



Statistical analysis of Indian rainfall and its relationship with the Southern Oscillation Index

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Abstract

Rainfall is an imperative producer of readily available water and is of great importance to most economies of the world. Similarly, for the Indian economy, especially for agribusiness, Indian rainfall is a serious entity. Indian rainfall in the months from June to September constitutes approximately 80% of the annual rainfall. This rainfall is highly variable over space and time, which causes floods or droughts in various parts of the country. Thus, a thorough study of rainfall variations and the factors that affect rainfall is required. Therefore, the objectives of the present study are (a) to analyze all-India rainfall along with its subdivisions (northwest, west-central, northeast, central northeast, and peninsular India) and (b) to determine correlations between rainfall and the Southern Oscillation Index (SOI) for three different subperiods: 1949–1965, 1966–1990, and 1991–2016. The statistical analysis of rainfall data and the regime shift analysis method form the basis of this analytical study. Our results showed a significant downward trend in rainfall from July to October for 1949–2016. The monsoon season (June to September) showed a strong positive correlation with SOI for the subperiods 1949–1965 and 1966–1990, which weakened in the period 1991–2016. The rainfall from October to December showed a strong positive correlation with the SOI during 1949–1965 that weakened in the later periods. This study's results are helpful for decision makers, planners, agriculturists, hydrologists, and other experts for the proper management of water resources.

Keywords Correlation · Rainfall · Regime shift · SOI · Trend

Introduction

For an agriculturally based country, such as India, rainfall is the chief climatic component. It is considerably more informative to study seasonal variation of the rainfall (associated with the monsoon system) than the seasonal variation of wind (Gadgil 2003).

These seasonal variations of rainfall significantly affect the agriculture sector, demonstrating that the Indian economy is dependent on the monsoon rains. For a large part of India, the monsoonal months are from June to September (summer

monsoon), except for the east coast of the southern peninsula, where most of the rainfall occurs during October–November (Kothawale and Rajeevan 2017). The all-India summer monsoon rainfall (ISMR), which is the weighted average of the June–September rainfall at 306 well-distributed rain gauge stations across India, is considered to be a useful index of the summer monsoon rainfall over the Indian Region in any year (Parthasarathy et al. 1992, 1995).

Walker (1923) stated that the Indian monsoon is a global phenomenon. Moreover, Walker (1923) reinforced that due to high variation in the ISMR, studies on the El Nino-Southern Oscillation (ENSO) are imperative. The relationship between all-India monsoon rainfall and ENSO has been long known (Kripalani et al. 2003; Kripalani and Kulkarni 1997; Krishnamurthy et al. 2002; Torrence and Webster 1999; Yadav 2009). Due to the spatial and temporal variability of monsoon rains, it is difficult to determine any single relationship between the ENSO and the ISMR that is relevant to the various subdivisions of India (Singh 2001). Therefore, a comprehensive study is still required to understand the correlations of SOI and ISMR, which the present study attempts to

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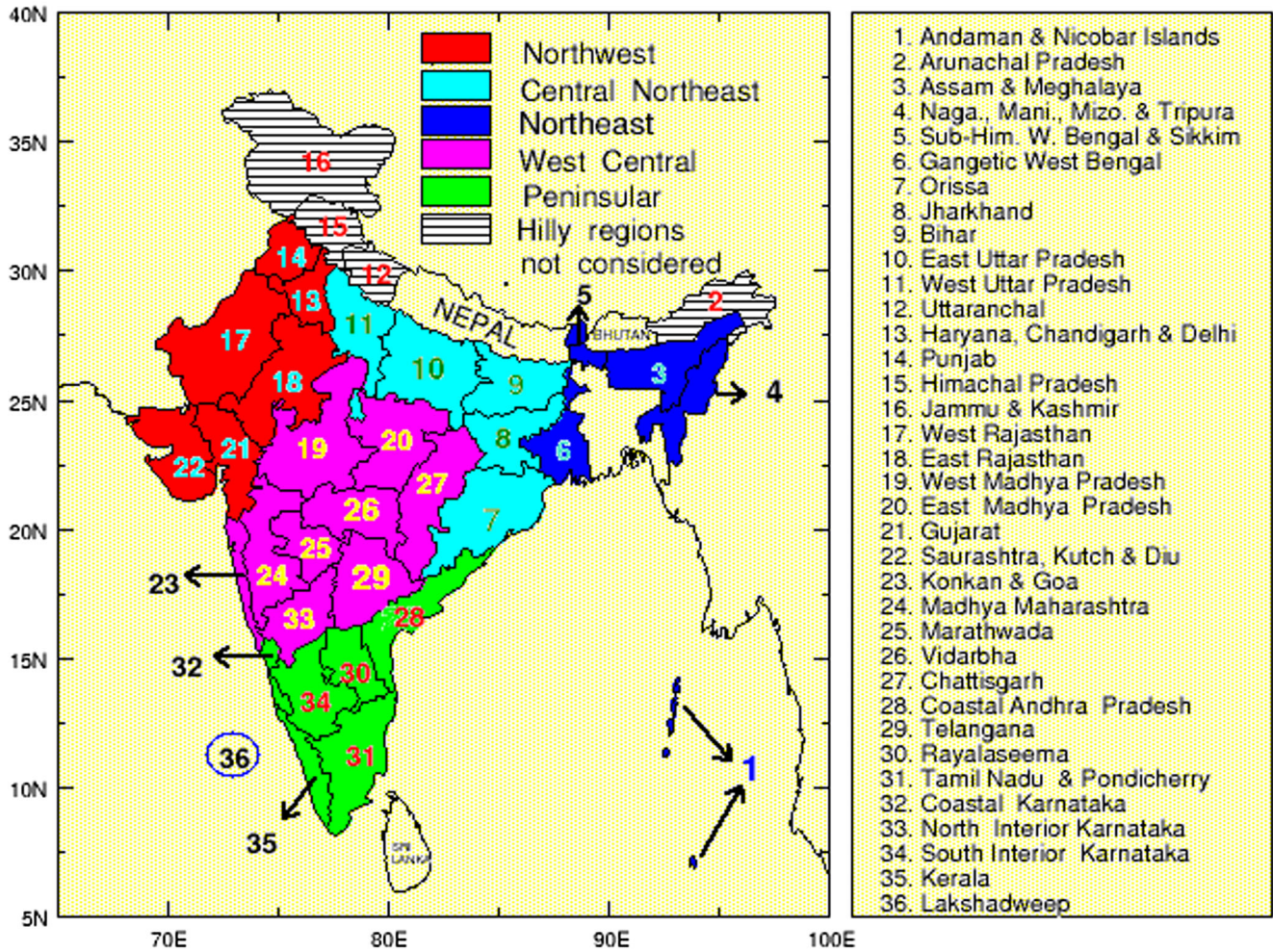
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Homogeneous Monsoon Regions



