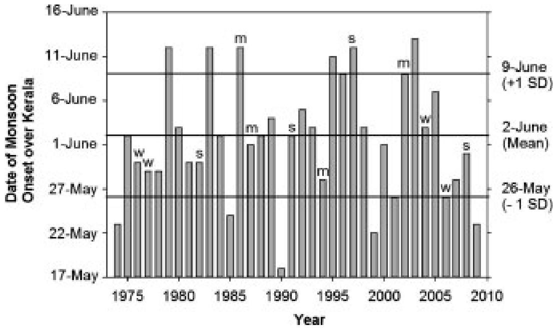

Figure 3. Inter-annual variability of onset of monsoon over Kerala and ENSO events (w, weak; m, moderate; s, strong ENSO).

all the four weak El Niño event years, the monsoon reached over the Kerala coast within the normal period (2 June ± 7 days) and out of eight moderate and strong El Niño years, only 2 years (1986 and 1997) the date of monsoon onset delayed. Since the arrival of monsoon is crucial for farmers to plan their farm management strategies during the *kharif* season, during El Niño years precautionary contingency measures should be prepared for timely sowing/transplanting of rice crop. A delay in the date of onset of monsoon over Kerala does not necessarily mean a delay in monsoon onset over NW India (Pai and Rajeevan, 2007). However, delayed date of onset of monsoon during the two El Niño years affected the monsoon rainfall in a dissimilar way over India (Table 2). Even though, there is −10.6% deviation of monsoon rainfall over India in 1986 (moderate El Niño), there was a wide variety of −48.2% over Gujarat to 9.2% over Orissa. All the states, except Orissa, received less rainfall during monsoon season. The distribution pattern showed a high deficit of 30.2% during September over India. The spatial variability of distribution of rainfall indicates that all the states, except West Bengal, received deficit rainfall during September. During strong El Niño and delayed onset caused no deficit in total monsoon rainfall over India. However, a maximum deficit of −18.9% occurred over Maharashtra and a maximum surplus of 39.6% occurred over Gujarat.

3.2. Spatial and temporal variability of monsoon

There exist a large scale spatial and temporal variability of annual rainfall in major rice growing states of India (Table 3). Kerala receives a high annual rainfall of 2753.7 mm followed by 2268.2 mm at Assam. However, the low annual rainfall of 585 mm received at Haryana followed by 671.4 mm at Punjab. Even though the CV of annual rainfall over India stands at 9%, wide spatial variability of 12% at West Bengal and Karnataka to 30% at Gujarat have been observed. The seasonal cycle indicates that all the states, except Tamil Nadu, receive higher rainfall during the monsoon season. Similarly, the CV during monsoon season is lower compared to all other seasons in all these states. It is also clear that the monthly distribution during the monsoon season shows all these states, except Andhra Pradesh, Orissa, Karnataka, Madhya Pradesh and Kerala, receive higher rainfall during the month of July which coincides with the sowing/transplanting window in these states for rice

Table 2. Variation of monthly rainfall anomalies during delayed onset and ENSO event years and its relation to normalized *kharif* rice productivity anomaly over important rice growing states and India.

S. no.	Important rice growing states	1986 – moderate ENSO						1997 – strong ENSO					
		June	July	August	September	Mon	KRPI	June	July	August	September	Mon	KRPI
1	West Bengal	−5.9	−13.5	−20.1	38.9	−2.2	−9.75	17.2	−0.9	11.0	3.3	6.9	3.81
2	Andhra Pradesh	−8.9	−23.7	26.8	−29.3	−8.3	−14.13	−45.1	−33.3	−36.5	68.5	−8.3	−11.58
3	Uttar Pradesh	−12.4	−11.5	−12.8	−40.8	−18.2	−3.21	−14.2	21.2	−14.8	5.3	1.8	16.88
4	Punjab	62.0	−28.6	−7.2	−56.9	−14.9	8.77	−2.0	−27.5	54.7	−64.6	−5.5	−0.72
5	Orissa	41.2	31.0	−10.8	−21.1	9.2	−1.03	5.9	−12.8	61.0	−5.2	16.0	10.01
6	Karnataka	−1.3	−39.3	12.6	−17.9	−12.1	−3.21	−11.5	21.1	24.2	−41.0	2.8	1.08
7	Tamil Nadu	−35.2	−29.3	2.8	−18.7	−17.7	1.02	11.2	2.8	−33.4	−13.9	−11.9	1.59
8	Assam	−34.3	−21.2	−13.4	−1.1	−19.0	−8.49	26.6	−19.3	−22.8	23.4	0.6	1.66
9	Bihar	−9.1	6.5	−25.7	−16.6	−10.2	10.43	43.4	16.9	25.6	−21.2	16.2	7.58
10	Haryana	14.8	−58.1	−34.2	−33.0	−35.7	3.63	39.0	−41.1	34.4	−60.6	−8.2	17.04
11	Maharashtra	11.7	−17.8	9.9	−41.6	−8.9	−23.18	−22.4	−18.4	−14.3	−21.9	−18.9	3.76
12	Madhya Pradesh	55.6	17.1	−22.0	−53.8	−2.0	−10.14	−12.2	8.1	9.0	0.1	3.7	−12.13
13	Gujarat	36.8	−68.9	−50.0	−97.9	−48.2	−30.56	207.5	−32.9	25.6	45.5	39.6	3.74
14	Kerala	−5.7	−45.3	−2.8	−4.4	−17.3	−3.61	−4.3	47.9	35.0	29.6	24.6	−3.92
	India	7.5	−9.2	−11.3	−30.2	−10.6	−4.27	9.6	−1.1	9.3	3.2	4.9	2.47

Table 3. Season-wise mean rainfall (mm) and its coefficient of variation (CV) (%) over important rice growing states and India.

S. no.	Important rice growing states	Winter		Summer		Monsoon		Post-monsoon		Annual	
		Mean	CV	Mean	CV	Mean	CV	Mean	CV	Mean	CV
1	West Bengal	31.2 (1.5)	61	278.4 (13.5)	23	1594.2 (77.2)	13	160.3 (7.8)	47	2064.1	12
2	Andhra Pradesh	16.6 (1.8)	110	71.9 (8.0)	65	562.4 (62.5)	24	248.9 (27.7)	33	899.6	15
3	Uttar Pradesh	31.1 (3.3)	75	40.2 (4.3)	59	818.9 (88.0)	21	40.8 (4.4)	92	930.9	18
4	Punjab	56.9 (8.5)	61	65.5 (9.7)	63	522.4 (77.8)	35	26.7 (4.0)	98	671.4	26
5	Orissa	28.7 (2.0)	72	135.8 (9.3)	57	1146.6 (78.7)	18	144.9 (10.0)	67	1456.1	17
6	Karnataka	4.6 (0.3)	126	138.6 (8.1)	50	1357.3 (79.6)	15	204.7 (12.0)	34	1705.2	12
7	Tamil Nadu	36.4 (3.9)	139	123.0 (13.1)	47	309.9 (33.0)	25	469.1 (50.0)	30	938.4	18
8	Assam	51.0 (2.2)	59	567.0 (25.0)	23	1456.8 (64.2)	17	193.4 (8.5)	44	2268.2	14
9	Bihar	30.7 (2.4)	76	103.6 (8.0)	34	1065.1 (82.8)	16	87.5 (6.8)	63	1286.9	14
10	Haryana	36.4 (6.2)	67	53.2 (9.1)	71	475.5 (81.3)	33	19.8 (3.4)	114	585.0	27
11	Maharashtra	14.4 (1.6)	94	36.6 (4.1)	65	728.6 (82.5)	19	103.5 (11.7)	59	883.1	17
12	Madhya Pradesh	26.6 (2.4)	82	33.7 (3.1)	58	979.5 (89.1)	16	58.9 (5.4)	65	1098.7	15
13	Gujarat	4.0 (0.6)	166	10.3 (1.5)	163	651.5 (93.2)	34	33.2 (4.8)	115	698.9	30
14	Kerala	26.7 (1.0)	113	368.1 (13.4)	39	1848.9 (67.1)	18	510.0 (18.5)	29	2753.7	13
	India	22.5 (2.1)	49	97.5 (9.1)	22	830.8 (77.4)	10	123.1 (11.5)	24	1073.9	9

