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Rainfall trends in twentieth century over Kerala, India

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ABSTRACT

Attempts were made to study temporal variation in monthly, seasonal and annual rainfall over Kerala, India, during the period from 1871 to 2005. Longterm changes in rainfall determined by Man-Kendall rank statistics and linear trend. The analysis revealed significant decrease in southwest monsoon rainfall while increase in post-monsoon season over the State of Kerala which is popularly known as the "Gateway of summer monsoon". Rainfall during winter and summer seasons showed insignificant increasing trend. Rainfall during June and July showed significant decreasing trend while increasing trend in January, February and April. Hydel power generation and water availability during summer months are the concern in the State due to rainfall decline in June and July, which are the rainiest months. At the same time, majority of plantation crops are likely to benefit due to increase in rainfall during the post-monsoon season if they are stable and prolonged.

1. Introduction

Several researchers studied on variability and trends in rainfall across the world. Nicholson (2000) observed that one of the most important contrasts in rainfall is the multi-decadal persistence of anomalies over northern Africa. Nicholson and Grist (2001) had identified several changes in the general atmospheric circulation that have accompanied the shift to drier conditions in West African Sahel. Rainfall variability in southern Spain on decadal to centennial time scales were studied by Rodrigo et al. (2000). Rotstayn and Lohmann (2002) showed a prominent feature is the drying of the Sahel in North Africa and suggest that the indirect effects of anthropogenic sulfate may have contributed to the Sahelian drying trend. Akinremi et al. (2001) reported that there has been a significant increase in rainfall and its events during the most recent 40-year period (1956–95). Increase in annual rainfall was 51 mm, or about 16% of the 40-year mean, while the number of rainfall events increased by 17, or about 29% on the Canadian prairies. Murphy and Timbal (2007) reported that most of the rainfall decline (61%) has occurred in Autumn (March–May) in southeastern Australia. A similar rainfall decline occurred in the southwest of Western Australia around 1970 that has many common features with the southeastern Australia decline. Nicholls and Lavery (2006) reported that summer rainfall over much of eastern Australia increased abruptly around 1950s. In the Southwest of the continent, majority of stations recorded a smoother trend to lower winter rainfall, although there is a small area with increased rainfall.

Attempts have been made to study trends in annul and seasonal rainfall over India since the beginning of the last century. Long term trends of Indian monsoon rainfall for the Country as well as for smaller subdivisions were studied by Pramanik and Jagannathan (1954), Parthasarathy and Dhar (1978), Parthasarathy (1984), Mooley and Parthasarathy (1983), Parthasarathy et al. (1993). All-India spatial scale showed treadles and random nature for a long period of time (Mooley and Parthasarathy, 1984). Rao and Jagannathan (1963), Thapliyal and Kulshrestha (1991) and Srivatsava et al. (1992) also reported that All-India southwest monsoon/annual rainfall observed no significant trend. Long term trend in small spatial scale was reported by Koteswaram and Alvi (1969), Jagannathan and Parthasarathy (1973), Jagannathan and Bhalme (1973), Naidu et al. (1999) and Singh and Sontakke (1999). Rupa Kumar et al. (1992) have found significant increasing trend in monsoon rainfall along the West Coast, north Andhra Pradesh and northwest India while significant decreasing trends over Madhya Pradesh and adjoining area, northeast India and parts of Gujarat and Kerala. Guhathakurta and Rajeevan (2007) observed decreasing trend in almost all subdivisions except for subdivisions in Himachal Pradesh, Jharkhand and Nagaland, Manipur, Mizoram and Tripura during winter. During pre-monsoon season, rainfall is decreasing over most parts of the Central India, Gujarat region, West Madhya Pradesh, East Madhya Pradesh, Vidarbha, Chattisgrath and Jharkhand. Rainfall is significantly increasing over Sourashtra and Kutch, Marathwada and Rayalseema during post-monsoon season. Annual and southwest monsoon rainfall showed

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significant decreasing trend over Chattisgrah, Jharkhand and Kerala. All these studies reveal that there is no similarity in rainfall trends at the regional level.

