# Inter-annual and Long term Variability of Rainfall in Kerala

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***ABSTRACT***

*Long term (141 years) surface meteorological data have been analysed to study inter-annual variability in rainfall for all seasons and months. Summer monsoon rainfall of India and Kerala has considerable inter-annual variability in the date of onset, withdrawal and the activity of the monsoon during the Indian summer monsoon season, even though the summer monsoon is considered to be prevailed during the period 01 June to 30 September. Similar is the case with the northeast monsoon rainfall also. The time series of 141 years rainfall exhibits a large amplitude inter-annual variability. It is found that a year with large above normal rainfall is generally followed by a year with large below normal rainfall and vice versa, a type of biennial oscillation. This biennial tendency is shown to be associated with the changes in ocean surface temperature of tropical Indian and west Pacific oceans. Results on various analyses show strong and vivid features contributed by climate change for this south western state. The rainfall pattern of the state displays large north-south and east-west gradients. The peculiar geographic orientation of Kerala with Arabian Sea as western boundary makes the weather pattern very unique in this part of Indian subcontinent. Summer monsoon rainfall of Kerala shows a decreasing trend of 10.9cm in 100 years and northeast monsoon rainfall shows an increasing trend of 7.5 cm in 100 years during the period of study. Epochal variability of rainfall with 31 year moving average of seasonal rainfall shows that presently rainfall is in the below normal epoch of its natural variability.*

***Key words:*** *Inter-annual variability, South west Monsoon, North east Monsoon, Biennial tendency, Epochal variability.*

## 1. Introduction

Inter-annual variability of summer monsoon has a serious impact on Indian economy (Mooley et al 1981, Mooley and Parthasarathy 1983) as agriculture; hydroelectric power and industry in India are heavily dependent on the performance of the monsoon, which provides 75-90% of the annual rain-water potential over most part of India. A large number of studies have been undertaken in India to assess the variability of monsoon rainfall and trends in rainfall in the country.

It has been noticed that there is considerable variability in the Indian summer monsoon rainfall (lSMR) for the past decades. Awareness of the need to understand and predict the monsoon over India has recently generated much interest in the possible relationship between the amount and distribution of Indian monsoon rainfall and antecedent regional and global features. The most important need in monsoon forecasting is to predict with a reasonable degree of success, the years of excess and deficient rainfall. The weather systems which occur globally and regionally, contribute some variability in the monsoon rainfall. It has been established that the El Nino, which occurs in the Pacific Ocean, has some influence on the Indian summer monsoon rainfall. Normally during

the El Nino years Indian monsoon is weaker compared to other years.

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) 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 decreases 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 postmonsoon season. Annual and southwest monsoon rainfall showed 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, which is located between latitudes $8^0$15' N and $12^0$ 50' N and longitudes $74^0$50'E and $77^0$30' E, is a strip of land running almost in North–South direction and is situated between the Arabian sea on the West and Western Ghats on the East both are lying 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 utilizing 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.

It was shown that the variations in the monsoon have some link with the upper tropospheric thermal and circulation anomalies (Murakami, 1974; Krishnamurti et al., 1975; Kanamitsu & Krishnamurti, 1978). The stratospheric quasi-biennial oscillation (QBO) is a dominant mode of interannual variation of the equatorial lower stratospheric zonal wind and there is some relation with the phases of the QBO (zonal wind direction changes from easterly to westerly, in the

tropical stratosphere and upper troposphere with periodicity of about 26 months) and Indian summer monsoon.

The strong easterly phase of the QBO is associated with weak (DRY) Indian monsoon and weak easterly/westerly phase with strong (WET) monsoon (Mukherjee et al., 1985). If a relation between QBO and Indian monsoon rainfall could be established, it would be of immense use for making long-range prediction of the monsoon variability, which will be highly beneficial for agriculture and thus the economy of the country.