The numbers in parenthesis indicate the percent contribution to annual rainfall.

Table 4. Monthly distribution of monthly mean rainfall (mm), standard deviation (SD) (mm) and coefficient of variation (CV) (%) over important rice growing states and India.

S. no.	Important rice growing states	June		July		August		September	
		Mean ± SD	CV	Mean ± SD	CV	Mean ± SD	CV	Mean ± SD	CV
1	West Bengal	345.5 ± 73.6 (16.7)	21	503.9 ± 74.8 (24.4)	15	400 ± 99.8 (19.4)	25	344.8 ± 102.2 (16.7)	30
2	Andhra Pradesh	100.3 ± 44.6 (11.1)	44	148.1 ± 62.4 (16.5)	42	159.4 ± 56 (17.7)	35	154.6 ± 65.4 (17.2)	42
3	Uttar Pradesh	116.5 ± 63.3 (12.5)	54	278.2 ± 87.7 (29.9)	32	251.9 ± 72.6 (27.1)	29	172.3 ± 72.8 (18.5)	42
4	Punjab	70.9 ± 51.5 (10.6)	73	193.3 ± 103.1 (28.8)	53	161.5 ± 74.2 (24.0)	46	96.7 ± 86.5 (14.4)	89
5	Orissa	219.1 ± 82.5 (15.0)	38	331.9 ± 103.4 (22.8)	31	369.2 ± 108.7 (25.4)	29	226.5 ± 80.8 (15.6)	36
6	Karnataka	421.9 ± 92.4 (24.7)	22	419.4 ± 102.6 (24.6)	24	320.8 ± 81.5 (18.8)	25	195.3 ± 86.1 (11.5)	44
7	Tamil Nadu	46.5 ± 30.5 (5.0)	66	63.2 ± 28.2 (6.7)	45	81.7 ± 34.8 (8.7)	43	118.5 ± 44 (12.6)	37
8	Assam	391.1 ± 97.7 (17.2)	25	441.9 ± 117.9 (19.5)	27	336 ± 90 (14.8)	27	287.9 ± 86.5 (12.7)	30
9	Bihar	197.9 ± 82.9 (15.4)	42	347.5 ± 83.4 (27.0)	24	296 ± 71 (23.0)	24	223.7 ± 77.3 (17.4)	35
10	Haryana	69.7 ± 36.4 (11.9)	52	175.3 ± 90.9 (30.0)	52	152.9 ± 80 (26.1)	52	77.6 ± 58.2 (13.3)	75
11	Maharashtra	153 ± 48.1 (17.3)	31	211.4 ± 59.1 (23.9)	28	206.2 ± 62.1 (23.4)	30	157.9 ± 77.7 (17.9)	49
12	Madhya Pradesh	161.4 ± 69.2 (14.7)	43	317.7 ± 68.9 (28.9)	22	331.5 ± 81.5 (30.2)	25	168.9 ± 77.7 (15.4)	46
13	Gujarat	118.3 ± 79.3 (16.9)	67	244.1 ± 113.4 (34.9)	46	195.8 ± 105.5 (28.0)	54	93.3 ± 79.1 (13.3)	85
14	Kerala	647.5 ± 186.2 (23.5)	29	578.7 ± 175.9 (21.0)	30	374.1 ± 114.6 (13.6)	31	248.5 ± 138.5 (9.0)	56
	India	165.3 ± 33.5 (15.4)	20	262.5 ± 37.7 (24.4)	14	240.6 ± 30.2 (22.4)	13	162.4 ± 34.2 (15.1)	21

The numbers in parenthesis indicate the percent contribution to annual rainfall.

Table 5. Percentage of trend from mean for monthly, seasonal and annual rainfall over major rice growing states during the study period.

S. no.	Important rice growing states	Percent deviation from mean					
		June	July	August	September	Monsoon	Annual
1	West Bengal	18.1	−5.8	17.0	4.6	5.0	6.0
2	Andhra Pradesh	−17.2	−47.2*	−9.4	8.8	−9.6	−3.8
3	Uttar Pradesh	39.3	−16.5	−14.7	−11.7	−12.9	−10.0
4	Punjab	46.9	−36.7	−51.8	−2.5	−32.8	−29.5
5	Orissa	29.2	33.1*	1.8	32.7	26.6*	30.5**
6	Karnataka	−6.2	−21.5	−29.0	−9.2	−11.8	−6.7
7	Tamil Nadu	10.1	−34.4	16.7	−35.5	−16.0	12.3
8	Assam	−6.6	−35.5**	−0.7	−19.2	−15.6	−3.6
9	Bihar	40.6	−15.8	17.9	−6.0	2.1	5.7
10	Haryana	53.8	−69.7*	−34.1	33.7	−28.1	−19.6
11	Maharashtra	6.2	0.9	−13.5	27.3	3.4	−1.1
12	Madhya Pradesh	14.6	8.3	−39.4**	−1.2	−12.2	−11.0
13	Gujarat	−6.5	50.4	−14.8	20.4	18.3	8.4
14	Kerala	−25.8*	−6.2	−35.3*	25.4	−14.7	−0.4
	India	14.3	−6.5	−13.2	6.5	−3.5	0.6

*, ** indicate statistical significance at 95% and 99% confidence level, respectively as per the Mann–Kendall test (+, increasing and −, decreasing).