Kerala State is located between 8°15′N and 12°50′N latitudes and between 74°50′E and 77°30′E longitudes (Fig. 1). The State of Kerala is popularly known as the "Gateway of summer monsoon" over India. It is a strip of land running almost in North–South direction and is situated between the West Arabian sea on the West and the ranges of Western Ghats and Nilgiri hills on the East both running parallel to each other. From the Western Ghats, the State undulates to the West and presents a series of hills and valleys intersected by numerous rivers. On extreme West, the State is more or less flat. These characteristics demarcate the State into three natural regions viz., the eastern high lands, the hilly midlands and western low lands. The changes in the geographical and topographical features due to man-made interventions are likely to influence atmospheric circulation altitudinally to a large extent. It may be one of the reasons in recent times for uncertainties in monsoon variability and rainfall distribution over Kerala. Ananthakrishnan and Soman (1988, 1989) studied the onset of monsoon and monsoon rainfall in detail over Kerala utilising the data up to 1980. Soman et al. (1988) reported that annual rainfall over Kerala showed significant decreasing trend. In view of the importance of variability in rainfall, as indicated above, it would be of interest to study the long-term variation of monthly, annual and seasonal rainfall over Kerala which is known as the "Gateway of summer monsoon" over India.

2. Data and methodology

The source of monthly rainfall (mm) over Kerala from 1871 to 1994 is from the IITM publication entitled "Monthly and seasonal rainfall series for all-India homogeneous regions and meteorological subdivisions: 1871–1994" (Parthasarathy et al., 1995). Monthly, seasonal and annul rainfall series of Kerala State were constructed using monthly rainfall data of fixed network of 10 raingauge stations. On an average, there is one raingauge station for every 3886.4 sq. km area. From 1995 to 2005, the monthly rainfall data were collected from the daily weather reports published by the IMD, Trivandrum. From the Basic monthly rainfall data, monthly mean, seasonal rainfall, Standard Deviation (SD) and Coefficient of Variation (C.V.) and 75 per cent rainfall probability were computed monthly and season-wise viz., Pre-monsoon (March–May), Southwest monsoon (June–September), Post-monsoon (October–November) and Winter (December–February) that are depicted in Table 1. The data were subjected to 11-year-running mean to find out long term trends. A linear trend line was added to the series for simplify the trends. To support trends in annual and seasonal rainfall, decade-wise shifts in rainfall over Kerala were also analysed from the period 1871 to 2005. Temporal changes in the seasonal and annual rainfall were also analysed by Man-Kendall rank statistics (t) to confirm the significance of the observed trend. The values of t were used as the basis of a significant test by comparing it with

$$T_t = 0 \pm t_g \sqrt{4N + 10/9N(N-1)}$$

where t_g is the desired probability point of the Gaussian normal distribution. In the present study, t_g at 0.01 and 0.05 points were considered for comparison. Apart from this, the linear trend fitted to the data was also tested with t test to verify results obtained by Man-Kendall test.

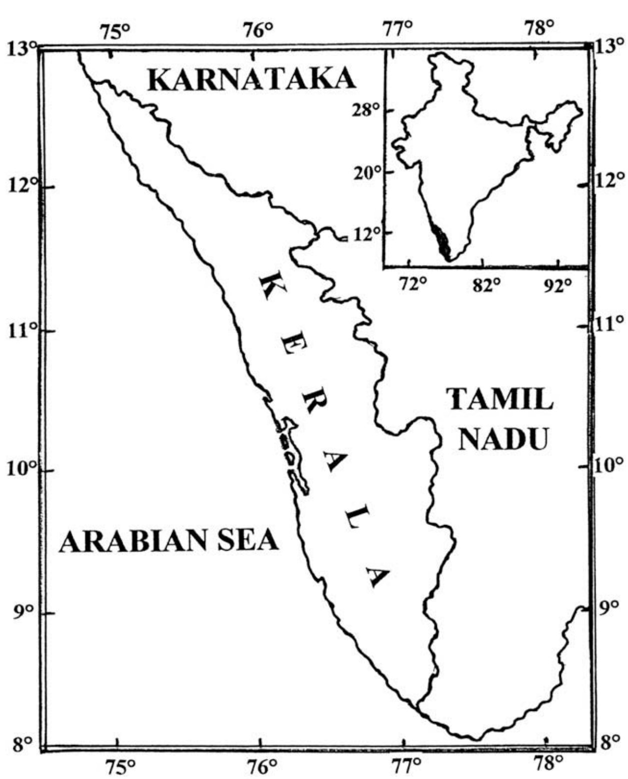

Fig. 1. Location map of Kerala.