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Fig. 1 Homogeneous Monsoon Regions. Modified from Indian Institute of Tropical Meteorology

enhance. Regarding trend analysis, no significant rainfall trend was obtained on monthly, seasonal, and annual bases

for all-India, as well as for its subdivisions from 1871 to 2008 (Kumar et al. 2010; Jain et al. 2013). Consequently, to

Table 1 Means and standard deviations of rainfall for five subdivisions and the Indian Subcontinent (1949–2016)

		Jan-Feb	Mar-Apr-May	Jun-Jul-Aug-Sep	Oct-Nov-Dec
AIR	Mean	20.7	95.2	841.6	121.5
	STD	± 9.8	± 19.8	± 84.5	± 31.7
NWIR	Mean	12.2	21.4	501.4	23.6
	STD	± 8.9	± 16.7	± 122.3	± 24.8
WCIR	Mean	17.0	45.4	919.0	84.8
	STD	± 12.2	± 21.3	± 121.7	± 39.2
NEIR	Mean	37.4	416.0	1380.7	183.0
	STD	± 21.9	± 80.0	± 136.5	± 75.7
CNEIR	Mean	30.9	73.5	968.2	92.1
	STD	± 17.9	± 26.9	± 115.5	± 52.7
PIR	Mean	17.3	143.7	671.2	342.4
	STD	± 18.0	± 47.4	± 98.3	± 90.0

Table 2 Descriptive statistics of monthly rainfall for AIR (1949–2016)

Rf	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
Mean (mm)	9.6	11.1	15.3	26.5	53.4	158.1	269.2	244.9	169.4	80.4	29.5	11.7
S.D. (mm)	6.0	7.4	8.9	8.7	15.7	31.9	36.1	31.5	35.4	28.9	17.4	9.8
Skewness	0.7	0.9	1.7	0.6	1.1	0.1	−1.0	−0.1	0.4	0.5	1.1	2.4
Kurtosis	−0.2	0.0	4.3	0.9	1.4	−0.4	3.1	−0.7	−0.8	−0.5	1.1	8.3
Min (mm)	0.8	1.1	2.6	8.0	25.2	89.9	121.3	185.5	113.5	31.9	1.8	0.8
Max (mm)	27.1	28.8	52.8	54.0	107.7	228.5	341.5	307.5	250.7	152.5	88.3	56.8
P-Ann %	0.89	1.02	1.42	2.45	4.95	14.65	24.95	22.70	15.70	7.45	2.73	1.08

observe the variation in the rainfall pattern, it is essential to perform trend analyses for different periods.

Statistical techniques, such as mean, variance, standard deviation, coefficient of variation, and Pearson's correlation coefficient, assist in measuring the variations in rainfall. A mathematical study to depict the temporal distribution of rainfall patterns (1993–2012) in Nasarawa State showed that August was the month of highest rainfall (Ekwe et al. 2014). The statistical characteristics of rainfall (1981–2011) for Ghana were studied by dividing the country into three zones; it was found that the northern zone had the highest precipitation followed by the middle zone and then the coastal zone (Nyatuame et al. 2014). Rajeevan et al. (2008) studied the extreme rainfall events (rainfall ≥ 150 mm/day) in Central India and observed an increasing trend in rainfall events for the period 1901–2004.

The statistically significant changes in the climatic variables at one time-scale are known as climate regime shift. The simple definition of abrupt climate change is the shifting of the climate system from a steady state to another steady state (Liu et al. 2016). The shift detection technique was used by Keevallik and Soomere (2008) to study the switching time of the upper air flow at 850- and 500-hPa levels over the northeastern Baltic Sea; they found multiple regime shifts during March. Verdon-Kidd and Kiem (2015) studied the evidence of regime shifts in annual maximum rainfall time series (1913 to 2010) across Australia and observed a relationship between rainfall intensity, frequency, and duration (IFD). IFD

is a significant parameter in the design and planning of water supply and management systems.