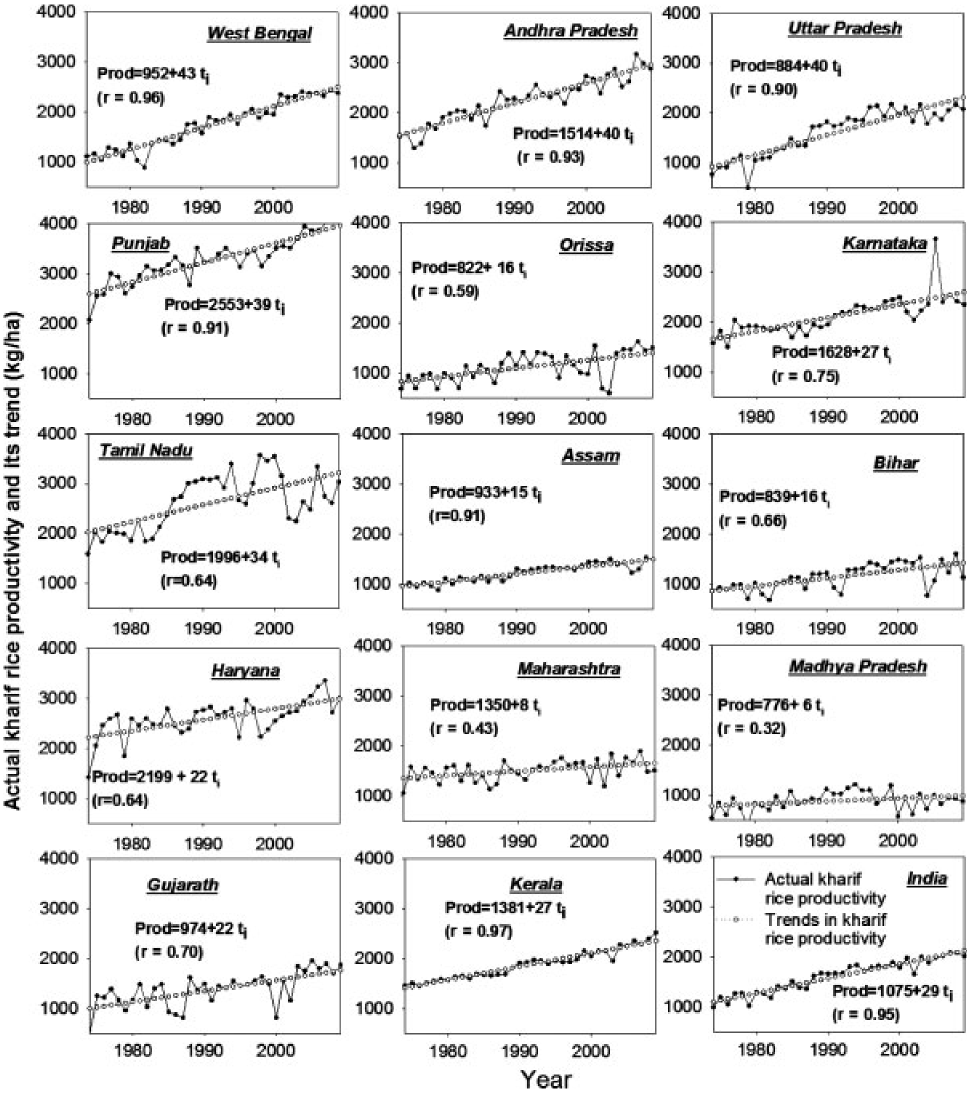

Figure 4. Variability of actual *kharif* rice productivity and its trends during the study period over major rice growing states as well as India.

(Table 4). During the middle of the season, during the last week of July/first week of August, most of the rivers/dams will normally be replenished. However, Andhra Pradesh, Orissa and Madhya Pradesh received the highest rainfall during August, shows the shift of rainfall pattern (Guhathakurta and Rajeevan, 2006). Interestingly, Karnataka and Kerala receive higher rainfall during June, which may be due to coincidence of pre-monsoon showers with monsoon rains.

3.3. Trends in monsoonal rainfall

The all India annual, monsoon and monthly rainfall for the monsoon months do not show any significant trend. But, large spatial variations observed over the states (Table 5). A significant increasing trend of 26.6 and 30.5%, respectively over normal rainfall has been observed during monsoon and annual rainfall over Orissa. The majority of states (Andhra Pradesh, Uttar Pradesh, Punjab, Karnataka, Tamil Nadu, Assam, Haryana, Madhya Pradesh and Kerala) shows decreasing trend in monsoon rainfall and only in five states, namely, West Bengal, Orissa, Bihar, Maharashtra and Gujarat show an increasing trend. June rainfall has shown decreasing trend for five states (Andhra Pradesh, Karnataka, Assam, Gujarat and Kerala) and significant decreasing trend of −25.8% over Kerala. But, July rainfall has decreased for most of

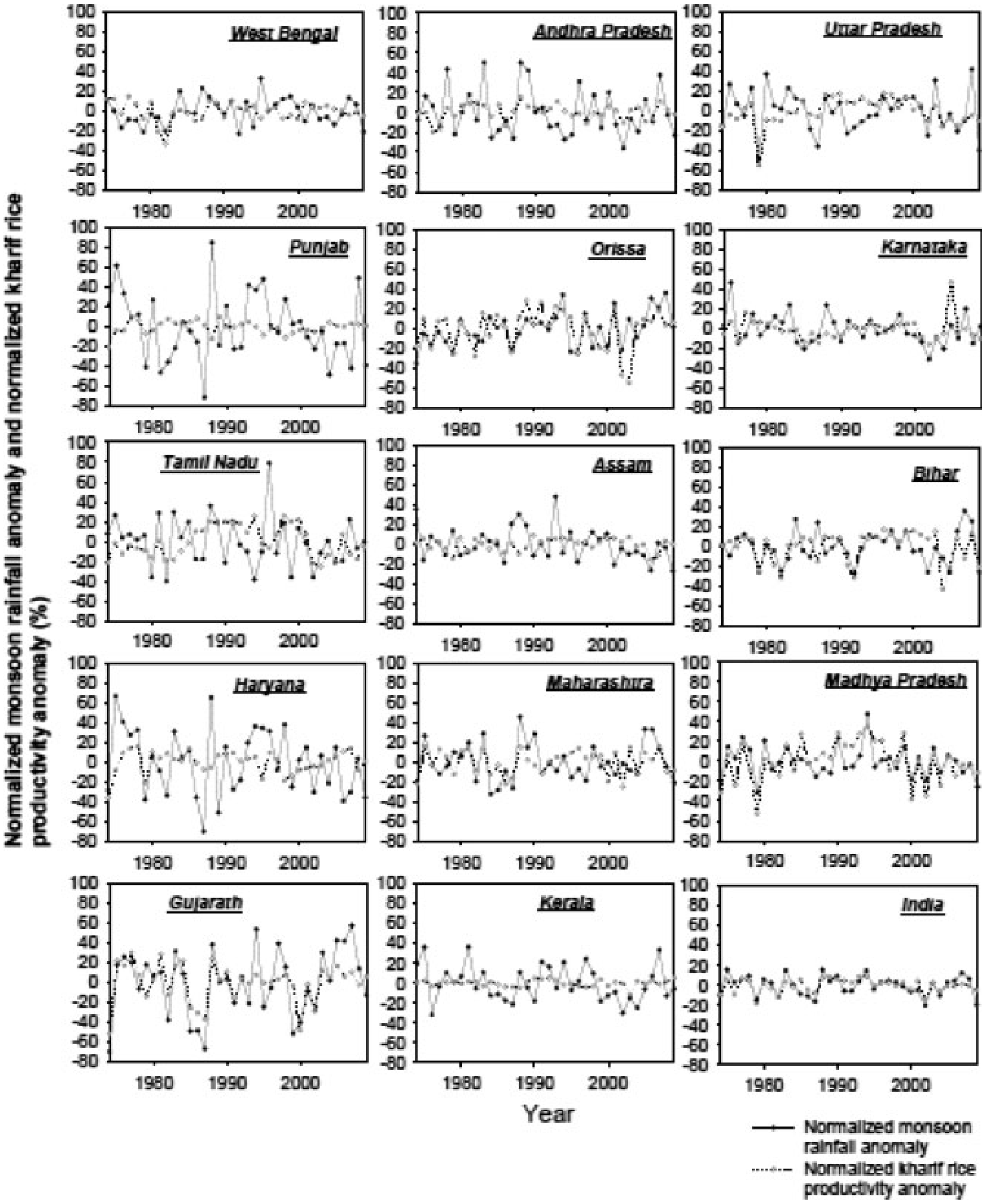

Figure 5. Variability of normalized monsoon rainfall anomaly and normalized *kharif* rice productivity during the study period over major rice growing states as well as India.