3. Rainfall features

Rainfall characteristics of Kerala are reported in Table 1. The annual normal rainfall over Kerala from 1871 to 2005 is 2817 mm with a standard deviation of 406 mm. The dependable annual rainfall at 75 per cent level is 2493 mm and the dependable seasonal rainfall at 75 per cent for pre-monsoon, southwest monsoon, post-monsoon and winter season is 269.3 mm, 1624.2 mm, 341.0 mm and 30.3 mm, respectively. The coefficient of variation of annual rainfall is 14.4%, indicating that it is highly stable. Rainfall during June is the highest (684 mm) and contributes to 24.3% of annual rainfall (2817 mm), followed by July (22.4%). Rainfall in August and September contributes to 13.2% and 8.0% of

Table 1
Monthly and seasonal means of rainfall (mm) over Kerala from 1871 to 2005.

Month	Rainfall (mm)				
	Normal	Standard deviation	CV (%)	75% probability	Percentage contribution to annual rainfall
January	12	17	146.1	0.4	0.4
February	17	19	115.4	2.9	0.6
March	36	28	78.5	15.5	1.3
April	112	52	46.5	75.3	4.0
May	246	159	64.6	131.1	8.7
June	684	194	28.4	576.3	24.3
July	632	209	33.2	502.8	22.4
August	373	157	42.0	270.5	13.2
September	224	122	54.7	134.7	8.0
October	288	108	37.5	204.5	10.2
November	156	85	54.4	91.5	5.5
December	38	39	102.1	11.3	1.3
Annual (mm)	2817	406	14.4	2493.0	100
Pre-monsoon	393.7	163.5	41.5	269.3	14.0
Southwest	1913.5	377.7	19.7	1624.2	67.9
Post-monsoon	444.1	138.4	31.2	341.0	15.8
Winter	65.3	46.7	71.4	30.3	2.3

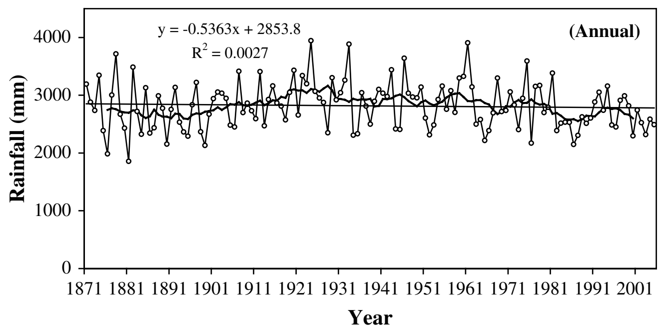

Fig. 2. Annual rainfall trends over Kerala from 1871 to 2005.

the annual rainfall, respectively. Rainfall in January is the least (12.0 mm) and contributes only 0.4% to the annul rainfall. The coefficient of variation is also the highest during January (146.1%), followed by February (115.4%) and December (102.1%) and the least during the high rainfall months of June (28.4%) and July (33.2%). Rainfall during the southwest monsoon (June–September) contributes 67.9% of the annul rainfall. The contribution of pre-monsoon (March–May), post-monsoon and winter rainfall to the