The objective of this paper is to determine the relationship between Indian subdivisional rainfall and the Southern Oscillation Index using the regime shift technique because there are few studies employing this method. The results and studies carried out in this work may be applied in the long-range forecasting of rainfall on monthly and subdivisional scales. Subsequently, these highlights are beneficial in the agriculture sector, as well as for extreme events, such as floods and droughts.

Materials and methods

Dataset

The all-India Monthly Rainfall and the subdivisional monthly rainfall dataset were obtained from the website of the Indian Institute of Tropical Meteorology (IITM), Pune, India (Kothawale and Rajeevan 2017); data are freely available for research. The data period used in the analysis was from 1949 to 2016. The subdivisional rainfall regions of India are All India Rainfall (AIR), Northwest India rainfall (NWIR), West Central India rainfall (WCIR), Central North East India Rainfall (CNEIR), North East India Rainfall (NEIR), and Peninsular India Rainfall (PIR) (Fig. 1). The Southern Oscillation Index (SOI) data were taken from Ropelewski

Table 3 Descriptive statistics of monthly rainfall for NWIR (1949–2016)

Rf	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
Mean (mm)	5.7	6.5	6.3	4.4	10.7	63.3	188.4	164.4	85.4	14.4	5.9	3.3
S.D. (mm)	5.4	7.3	9.0	6.5	10.2	33.4	64.7	60.5	58.5	21.8	12.6	5.8
Skewness	1.5	1.8	3.7	3.6	1.7	0.4	0.1	0.3	0.6	2.4	2.9	3.6
Kurtosis	2.5	3.0	17.7	16.7	3.3	−0.5	0.5	−0.7	−0.5	5.9	7.8	15.0
Min (mm)	0	0	0	0	0.2	4.3	22.0	40.1	5.7	0.1	0	0
Max (mm)	24.9	31.8	58.3	41.8	50.9	146.9	345.7	308.3	235.6	105.6	55.6	33.4
P-Ann %	1.02	1.16	1.13	0.78	1.92	11.32	33.73	29.42	15.28	2.58	1.05	0.60

Table 4 Descriptive statistics of monthly rainfall for WCIR (1949–2016)

Rf	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
Mean (mm)	8.9	8.1	11.0	11.7	22.7	161.2	299.2	276.9	181.6	62.5	15.1	7.2
S.D. (mm)	8.4	8.2	11.9	6.5	16.8	47.3	59.8	50.7	59.3	36.1	18.6	13.5
Skewness	1.2	1.8	1.7	0.8	2.0	0.4	-0.2	0.2	0.5	0.4	1.7	3.5
Kurtosis	1.1	3.6	2.2	0.4	5.4	-0.6	1.4	-0.5	-0.3	-0.8	2.1	13.0
Min (mm)	0	0	0.1	1.4	2.6	73.7	89.2	178.8	70.5	4.5	0	0
Max (mm)	36.4	40.7	49.6	30.7	97.8	269.3	432.4	380.6	324.0	147.6	77.1	71.1
P-Ann %	0.83	0.76	1.04	1.10	2.13	15.12	28.06	25.98	17.03	5.86	1.41	0.68

and Jones (1987), and the updated data were obtained from the website of NOAA (National Oceanic and Atmospheric Administration’s) ESRL (Earth System Research Laboratory) Physical Sciences Division.

Methods

Statistical analysis measured the central tendency (e.g., mean, range, and others) and dispersion (e.g., standard deviation, coefficient of variation, and others) of the considered data. The simplest linear regression method was used to identify the trends in the rainfall data. Because the equation of a linear regression line is $Y = + \frac{Y}{X}$, X being the independent variable and Y the dependent variable, the variable Y here is rainfall and X is the year. For the null hypothesis, the slope of the line is zero (it is assumed that there is no trend in the data). The probability value (P value) shows the significance of the slope (P is the test for the significance level $\alpha = 0.05$), and the R-square value shows the relationship between the variables X and Y . P and R values are not provided in the tables.

The method used in the analysis is based on the sequential t test analysis of regime shifts (STARS) developed by Rodionov and Overland (2005). In this method, a new observation in the time series data is checked to determine if it has deviated (statistically significant) from the mean values of the current regime. If there is significant deviation, that year is then marked as a potential change point c , and the successive observations

are used to confirm or reject the hypothesis. The regime shift index is used to test the hypothesis calculated for each c :

$$RSI_c = \sum_{i=c}^{c+m} \frac{x_i^*}{l\sigma_1}$$

where $m = 0, \dots, l-1$ (number of years since the start of a new regime), l is the cut-off length of the regimes, σ_1 is the average standard deviation for all one-year intervals in the time-series, and RSI is the cumulative sum of normalized deviations x_i^* from the hypothetical mean level for \bar{x}_{new} (new regime), for which the difference from the mean level for \bar{x}_{cur} (current regime) is statistically significant as per the Student’s t test:

$$diff = \bar{x}_{new} - \bar{x}_{Cur} = t\sqrt{2\sigma_1^2/l}$$

where t is the value of the t -distribution with $2l-2$ degrees of freedom at the given probability level p .

If the value of RSI becomes negative from the start of the new regime, the test fails and a zero value is assigned. However, if the value of RSI remains positive throughout $l-1, c$ at level $\leq p$ is declared to be the time of the regime shift.