the states with significant decrease of −69.7 and −47.2%, respectively over Haryana and Andhra Pradesh. However, Orissa has shown a significant increasing trend of 33.1% during this period. Out of 14 states, 10 states show decreasing trend in rainfall in July and since July is the most important month as far as the rice crop is concerned and almost all the places the ‘sowing/transplanting window’ falls during this month and thereby decreasing trend in rainfall may be a threat to sustainable rice cultivation. A significant decreasing trend of −39.4 and −35.3%, respectively have been noticed over Madhya Pradesh and Kerala during August. However, no significant trend has been observed during September in any of the States. Interestingly, Karnataka and Assam show a decreasing trend in rainfall in all the four monsoon months. Andhra Pradesh, Uttar Pradesh, Punjab and Kerala show decreasing trend in rainfall in three consecutive monsoon month’s rainfall.

3.4. Relation between normalized rice productivity anomaly and normalized monsoon rainfall anomaly

The *kharif* rice productivity of all the states as well as India was fitted into the linear model (Figure 4). There exists a large inter-annual variability of normalized rice productivity anomaly in all the states (Figure 5). Interestingly, India as a whole, the anomaly confined within ±20%. However, in Punjab, Haryana, Uttar Pradesh, Andhra Pradesh and Gujarat, the anomaly reached above ±50% in some of the years. The relation between normalized rice productivity anomaly and normalized monsoon rainfall anomaly shows monsoon rainfall contributes 48% (squares of the correlation coefficient) variations in rice productivity over India. Despite 56% rice area being

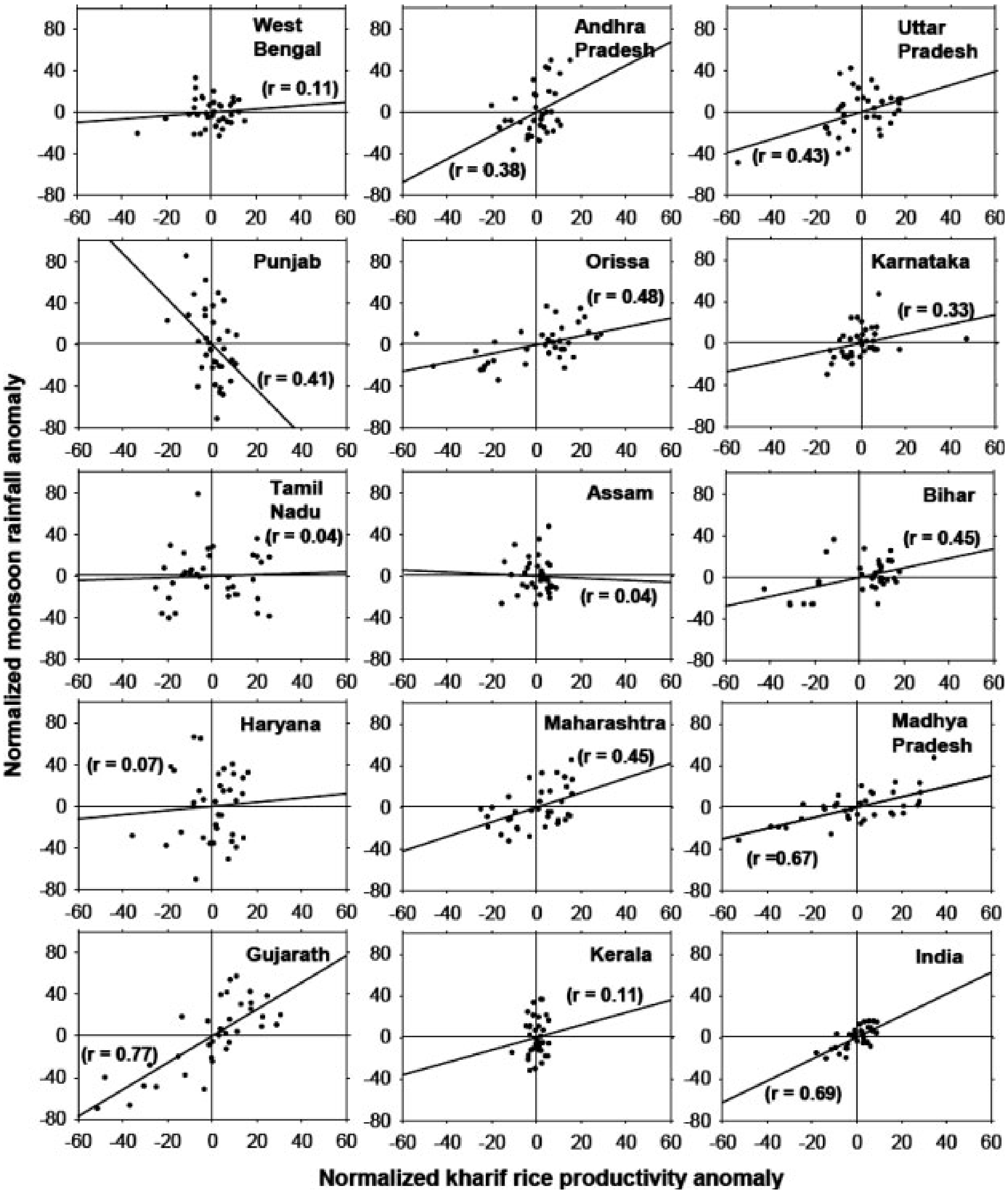

Figure 6. Relation between normalized monsoon rainfall anomaly and normalized *kharif* rice productivity anomaly over major rice growing states as well as India.

under irrigation in India, 48% contribution of monsoon rainfall to productivity indicates the importance of monsoon rainfall. However, this varies from states to states and no uniform relation exists between monsoon rainfall and rice productivity. This may be due to two reasons; one is the difference in percent of irrigated area as well as the irrigation facilities created in these states and the other is the variation of the crop growing period in these states. The percent area under irrigation in rice growing states varies from 4.6% in Assam to 99.9% in Haryana. Andhra Pradesh, Punjab, Tamil Nadu has more than 90% and Uttar Pradesh and Karnataka have more than 70% irrigated area. This may be the reason for the large variation of correlation coefficients between productivity and monsoon rainfall anomaly (Figure 6). In some states, especially, Punjab, Haryana and Assam got a negative relationship with monsoon rainfall.