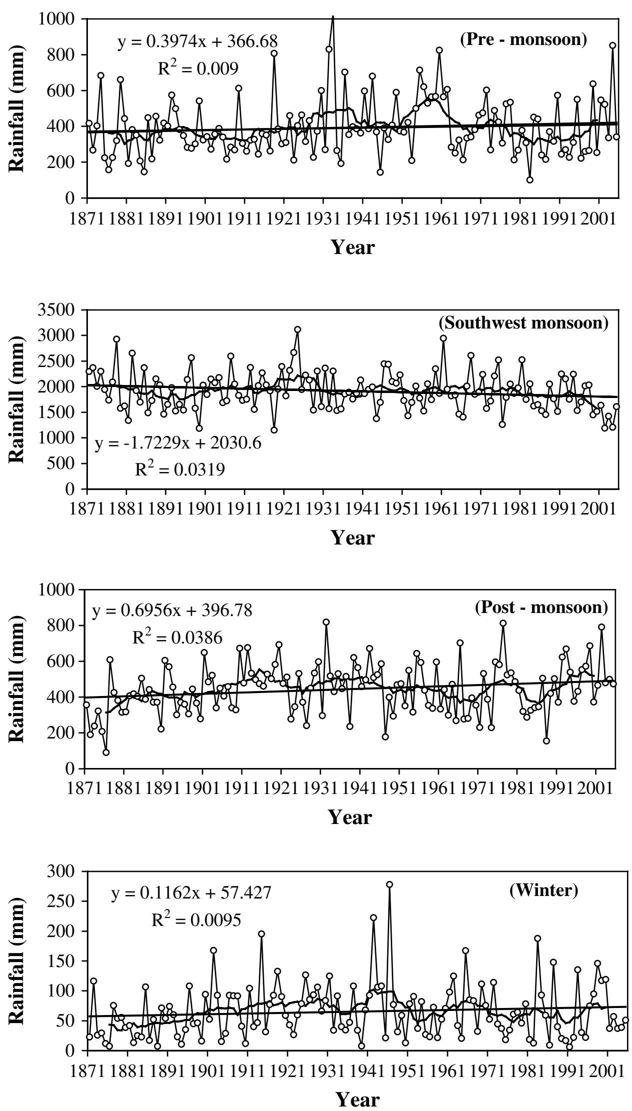

Fig. 3. Seasonal rainfall trends over Kerala from 1871 to 2005.

Table 2
Linear equations and their significance tested by *t*-test.

Rainfall	Linear equations	Calculated *t*
Annul	$y = -0.5363x + 2853.8$	0.6006
Pre-monsoon	$y = 0.3974x + 366.68$	1.0990
Southwest monsoon	$y = -1.7229x + 2030.6$	2.0934**
Post-monsoon	$y = 0.6956x + 396.78$	2.3108**
Winter	$y = 0.1162x + 57.427$	1.1294

*Significant at 0.05 level, **significant at 0.01 level.

annual is 14.0, 15.8 and 2.3, respectively. The seasonal rainfall during monsoon (June–September) is dependable as the coefficient of variation is 19.7%. At the same time, rainfall during winter is undependable as the coefficient of variation is very high (71.4%), varying between 102.1% in December and 146.1% in January.

4. Annual rainfall trends

The mean annual rainfall over Kerala showed a long term insignificant declining trend. However, the declining trend in annual rainfall was significant if the annual rainfall considered from 1951 onwards. The annual rainfall in recent years from 1999 to 2005 was less by 9.8%. A relatively wet period (excess rainfall) was seen in earlier decades from 1900 to 1980 (Fig. 2). A decrease of 72.4 mm only was noticed during the study period of 135 years as against the normal rainfall of 2817 mm.

5. Seasonal rainfall trends

5.1. Pre-monsoon (March–May)

A decline in pre-monsoon rainfall was noticed up to mid 1920 and then increased up to later 1930s (Fig. 3). There was an overall insignificant increase during the study period of 135 years. An increase of 53.7 mm was noticed as against the normal (393.7 mm).

5.2. Southwest monsoon (June–September)

The southwest monsoon rainfall was more from 1901 to 1930 against the normal while decreasing from 1981 to 2005. The Man-Kendall test statistics (−2.0582) indicates that the decrease in southwest monsoon rainfall is significant at 0.01 level. Overall, a decline of 232.6 mm was noticed during the study period of 135

Table 3
Man-Kendall rank statistics of monthly and seasonal rainfall over Kerala.

Month	Rainfall (mm)
January	**2.1438****
February	1.7961*
March	0.9454
April	1.7443*
May	0.3139
June	−**2.5660****
July	−1.7177*
August	0.2771
September	0.7342
October	1.4457
November	1.5351
December	−0.2891
Annual (mm)	−0.6619
Pre-monsoon	0.9568
Southwest monsoon	−**2.0582****
Post-monsoon	**2.2160****
Winter	1.0082

*Significant at 0.05 level, **significant at 0.01 level.

Table 4
Monthly and seasonal contribution of rainfall (%) to annual from 1871 to 2005 over Kerala.