For regime shift detection, the magnitude and scale of the detected regime are controlled by two parameters. The first is the difference between the mean values of the old and new regimes, which is statistically significant whenever a regime shift is detected; the lower the significance level, the larger the magnitude of the shift detected. Second, the longer the cut-off length, the longer the regime detected, and vice versa

Table 5 Descriptive statistics of monthly rainfall for NEIR (1949–2016)

Rf	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
Mean (mm)	12.8	24.6	56.1	129.6	230.3	367.6	401.8	338.8	272.6	145.4	28.4	9.2
S.D. (mm)	11.6	17.0	32.0	50.5	54.1	65.9	74.8	54.3	58.1	66.3	28.9	13.1
Skewness	1.9	1.0	0.8	0.7	0.3	0.4	0.6	0.3	0.3	0.5	1.8	2.6
Kurtosis	4.9	1.8	0.4	0.7	0.1	0.6	0.3	0.0	-0.6	0.3	3.4	7.3
Min (mm)	0.2	0.1	9.5	27.9	110.4	233.4	287.5	239.7	166.2	32.8	0.2	0
Max (mm)	62.8	86.2	157.0	282.1	364.9	574.1	646.3	509.9	393.6	357.2	136.3	65.4
P-Ann %	0.63	1.22	2.78	6.43	11.42	18.22	19.92	16.79	13.51	7.21	1.41	0.46

Table 6 Descriptive statistics of monthly rainfall for CNEIR (1949–2016)

Rf	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
Mean (mm)	14.7	16.2	14.6	16.6	42.3	155.3	304.8	299.7	208.4	74.1	12.2	5.9
S.D. (mm)	11.1	13.7	12.9	11.7	20.1	58.3	53.1	49.4	45.8	51.7	13.2	7.9
Skewness	1.0	1.2	1.0	1.4	0.3	0.6	-0.3	0.0	-0.4	1.1	1.4	2.8
Kurtosis	1.2	0.9	0.5	3.7	-0.5	0.0	0.2	0.4	0.0	0.5	1.4	10.3
Min (mm)	0.1	0	0	1.0	5.6	64.9	148.6	151.1	94.0	4.8	0	0
Max (mm)	51.7	57.9	55.7	66.8	95.8	319.5	413.0	416.9	303.1	235.7	59.6	46.5
P-Ann %	1.26	1.39	1.25	1.43	3.63	13.34	26.17	25.73	17.89	6.36	1.05	0.51

Table 7 Descriptive statistics of monthly rainfall for PIR (1949–2016)

Rf	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
Mean (mm)	8.2	9.1	14.0	40.7	89.1	163.9	193.4	163.1	150.7	182.5	117.7	42.2
S.D. (mm)	9.5	13.7	18.3	19.9	43.3	36.8	43.3	39.8	44.9	56.9	63.7	32.1
Skewness	2.0	3.0	4.3	0.8	1.2	0.8	-0.1	0.0	0.2	0.1	0.8	0.9
Kurtosis	3.9	11.6	24.8	0.2	1.4	1.1	0.2	-0.4	-0.5	-0.1	0.0	-0.3
Min (mm)	0	0	0	5.2	29.9	90.3	84.5	81.5	51.4	51.5	10.8	1.4
Max (mm)	44.8	80.2	131.6	94.3	224.1	283.9	294.1	252.7	252.0	312.9	278.5	118.4
P-Ann %	0.70	0.77	1.19	3.47	7.58	13.95	16.47	13.89	12.83	15.54	10.02	3.59

(Keevallik 2011). In this study, the cut-off length is considered to be 15 years with a Huber’s weight parameter of 2, where Huber’s parameter controls the weights assigned to the outliers that affect the average value of the regimes (Rodionov 2004). Two basic software packages, SPSS and Microsoft Excel, were used in performing the statistical analysis.

upper limit considered is the target probability level p of the desired significance level of the shifts, whereas the p values calculated after all shifts are detected in a series are usually lower (Rodionov 2005; Rodionov 2016).

*In a simple definition, statistical significance means that the statistic is reliable; alternatively, it is the probability of finding a given deviation from the null hypothesis. The significance level ‘ p ’, also known as the probability level, depends on the magnitude of shifts. For example, if the objective is to detect shifts of smaller magnitude, the appropriate choice of p should be 0.1 or higher (note that the value of p for a time series is the maximum significance level at which regimes shifts can be detected). The

Results and discussion

Climatological and fluctuation features of seasonal rainfall and temperatures of the subdivisions of India

Table 1 shows the climatology (means) and standard deviations of seasonal rainfall for all-India and its subdivisions. The table clearly shows that June-July-August-September is the

Table 8 Trends (mm/year) in monthly rainfall for the period 1949–2016 for all-India and five subdivisions

	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
AIR	-0.24	0.48	0.12	0.65	0.02	1.92	-3.7	-2.57	-2.73	-2.45	0.69	0.11
NWIR	-0.35	0.54	-0.03	0.78	1.01	3.79	-3.35	0.68	-2.21	-1.07	-0.29	0.03
WCIR	0.41	0.53	0.4	-0.08	-1.02	3.73	-3.32	-3.12	-5.16	-1.91	0.29	-0.16
NEIR	-0.72	0.52	-0.77	3.09	-1.58	-11.02	-3.5	-3.83	0.76	-4.6	-2.24	0.04
CNEIR	-1.03	0.36	-0.70	0.72	3.43	3.22	-2.29	-8.27	-3.18	-4.54	-0.36	0.31
PIR	-0.20	0.41	1.33	0.48	-2.60	1.47	-6.94	2.08	0.30	-1.60	6.06	0.60