3.5. El Niño and spatial variability of monsoon rainfall

As far as India is concerned, out of 8 El Niño years, 6 years received deficit rainfall during monsoon season. But the quantity of deficit varies from −20.3% in 2002 to −5.5% in 1991 (Tables 6 and 7). The monthly distribution of monsoon rainfall shows higher frequency of the deficit during July and September. Interestingly, all El Niño years, except in 1997, September received deficit in rainfall which indicate the early withdrawal of monsoon. The spatial variability of rainfall during moderate and strong El Niño years indicates that there exists a wide variation. During moderate El Niño years, Andhra Pradesh, Uttar Pradesh and Tamil Nadu received deficit monsoon rainfall in all the years and Karnataka, Assam, Haryana, Punjab, Maharashtra, Madhya Pradesh, Gujarat and Kerala received deficit monsoon in 3 years (Table 8). During strong El Niño years, the scenario is different and Punjab, Haryana and Maharashtra received deficit monsoon rainfall in all the years while Andhra Pradesh, Tamil Nadu, Bihar, Madhya Pradesh and Gujarat received deficit monsoon in 3 years. The monthly distribution pattern also shows no clear trend in deficit rainfall during moderate and strong El Niño years. However, Andhra Pradesh received negative rainfall anomaly in

Table 6. State-wise monthly normalized rainfall anomalies during monsoon season and normalized *kharif* rice productivity anomalies in moderate ENSO years.

S. no.	Important rice growing states	Year 1986						Year 1987					
		June	July	August	September	Mon	NKRP	June	July	August	September	Mon	NKRP
1	West Bengal	−6.0	−13.5	−20.1	39.0	−2.2	−9.7	−0.3	12.3	71.1	8.4	23.5	−6.8
2	Andhra Pradesh	−8.9	−23.7	26.8	−29.3	−8.3	−14.1	−37.0	−30.1	6.3	−50.6	−26.7	0.7
3	Uttar Pradesh	−12.4	−11.4	−12.8	−40.8	−18.2	−3.2	−83.9	−42.3	−30.1	−0.6	−35.7	−6.0
4	Punjab	62.1	−28.6	−7.2	−56.9	−14.9	8.8	−62.5	−80.0	−52.7	−90.4	−71.1	2.1
5	Orissa	41.3	30.9	−10.8	−21.1	9.2	−1.0	−44.6	27.6	−44.9	−29.2	−20.7	−26.0
6	Karnataka	−1.3	−39.3	12.6	−17.9	−12.1	−3.2	11.0	−23.4	11.4	−41.2	−7.0	−12.9
7	Tamil Nadu	−35.3	−29.3	2.8	−18.6	−17.7	1.0	6.9	−74.4	−16.9	2.1	−17.8	−2.9
8	Assam	−34.3	−21.2	−13.4	−1.1	−19.0	−8.5	13.6	26.3	−2.4	47.0	20.4	0.8
9	Bihar	−9.1	6.5	−25.7	−16.6	−10.2	10.4	−47.5	16.0	65.6	46.8	24.5	−13.9
10	Haryana	14.8	−58.1	−34.2	−33.0	−35.6	3.6	−43.0	−87.9	−54.0	−85.7	−70.1	−2.1
11	Maharashtra	11.7	−17.8	9.9	−41.6	−8.9	−23.2	−19.5	−36.9	14.3	−72.3	−26.4	−16.9
12	Madhya Pradesh	55.6	17.2	−22.0	−53.8	−2.0	−10.1	−56.2	−9.2	−11.5	4.0	−15.4	−6.3
13	Gujarat	36.9	−68.9	−50.0	−97.9	−48.2	−30.6	−58.4	−71.4	−51.7	−96.5	−66.7	−36.9
14	Kerala	−5.7	−45.3	−2.8	−4.4	−17.3	−3.6	−2.9	−58.9	14.9	−35.8	−21.2	−3.8
	India	7.4	−9.1	−11.7	−29.7	−10.6	−4.3	−29.9	−21.2	−2.0	−14.9	−16.1	−7.8

S. no.	Important rice growing states	Year 1994						Year 2002					
		June	July	August	September	Mon	NKRP	June	July	August	September	Mon	NKRP
1	West Bengal	4.2	−25.4	−5.6	−35.9	−16.3	5.1	−0.4	19.9	7.3	−10.0	5.9	4.4
2	Andhra Pradesh	−40.3	−0.6	−6.5	−66.5	−27.5	1.2	−15.1	−61.3	−8.4	−55.1	−36.4	−10.5
3	Uttar Pradesh	−14.0	16.9	−5.1	−35.0	−5.2	8.2	−50.0	−74.6	−5.2	43.1	−25.0	−9.9
4	Punjab	−11.3	63.3	65.3	−25.1	37.4	0.3	−38.8	−45.4	−31.9	53.2	−22.1	−4.8
5	Orissa	37.7	41.7	39.0	15.1	34.8	17.1	−13.1	−50.9	−10.6	−0.5	−20.7	−45.8
6	Karnataka	31.1	21.5	−1.2	−50.6	8.8	7.6	−0.9	−59.9	−17.4	−49.5	−30.0	−14.6
7	Tamil Nadu	−65.2	−5.5	−41.2	−44.0	−38.6	14.7	23.0	−60.9	−32.4	−48.5	−36.1	−22.1
8	Assam	12.6	−28.1	−6.6	−11.0	−8.8	6.1	7.1	3.5	−14.3	−20.5	−4.4	1.8
9	Bihar	46.7	−1.7	26.5	−17.8	11.8	3.1	−36.4	−31.8	−24.5	−6.8	−25.4	7.0
10	Haryana	14.8	89.3	32.3	−58.1	36.0	17.3	−36.2	−82.8	−11.2	55.3	−30.4	13.5
11	Maharashtra	27.5	16.7	−4.4	−16.7	5.7	1.0	86.8	−68.3	22.6	−28.7	−1.5	−24.6
12	Madhya Pradesh	106.5	54.5	33.2	6.5	47.6	27.4	−4.6	−71.7	20.6	−10.6	−18.8	−35.4
13	Gujarat	51.3	50.4	8.3	162.5	54.0	8.0	72.3	−87.4	−7.7	−42.9	−28.1	−27.9
14	Kerala	23.6	39.9	23.3	−30.9	21.3	−1.5	−18.9	−54.6	9.5	−62.1	−30.1	−0.7
	India	31.5	22.6	11.4	−10.5	14.7	9.0	4.4	−55.2	−1.2	−17.8	−20.3	−13.8

Table 7. State-wise monthly normalized rainfall anomalies during monsoon season and normalized *kharif* rice productivity anomalies in strong ENSO years.