Month/Season	1871–1900	1901–1930	1931–1960	1961–1990	1991–2005
June	27.7	24.1	23.1	22.4	24.0
July	22.9	23.6	21.8	22.8	19.7
August	13.2	12.9	12.8	14.6	12.2
September	7.3	8.2	7.3	9.1	7.6
October	9.3	10.4	10.2	9.5	13.3
November	4.3	5.9	6.0	5.5	6.3
Pre-monsoon	13.4	12.2	16.4	13.6	14.4
Southwest monsoon	71.2	68.8	65.1	68.9	63.6
Post-monsoon	13.6	16.3	16.2	15.0	19.5
Winter	1.2	2.6	2.5	2.4	2.4

years indicating that on an average, the southwest monsoon rainfall decline was about 1.7 mm year^{-1}. In recent years, the distribution of rainfall during the season is poor and in the major water reservoirs, the water level was low on which the hydel power generation depends across the State.

5.3. Post-monsoon (October–November)

Post-monsoon rainfall depicts two epochs of high rainfall around mid 1910s and 1940s. The Man-Kendall test indicated that the seasonal rainfall during the post-monsoon is significant at 0.01 level and increasing trend was noticed. Therefore, it can be inferred that the post-monsoon rainfall was significantly increasing. Such trend was more evident since 1961 onwards. It also showed through the trend line that an increase of 93.9 mm was noticed during the study period of 135 years. The post-monsoon rainfall increasing was about 0.7 mm year^{-1} during the study period.

5.4. Winter (December–February)

The winter rainfall had an increasing tendency, which is not statistically significant. The 11-year – running – mean indicated that winter rainfall increased from 1900 to 1950. It also showed through the trend line that an increase of 15.7 mm only was noticed during the study period of 135 years. Increase in rainfall during the season is beneficial to the plantation crops. However, high variability of rainfall lead to uncertainty and the crops need assured irrigation. The *t*-test when applied (Table 2) indicated that southwest and post-monsoon rainfall trends are significant at 0.01 level.

6. Monthly rainfall trends

Behaviour of monthly rainfall has been studied for individual months by subjecting them to the Man-Kendall test. The results are presented in Table 3. It is interesting to note that rainfall in June and July showed a decreasing trend and significant at 0.01 and 0.05 level, respectively. Rainfall of August, September, October and November showed an insignificant increasing trend. Rainfall during January showed an increasing trend which is significant at 0.01 level. February and April also showed increasing trend, which is statistically significant at 0.05 level, while remaining months showed no particular significant trend. There was a decline in (27.7–22.4%) rainfall contribution of June to the annual rainfall over a period of time (Table 4). Unlike in June, the contribution of rainfall during July is stable though variations were noticed from one- and three-decadal-period to another. In contrast, the contribution of rainfall during August (13.2–14.6%) and September (7.3–9.1%) is increasing. Similar increasing trends were noticed during October and November in rainfall contribution to the annual. As a whole, the percentage rainfall contribution during the southwest monsoon was declining while increasing during pre- and post-monsoon season and winter over Kerala. The above phenomenon was more significant in recent decades. However, rainfall during the monsoon season is stable while instable in remaining months. These two contrasting phenomena in seasonal rainfall trends are the major concern across the State. Rainfall increase during January, February and April will be beneficial to majority of the plantation crops. However, cloudy weather and rain during the above months may adversely affect the fruit quality in mango, cashew and black pepper.

7. Shifts in decade-wise annual and seasonal rainfall

Decade-wise percentage departure of annual and seasonal rainfall, frequencies of excess and deficit years depicted in Table 5. The deficient or excess rainfall years are defined for those years when rainfall is less or more than the standard deviation. Pant and Rupa Kumar (1997) reported that Indian summer monsoon displays multi-decadal variations in which there is clustering of dry or wet anomalies. During the wet decade 1871–1880, there were four excess rainfall years. During the dry period of 1881–1900, three excess years and five deficit years were observed. During the next five decades of the wet period, ten excess years and two deficit years only have been found. In the dry period of 1951–2005, there were 14 deficit years and five excess years. During the period of

Table 5
Decadal mean (% departure from normal), frequency of excess and deficit rainfall years over Kerala from 1871 to 2005.