Bold numbers indicate the significant trend values

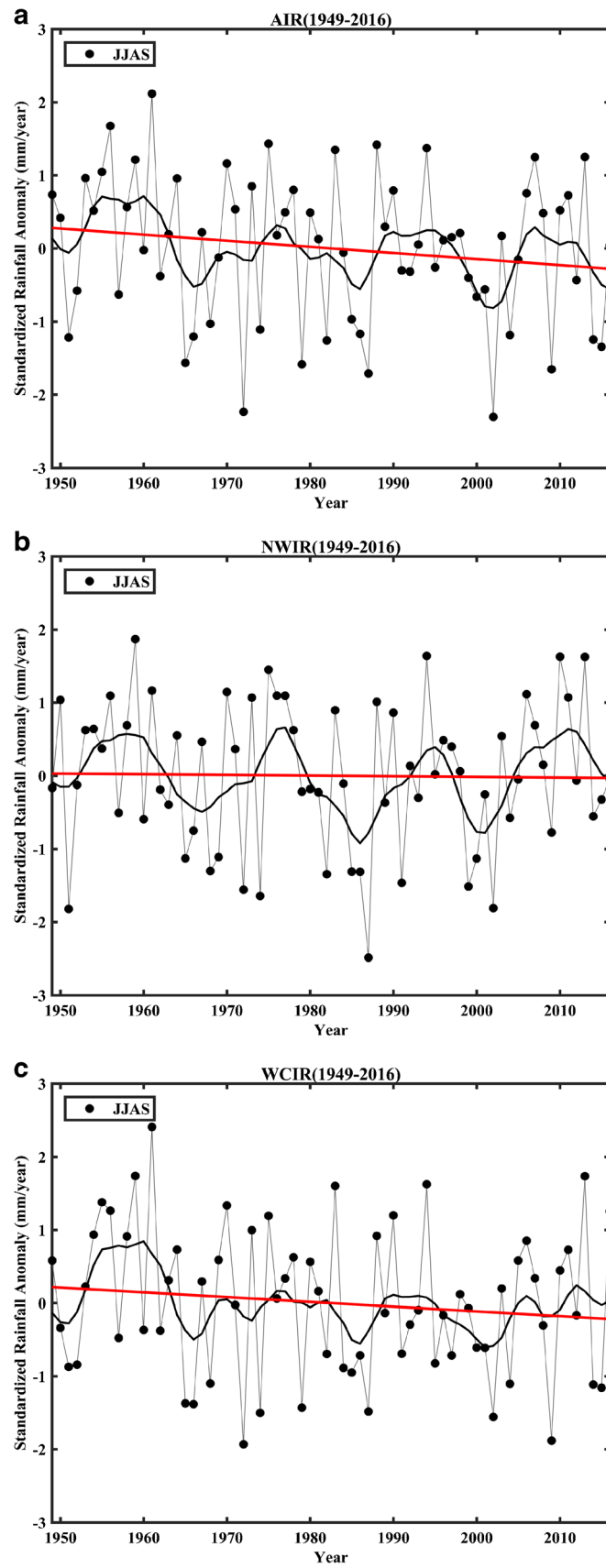


Fig. 2 a–f Standardized rainfall anomaly for the subdivisions during the season JJAS