S. no.	Important rice growing states	Year 1982						Year 1991					
		June	July	August	September	Mon	NKRP	June	July	August	September	Mon	NKRP
1	West Bengal	−17.7	−1.9	−28.0	−40.8	−20.3	−32.9	21.4	−11.3	−10.6	54.3	10.2	10.1
2	Andhra Pradesh	0.9	20.3	−37.4	−11.2	−8.2	9.4	83.2	−7.0	−29.3	−0.8	4.5	−0.4
3	Uttar Pradesh	−27.6	−34.3	42.6	21.1	2.0	−10.2	−32.5	−54.6	23.3	−32.1	−22.8	8.7
4	Punjab	−71.4	−48.3	33.0	−96.7	−35.2	8.2	24.0	−46.9	3.0	−48.8	−22.2	0.0
5	Orissa	−14.4	−43.6	55.3	−44.5	−6.3	−29.2	−34.6	33.8	22.0	−18.1	6.7	23.3
6	Karnataka	−9.9	10.7	50.9	−39.3	6.6	−1.4	22.8	24.8	5.0	−52.1	8.4	2.0
7	Tamil Nadu	−4.9	−40.7	−60.2	−40.2	−40.3	−4.9	162.2	−0.8	−20.4	3.8	20.2	4.2
8	Assam	7.0	−20.7	2.5	−2.5	−4.3	5.0	12.6	−31.3	1.2	31.5	0.4	2.5
9	Bihar	−6.1	−32.7	−15.8	−39.1	−24.4	−26.5	−8.1	−34.6	9.7	16.3	−6.7	−21.8
10	Haryana	−55.2	−39.6	13.7	−95.2	−33.8	10.5	7.5	−70.5	16.9	−48.5	−27.4	18.9
11	Maharashtra	−44.7	−0.2	−40.1	5.3	−19.7	−10.4	48.9	19.1	−38.8	−73.1	−11.0	−12.4
12	Madhya Pradesh	−42.6	−18.3	46.2	−25.9	−1.8	−12.9	−20.9	10.1	11.8	−62.7	−7.0	8.1
13	Gujarat	−85.0	−9.2	−24.4	−79.8	−37.7	−12.2	−52.5	31.8	−39.9	−72.8	−20.0	−15.3
14	Kerala	10.3	−13.1	21.5	−68.9	−5.4	1.6	66.8	22.7	9.9	−81.6	21.5	4.3
	India	−21.6	−17.6	11.0	−25.1	−11.5	−11.4	8.6	−3.2	−4.5	−25.2	−5.5	4.7

S. no.	Important rice growing states	Year 1997						Year 2009					
		June	July	August	September	Mon	NKRP	June	July	August	September	Mon	NKRP
1	West Bengal	17.1	−0.9	11.0	3.3	6.9	3.8	−38.9	−25.1	12.4	−34.2	−20.6	−4.7
2	Andhra Pradesh	−45.2	−33.3	−36.5	68.5	−8.3	−11.6	−39.7	−53.7	−16.0	8.4	−23.5	−2.4
3	Uttar Pradesh	−14.2	21.2	−14.8	5.3	1.8	16.9	−75.7	−46.6	−25.6	−24.5	−39.6	−10.1
4	Punjab	−2.0	−27.5	54.7	−64.6	−5.5	−0.7	−82.7	−17.7	−49.7	−30.2	−38.7	1.3
5	Orissa	5.9	−12.8	61.0	−5.3	16.0	10.0	−55.6	88.5	−21.3	−29.0	2.4	11.3
6	Karnataka	−11.5	21.1	24.2	−41.0	2.8	1.1	−44.0	40.9	−25.5	70.2	3.0	−10.0
7	Tamil Nadu	11.2	2.8	−33.4	−13.9	−11.9	1.6	−21.1	−17.9	19.5	3.0	−0.5	2.6
8	Assam	26.5	−19.3	−22.8	23.4	0.6	1.7	−40.3	−33.1	12.9	−45.8	−27.0	−0.3
9	Bihar	43.4	16.9	25.6	−21.2	16.2	7.6	−58.3	−36.1	2.7	−17.2	−25.5	−15.9
10	Haryana	39.0	−41.1	34.5	−60.6	−8.2	17.0	−74.7	−57.5	−67.1	111.6	−35.5	24.7
11	Maharashtra	−22.4	−18.4	−14.3	−21.9	−18.9	3.8	−56.4	8.1	−34.1	−8.6	−21.0	−7.4
12	Madhya Pradesh	−12.2	8.1	9.0	0.1	3.7	−12.1	−69.2	15.4	−44.2	−25.7	−25.8	−8.2
13	Gujarat	207.6	−32.9	25.6	45.4	39.6	3.7	−68.6	65.0	−49.4	−67.2	−12.6	6.2
14	Kerala	−4.2	47.9	35.0	29.6	24.6	−3.9	−32.0	36.4	−38.8	14.6	−5.7	5.5
	India	9.6	−1.0	8.8	3.8	4.9	2.5	−52.7	3.3	−25.3	−14.7	−19.6	−4.8

Table 8. Spatial variability of frequency of deficit/negative rainfall anomaly during monsoon months and season in moderate and strong ENSO years.

Month/Season	Four years negative rainfall anomaly	Three years negative rainfall anomaly
Moderate ENSO years		
June	Andhra Pradesh, Uttar Pradesh	West Bengal, Punjab, Bihar, Kerala
July	Andhra Pradesh, Tamil Nadu	Uttar Pradesh, Punjab, Karnataka, Haryana, Maharashtra, Gujarat, Kerala (India)
August	Uttar Pradesh, Assam	Punjab, Orissa, Tamil Nadu, Haryana, Gujarat (India)
September	Andhra Pradesh, Uttar Pradesh, Punjab, Karnataka, Maharashtra, Kerala (India)	Orissa, Tamil Nadu, Bihar
Monsoon	Andhra Pradesh, Uttar Pradesh, Tamil Nadu	Punjab, Karnataka, Assam, Haryana, Maharashtra, Madhya Pradesh, Gujarat, Kerala (India)
Strong ENSO years		
June	Uttar Pradesh, Madhya Pradesh	Punjab, Orissa, Karnataka, Bihar, Maharashtra, Gujarat
July	West Bengal, Punjab, Assam, Haryana	Andhra Pradesh, Uttar Pradesh, Tamil Nadu, Bihar (India)
August	Andhra Pradesh, Maharashtra	Tamil Nadu, Gujarat
September	Punjab, Orissa	Karnataka, Bihar, Haryana, Maharashtra, Madhya Pradesh, Gujarat (India)
Monsoon	Punjab, Haryana, Maharashtra	Andhra Pradesh, Tamil Nadu, Bihar, Madhya Pradesh, Gujarat (India)