Decade	Pre-monsoon			Southwest monsoon			Post-monsoon			Winter			Annual		
	Decadel mean (% departure from normal)	Excess	Deficit	Decadel mean (% departure from normal)	Excess	Deficit	Decadel mean (% departure from normal)	Excess	Deficit	Decadel mean (% Departure from normal)	Excess	Deficit	Decadel mean (% departure from Normal)	Excess	Deficit
1871–1880	−3.4	2	3	9.1	4	0	−28.8	1	4	−33.1	1	2	0.7	2	2
1881–1890	−20.2	0	4	−1.5	2	3	−12.7	0	1	−37.1	0	3	−6.9	1	4
1891–1900	−0.1	1	0	−6.8	1	2	−8.0	1	2	−21.6	0	2	−6.6	1	4
1901–1910	−14.1	1	1	3.8	1	0	5.5	2	0	4.9	1	2	1.6	1	0
1911–1920	−8.0	1	0	1.5	2	1	23.1	2	0	33.0	2	0	4.0	2	0
1921–1930	−3.6	1	2	13.3	4	0	−1.6	1	2	17.8	1	0	8.7	3	1
1931–1940	21.9	3	1	−1.5	2	0	12.9	2	2	−9.7	1	1	3.6	2	2
1941–1950	8.3	3	1	5.3	2	1	4.0	2	2	54.5	2	1	6.6	2	1
1951–1960	35.1	5	1	−5.0	1	2	5.6	3	0	−15.0	0	0	1.7	1	1
1961–1970	−4.5	2	1	3.4	2	2	−13.2	1	4	28.6	2	1	0.1	2	2
1971–1980	4.2	1	1	0.4	1	1	11.5	2	2	−15.7	1	0	2.3	1	2
1981–1990	−13.9	1	2	−6.4	1	3	−17.4	0	2	−7.5	2	3	−9.3	1	3
1991–2000	−17.8	1	2	−2.5	0	3	17.8	3	0	17.4	4	1	−1.4	0	1
2001–2005	32.0	1	0	−26.0	0	3	22.9	1	0	−32.3	0	0	−10.1	0	1

1871–2005, the number of deficit years was more (24) than the number of excess years (19) on annual basis while excess rainfall years more than or equal to deficit rainfall years during pre-monsoon, southwest monsoon, post-monsoon and winter seasons.

8. Conclusion

An important aspect of the present study is the significant decrease in southwest monsoon rainfall while increase in post-monsoon season. Rainfall decline is more predominant in June and July but not so in August and September within the monsoon season. There was a major shift in rainfall pattern temporarily during recent years as seasonal rainfall during the southwest monsoon was declining while increasing in post-monsoon season. The decreasing trend in southwest monsoon rainfall over Kerala is supported by other researchers (Rupa Kumar et al., 1992; Guhathakurta and Rajeevan, 2007). Joseph et al. (2004) reported that the period of Intra Seasonal Oscillation of South Kerala rainfall during summer monsoon has large inter-annual variability in the range of 23–64 days. Joseph and Xavier (1999) reported that monsoon depression frequency had a strong decreasing trend during last 100 years and the frequency now is less than half of the frequency of depressions at the beginning of the twentieth century. Rajendra Kumar and Dash (2001) showed that the decadal frequency of number of depressions was decreasing in recent years. Joseph and Simon (2005) reported that the southwest monsoon current through peninsular India from surface to 1.5 km altitude between 10 and 12°N latitude had significant decreasing trend. Sathiyamoorthy (2005) and Rao et al. (2004) showed that strength of Tropical Easterly Jet Stream was decreasing in recent 5 decades. The number of monsoon depressions formed during the southwest monsoon season, strength of monsoon current and strength of Tropical Easterly Jet Stream are the important rain bearing systems during southwest monsoon season. The frequency decline of the above weather systems in recent years over peninsula may be an important reason for decrease in southwest monsoon rainfall over Kerala. In addition to this, there is a drastic change in biophysical resources of Kerala State due to man-made interventions in recent decades. It indirectly affects the physical processes between the earth-atmosphere continuum and influenced the distribution of local rainfall during winter and pre-monsoon season. There has been a two-fold increase in the tropical cyclones frequency over Bay of Bengal during November in past 122 years (Singh et al., 2001). Cyclones developed during the post-monsoon season contribute significant amount of rainfall during the season. It is a peculiar climatic feature over southern peninsula due to the influence of Bay of Bengal. Increasing the frequency of tropical cyclones during the post-monsoon season may be the one of the important reasons for increasing post-monsoon rainfall over Kerala.

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