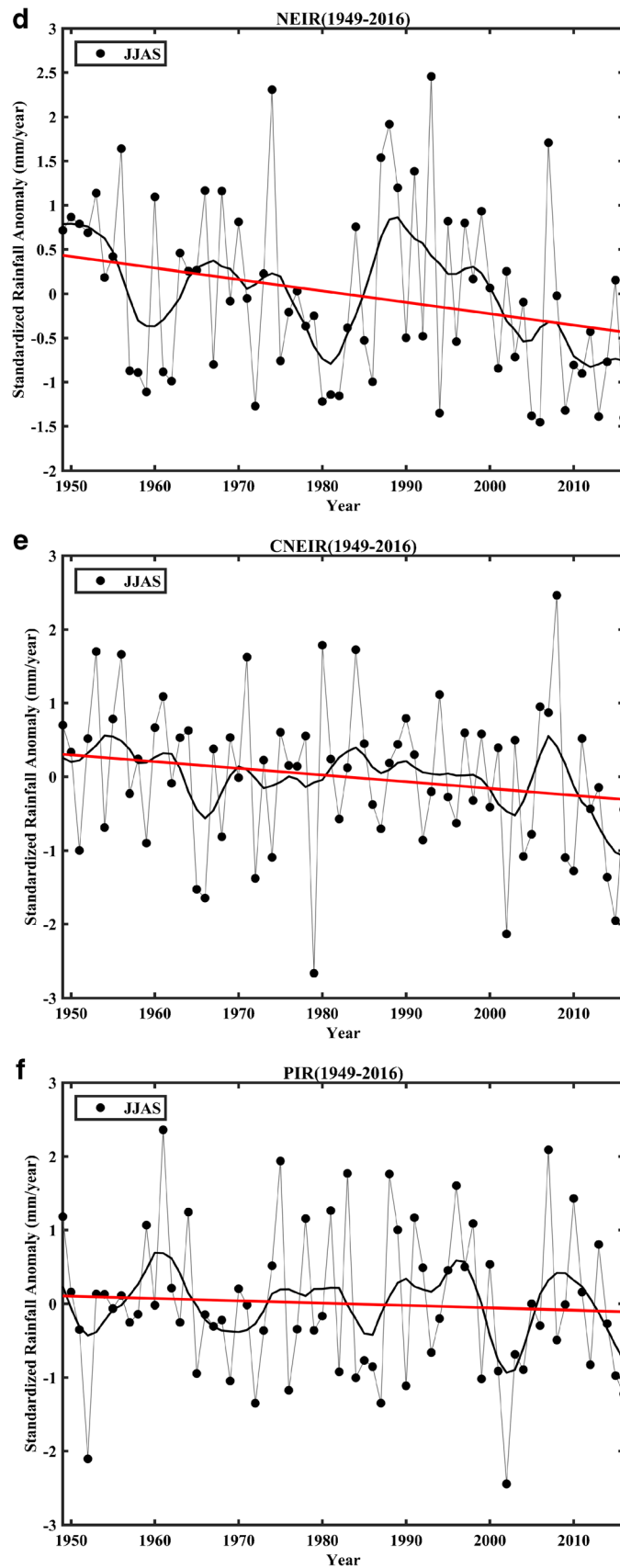


Fig. 2 continued.

rainiest season for each subdivision and that NEIR is the highest rainfall region.

Tables (Ekwe et al. 2014; Gadgil 2003; Jain et al. 2013; Keevallik and Soomere 2008; Sirje 2011; Kothawale and Rajeevan 2017) show the descriptive statistics of the monthly rainfall for each subdivision. Along with mean and standard deviation, the tables illustrate skewness and kurtosis. For a normal distribution of data, the skewness is zero, and for symmetric data it is near zero. The negative values indicate data skewed to the left, and positive values indicate data skewed to the right. From Tables 2, 3, 4, 5, 6, and 7, the winter months show positive values of skewness, which indicates that high extreme values of rainfall are rare; in general, the winter rainfall values are less than the averages. However, for the months of July and August, the above condition is reversed for the all-India rainfall. The positive values indicate the kurtosis peak distribution, and the negative values indicate a flat distribution.

Tables (Ekwe et al. 2014; Gadgil 2003; Jain et al. 2013; Keevallik and Soomere 2008; Sirje 2011; Kothawale and Rajeevan 2017) show the annual percentages (%) (P-Annual or P-Ann). For India as a whole, June, July, August, and September are the main rainy months with the mean values 158.1, 269.2, 244.9, and 169.4, respectively. The highest contribution of rainfall to the annual rainfall is in July (24.95%) and then in August (22.70%). Except for the PIR region, the rainiest months are from June to September and contribute the highest percentage to the annual rainfall; for the PIR region, the highest mean rainfall is in October. On the other hand, the highest contribution of rainfall to the annual rainfall is in July (16.47%) and then in October (15.54%).

Table 8 shows trends for monthly rainfall for all-India and its subdivisions. A decreasing trend was observed during the summer monsoon rainfall (JJAS) for AIR (Yadav 2009). However, on a monthly basis, the AIR region shows a downward trend for January and from July to October, whereas the rest of the months show an upward trend. The NWIR region shows a decreasing trend in January, March, July, September, October, and November. A downward trend during May and from July to October was observed in the WCIR region. A significant downward trend was observed in June for NEIR, whereas the months

May, July, August, October, and November show a downward trend, although it is not statistically significant.

There are significant upward and downward trends in the months of May and August, respectively, for the CNEIR region, whereas January, March, July, and from September to November show a decreasing trend (not statistically significant). A statistically significant decreasing trend was observed in July for PIR. The months of January, May, and October show a downward trend, whereas the rest of the months show an upward trend (not statistically significant). There was not a significant trend for all-India as well as for its subdivisions (Ekwe et al. 2014; Kripalani et al. 2003) for the period 1871–2008. However, the period 1949–2013 showed a significant trend for the subdivisions NEIR (June), CNEIR (May, August), and PIR (July).

Figure 2a–f shows the standardized rainfall anomalies for all the subdivisions during the season JJAS (June–July–August–September). The figure also depicts the trend line, and the dark line shows the smoothing of the rainfall data using the 9-point filter method. During the summer monsoon rainfall (i.e., from June to September), a downward trend is observed in all of the subdivisions.

Regime shift analysis

The regime shift method was used to analyze two data sets:

- The rainfall dataset for three seasons over the entire country (i.e., for the all-India rainfall region): March–April–May (MAM), June–July–August–September (JJAS), and October–November–December (OND).
- The SOI dataset for May–June–July (MJJ), August–September–October (ASO), November–December–January (NDJ), and February–March–April (FMA).

The cutoff length was set to 10 years, the probability to 0.5 and the Huber parameter to 2.