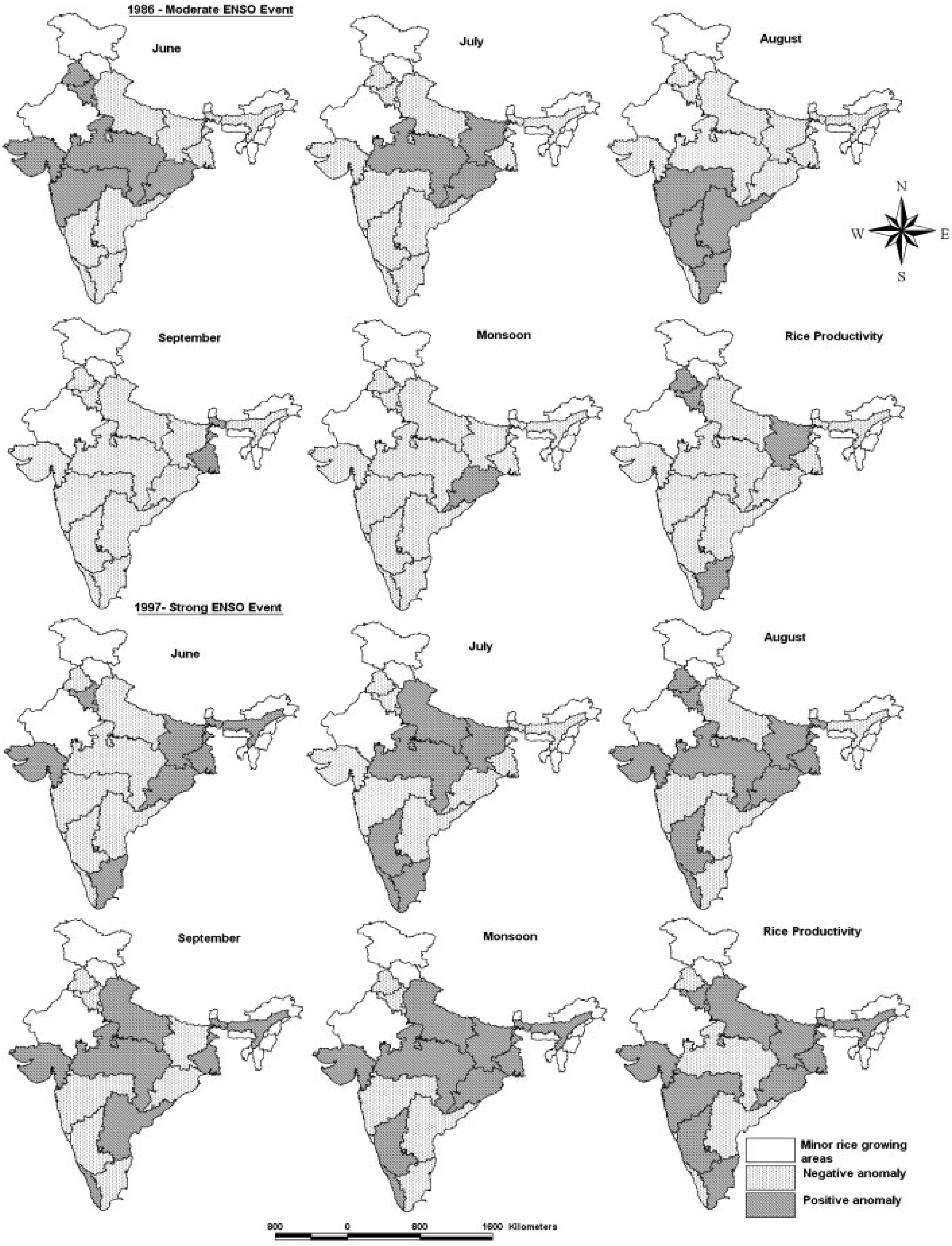

Figure 7. Spatial variability of rainfall and rice productivity during moderate and strong ENSO event years during delayed onset over India.

June, July and September months while Uttar Pradesh received deficit rainfall anomaly during two consecutive months (August and September) during all the moderate El Niño years. It is also clear from the spatial variability of the frequency of occurrence of deficit rainfall shows that Punjab and Kerala received deficit rainfall during June and July in three years. As far as strong El Niño years, Punjab received deficit rainfall in July and September in all the years.

3.6. Onset of monsoon, El Niño and rice productivity

The effect of delayed onset of monsoon and El Niño event influenced the rice productivity over India differently in moderate and strong El Niño years. In 1986 (moderate), rice productivity falls below trend productivity while in 1997 (strong) rice productivity touched above trend productivity. However, there exists wide spatial variation among the rice growing states (Figure 7). During 1986,

Table 9. State-wise average monthly normalized rainfall anomalies during monsoon season and normalized *kharif* rice productivity anomalies in moderate and strong ENSO years.

S. no.	Important rice growing states	Average-moderate ENSO					
		June	July	August	September	Mon	NKRP
1	West Bengal	−0.6	−1.7	13.2	0.4	2.7	−1.8
2	Andhra Pradesh	−25.3	−28.9	4.5	−50.4	−24.7	−5.7
3	Uttar Pradesh	−40.1	−27.8	−13.3	−8.3	−21.0	−2.7
4	Punjab	−12.6	−22.7	−6.6	−29.8	−17.7	1.6
5	Orissa	5.3	12.3	−6.8	−8.9	0.6	−13.9
6	Karnataka	10.0	−25.3	1.3	−39.8	−10.1	−5.8
7	Tamil Nadu	−17.6	−42.5	−21.9	−27.3	−27.5	−2.3
8	Assam	−0.3	−4.9	−9.2	3.6	−2.9	0.1
9	Bihar	−11.6	−2.7	10.5	1.4	0.2	1.7
10	Haryana	−12.4	−34.9	−16.8	−30.4	−25.0	8.1
11	Maharashtra	26.7	−26.6	10.6	−39.8	−7.8	−15.9
12	Madhya Pradesh	25.3	−2.3	5.1	−13.5	2.8	−6.1
13	Gujarat	25.5	−44.3	−25.3	−18.7	−22.2	−21.9
14	Kerala	−0.9	−29.7	11.2	−33.3	−11.8	−2.4
	India	3.3	−15.8	−0.3	−18.8	−8.1	−4.2

S. no.	Important rice growing states	Average-strong ENSO					
		June	July	August	September	Mon	NKRP
1	West Bengal	−4.5	−9.8	−3.8	−4.3	−6.0	−5.9
2	Andhra Pradesh	−0.2	−18.5	−29.8	16.2	−8.9	−1.2
3	Uttar Pradesh	−37.5	−28.6	6.4	−7.6	−14.7	1.3
4	Punjab	−33.0	−35.1	10.2	−60.1	−25.4	2.2
5	Orissa	−24.7	16.5	29.3	−24.2	4.7	3.9
6	Karnataka	−10.6	24.4	13.7	−15.5	5.2	−2.1
7	Tamil Nadu	36.8	−14.1	−23.7	−11.8	−8.1	0.9
8	Assam	1.4	−26.1	−1.5	1.6	−7.6	2.2
9	Bihar	−7.3	−21.6	5.6	−15.3	−10.1	−14.2
10	Haryana	−20.9	−52.2	−0.5	−23.2	−26.2	17.8
11	Maharashtra	−18.6	2.2	−31.8	−24.6	−17.6	−6.6
12	Madhya Pradesh	−36.2	3.9	5.7	−28.5	−7.7	−6.3
13	Gujarat	0.4	13.7	−22.0	−43.6	−7.7	−4.4
14	Kerala	10.2	23.5	6.9	−26.6	8.7	1.9
	India	−14.0	−4.7	−2.1	−15.7	−7.9	−2.3

highest negative anomaly of −30.6% noticed in Gujarat followed by 23.2% in Maharashtra. Interestingly, the higher productivity states Punjab and Haryana and lower productivity state Bihar noticed positive rice productivity anomaly and all other states recorded negative anomaly. However, during 1997 all states, except Madhya Pradesh, Andhra Pradesh, Punjab and Kerala recorded positive anomaly. Thus, the delayed onset of monsoon along with El Niño have a mixed influence on rice productivity over different rice growing states as well as over India.