Figures 3 and 4 show the combined regime shift index (RSI) for the seasonal rainfall over the country (AIR) and the Southern Oscillation Index, respectively. The indices shown on the y-axis are averages of the seasonal rainfall and the SOI

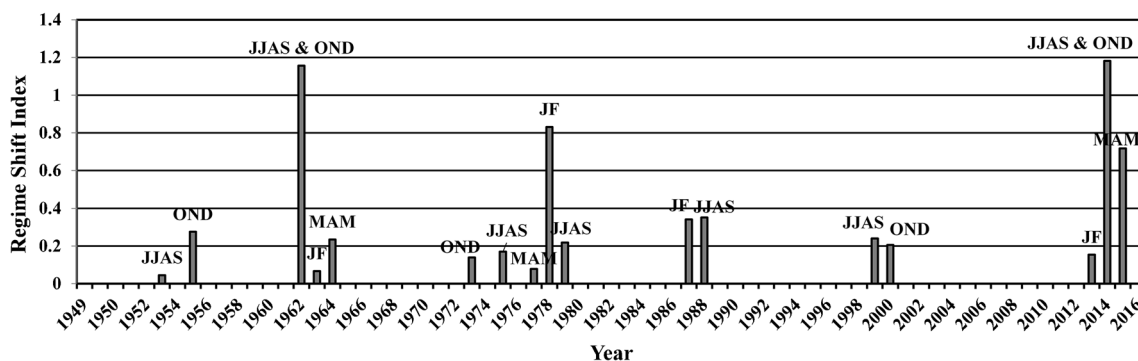


Fig. 3 Regime shift index values for seasonal rainfall for all India (AIR)

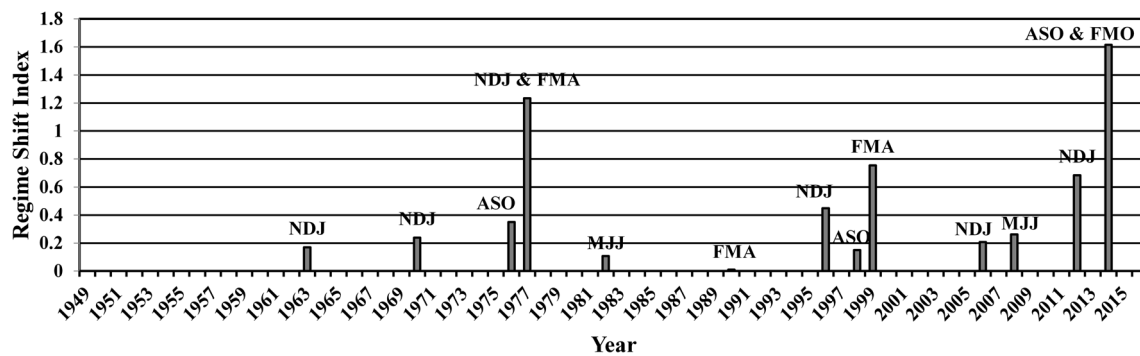


Fig. 4 Regime shift index values for Southern Oscillation Index

data. They are thus combinations of the reliability of the shifts detected in different seasons and the number of seasons that depict shifts. The most noticeable features of Fig. 3 are the six shifts that were detected during the period 1949–1965 for the three seasons MAM, JJAS, and OND and the seven shifts that were detected during the period 1972–1990. Figure 4 shows a noticeable six shifts during the periods 1963–1983 and 1990–2009 for SOI in different seasons. The ends of the time series should be taken as signals for the rise of potential shifts. The shifts detected at the end of the time series should not be considered because they require additional data. Therefore, one can confidently say that statistically significant changes have taken place nearly simultaneously in rainfall and SOI that refer to a regime shift in the weather conditions for all of India.

These significant changes may be similar to the rainfall conditions in the country as suggested by Parthasarathy et al. (1991). Note that there have been alternating periods ranging to 3–4 decades with less and regular weak monsoons over India. The period 1921–1964 witnessed three drought years; thus, a weak correlation is observed between the monsoon and the ENSO. During the period 1965–1987, ten drought years were observed and the monsoon was strongly linked to the ENSO (Parthasarathy et al. 1991). Therefore, by the above-detected shifts, the entire period is divided into three subperiods: 1949–1965, 1966–1990, and 1991–2016. With the help of these subperiods, the correlations between rainfall during different seasons and the Southern Oscillation Index become clear in the next section.

Link between rainfall and SOI

It has been established that positive SOI during March to September is associated with good Indian summer monsoon rainfall (i.e., from June to September) and that negative SOI correlates to a weaker monsoon. According to Raj and Geetha (2008), the relationship is comparatively stronger in the concurrent mode (i.e., between SOI (JJAS) and rainfall (JJAS)). However, this relationship is not strong in the antecedent mode, i.e., the relationship between SOI (MAM) and rainfall (JJAS). The relationships between subdivisional rainfall (for the seasons MAM, JJAS, and OND) and the Southern

Oscillation Index (for MJJ, ASO, NDJ, and FMA) were determined for the subperiods and are presented in Fig. 5a–c.

The subperiod 1949–1965 shows a weak correlation between rainfall (MAM) and SOI for all the defined subdivisions, except for the region CNEIR, which shows a good positive correlation (+0.4) between rainfall (MAM) and SOI (FMA). This weak correlation continues for the subperiod 1966–1990, except for the region NWIR, which strongly correlated with the SOI (−0.4 to −0.6). During the subperiod (1991–2016), a stable negative relationship was observed between rainfall (MAM) and SOI (MJJ and ASO) for the subdivisions NWIR and WCIR. The rainfall (MAM) is positively linked to SOI (FMA) for the PIR region.