3.7. El Niño and rice productivity

To quantify the effect of El Niño on monthly rainfall and rice productivity, the average monthly normalized rainfall anomaly and average normalized *kharif* rice productivity during moderate and strong El Niño years are computed (Table 9). On an average, there is a deficit monsoon rainfall of −8.1% over India which influenced the rice productivity of the order of −4.2% during moderate El Niño years while a deficit rainfall of −7.9% influenced the rice productivity of the order of −2.3% during strong El Niño years. The higher deficit of rice productivity during moderate El Niño years might be due to a higher rainfall deficit of −15.8% during July, which is the main sowing window of rice crop in majority of the states. There exists a wide spatial variability of normalized *kharif* rice productivity anomaly during the moderate El Niño event, with a maximum of −21.9% over Gujarat followed by −15.9% at Maharashtra. However, during the strong El Niño event, there is a maximum of −14.2% at Bihar and −6.6% over Maharashtra. To know what extent rainfall can explain the difference in rice productivity between the states, the normalized rice productivity anomaly plotted against the normalized monthly rainfall anomaly of all the states during one strong and moderate El Niño years (Figure 8). It shows there are a lot of variability in each month among the states. The correlation between normalized monthly rainfall anomaly and rice productivity anomaly during the El Niño years indicated that in July, rainfall explains 71% of the variations in rice productivity.

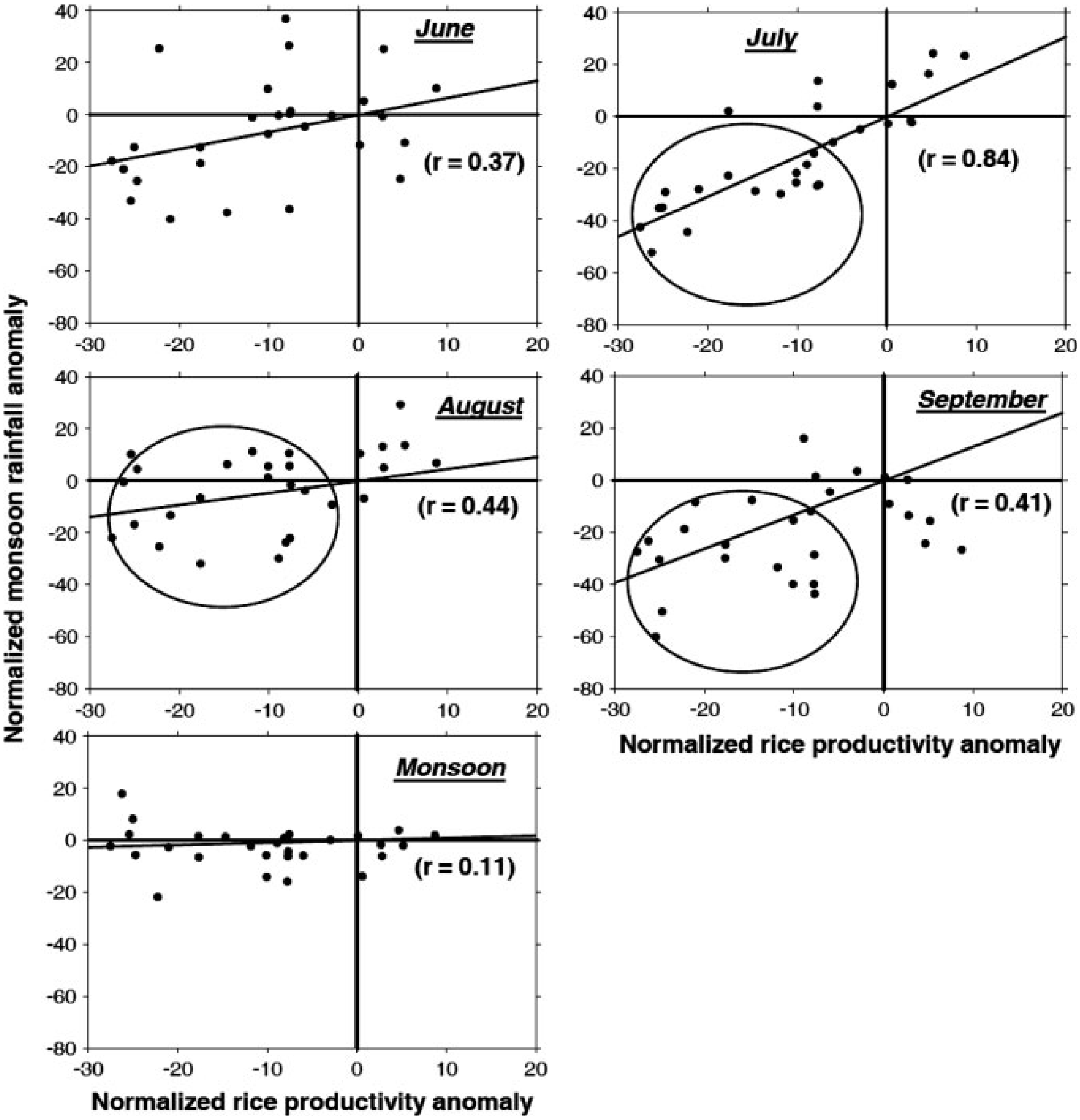

Figure 8. Relation between normalized rainfall anomaly during monsoon months and normalized *kharif* rice productivity anomaly during ENSO years. The position dots indicate the relation between normalized rainfall anomaly during monsoon months and normalized kharif rice productivity anomaly. The circle indicates that most of the points are clustered around this area in July, August and September.

4. Conclusions

This study examined the effect of El Niño on the date of monsoon onset over India, quantity of monsoon rainfall and its distribution during June to September and its spatial variability pertaining to main rice growing states. This study also demonstrated the assessment of El Niño episodes on rice productivity over different states during moderate and strong El Niño years. No specific trends of the relationship between El Niño and date of monsoon onset have been found during the study period 1974–2009. Date of onset of monsoon delayed only once in each out of four moderate and strong El Niño years. Interestingly, delayed date of onset of monsoon during the two El Niño years affected the monsoon rainfall and its distribution in a dissimilar way over India. Similarly, the spatial variation over different rice growing states also shows no definite pattern during these 2 years. It has also emerged that the delayed onset of monsoon along with El Niño have a mixed influence on rice productivity over different rice growing states as well as over India.

Out of 14 states, 10 states show decreasing trend in July rainfall (3 states, Andhra Pradesh, Assam and Haryana are showing statistically significant), which derail sowing/transplanting operations because almost all the states the ‘sowing/transplanting window’ falls during this month and this may be threat to sustainable rice cultivation in these states. Hence, site specific contingency plans incorporating low water low-cost sowing/transplanting technologies may be prepared. The simple correlation between normalized rice productivity anomaly and normalized monsoon rainfall anomaly shows monsoon rainfall contributes 48% variation in rice productivity over India. Analysis of El Niño impact on spatial rice productivity may be useful for formulating farm management planning and policy decisions. Since the El Niño affect the rice productivity spatially, site specific management practices such as balanced nutrient application, varietal selection, moisture conservation measures, cost-effective need based irrigation strategies and popularizing suitable household/small farm level integrated farming system models should be explored to minimize/reduce the climatic risk.

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