For the monsoon season (JJAS), the rainfall in the subperiod 1949–1965 shows a direct correlation with the SOI (+0.2 to +0.5) for all the subdivisions. The same condition applies (positive correlation +0.3 to +0.65) for the subperiod 1966–1990, except for the SOI during FMA. This relationship weakens for the subperiod 1991–2016 compared with the other two subperiods. The subperiod 1949–1965 shows a good positive correlation between rainfall (OND) and SOI (+0.15 to +0.45). This correlation decreases for the subperiod 1966–1990, except for the regions NEIR (+0.3 to +0.7) and PIR (−0.6 to −0.3). During 1991–2016, rainfall (in OND) is negatively correlated to SOI (during FMA; approx. −0.3) for all regions. The rainfall region NWIR shows a positive correlation (approx. +0.3) with SOI (MJJ and ASO), and the rest show a weak bonding.

Conclusions

The rainiest months for the country (India) are from June to September, and the NEIR is the highest rainfall region. The rainfall in these months contributes the highest percentage of the annual rainfall (approx. 80%) and in some way influences the food grain production of the country.

The all-India region along with its subdivisions showed a downward trend in rainfall, mostly during the monsoon months (i.e., from July to October) for the period 1949–2016. Rainfall shifts were detected during the periods 1949–

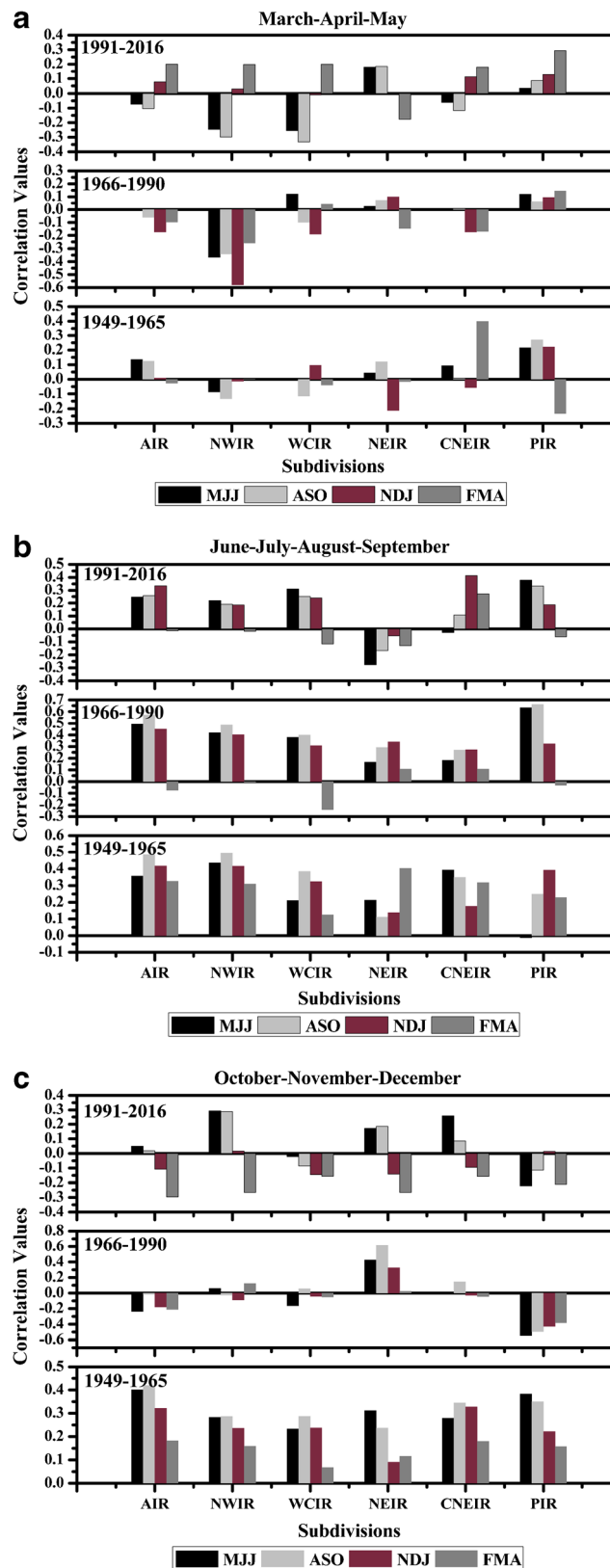


Fig. 5 a–c Correlation between rainfall (during the seasons MAM, JJAS, and OND) and SOI

1965 (6 shifts) and 1972–1990 (7 shifts). The monsoon season (JJAS) showed a strong positive correlation with the Southern

Oscillation Index for the subperiods 1949–1965 and 1966–1990, which weakened in the subperiod 1991–2016. The

premonsoon months (MAM) showed a weak correlation with the SOI for all the subdivisions. However, the region NWIR showed strong correlation with the SOI during 1966–1990 during MAM. The rainfall in the postmonsoon months (OND) showed a strong positive correlation with the SOI during the subperiod 1949–1965 for all the subdivisions, whereas the other two subperiods showed a weak correlation.

The above correlations were studied for the period 1875 to 1980, and it was found that the season ASO (for SOI) is strongly related to the monsoon rainfall, which implies that the significant positive (negative) value of the SOI, which suggests strengthening (weakening) of the Walker circulation, coincides with large excess (deficient) monsoon rainfall over the country (India) (Bhalme and Jadhav 1984). The present study confirms that a strong relationship exists between the monsoon months (JJAS) and the SOI (including ASO) for the period 1949–1964, which slowly weakens for the following subperiods. The present study reflects the cause of the variation of rainfall and its association with the Southern Oscillation Index in different subperiods. The result appears to be optimal: Greater accuracy is seen with more parameters and regions added to the rainfall analysis over the subcontinent.

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