In this paper attempts are made to study temporal variation in monthly, seasonal and annual rainfall during the period from 1871 to 2011, over Kerala, which is the ‘‘Gateway of summer monsoon to the country’’. Long term variability in rainfall has been determined by linear regression method.The analysis revealed that significant decrease is there in southwest monsoon rainfall while increase in post-monsoon rainfall over the State of Kerala. 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. Scarcity in Hydel power and water availability during summer months is the concern in the State due to rainfall deficiency in June and July, which are the rainiest months.

## 2. Data and Methodology

The monthly rainfall (mm) values over Kerala from 1871 to 2011 are obtained from the website of IITM Pune. Therein even though the available data set is based on limited number of stations, it is homogeneous in nature. From the Basic monthly rainfall data, monthly mean, seasonal rainfall, Standard Deviation (SD) and Coefficient of Variation (CV) are computed and these statistical parameters for monthly and seasonal viz., Winter (January–February), Pre-monsoon (March–May), Southwest monsoon (June–September) & Post-monsoon (October–December) and annual rainfall are depicted in Table 1. The data were subjected to 11-year-moving average to find out long term trends. A linear trend line was added to the series to 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 2011.

## 3. Results and Discussion

### 3.1 Rainfall features

From the Table 1, which depicts the rainfall characteristics of Kerala, it is seen that the annual normal rainfall over Kerala from 1871 to 2011 is 2828 mm with a standard deviation of 401 mm. The coefficient of variation of annual rainfall is 14.2%, indicating that it is highly stable. Rainfall during the winter month, January is the least (11 mm) contributing only 0.4% to the annual rainfall and with highest coefficient of variation (149.4%), which means that rainfall during January is highly uncertain. Rainfall during February (17mm) and December (37mm) are also undependable as CV is 115.4% & 102.1% contribution to annual rainfall is 0.6% and 1.3% respectively. The rainfall during June is the highest (683 mm) and contributes to 24.2% of annual rainfall (2828 mm), followed by July (22.5%). Rainfall in August and September contributes to 13.3% and 8.1% of annual rainfall respectively. Highly dependable rainy month is June with least CV of 28% followed by July with CV 32.1%.

Rainfall during the southwest monsoon (Indian Summer Monsoon) season (June-September) contributes 68.1% of the annual rainfall. Among all seasons, the seasonal rainfall during ISM is highly dependable as

the coefficient of variation is only 19.1%, whereas rainfall during winter is undependable as the coefficient of variation is very high (96.2%). The contribution of winter, pre-monsoon and post monsoon season to the annual rainfall is 1.0%, 13.8% and 17.1% respectively (Fig.1).

**Table 1: Monthly and seasonal rainfall (mm) over Kerala from 1871 to 2011**

| Month / Season | Rainfall (mm) | | | |
|---|---|---|---|---|
| | Average | Standard Deviation | CV(%) | % contribution of Annual R/F |
| January | 11 | 17 | 149.4 | 0.4 |
| February | 17 | 21 | 121.8 | 0.6 |
| March | 37 | 32 | 88.6 | 1.3 |
| April | 112 | 51 | 45.8 | 3.9 |
| May | 242 | 156 | 64.6 | 8.6 |
| June | 683 | 191 | 28.0 | 24.2 |
| July | 636 | 204 | 32.1 | 22.5 |
| August | 375 | 155 | 41.3 | 13.3 |
| September | 230 | 123 | 53.5 | 8.1 |
| October | 289 | 107 | 37.1 | 10.2 |
| November | 158 | 86 | 54.2 | 5.6 |
| December | 37 | 38 | 101.3 | 1.3 |
| Winter | 28 | 27 | 96.2 | 1.0 |
| Pre-monsoon | 390 | 159 | 40.7 | 13.8 |
| SW Monsoon | 1925 | 367 | 19.1 | 68.1 |
| Post Monsoon | 484 | 147 | 30.4 | 17.1 |
| Annual R/F | 2828 | 401 | 14.2 | 100.0 |

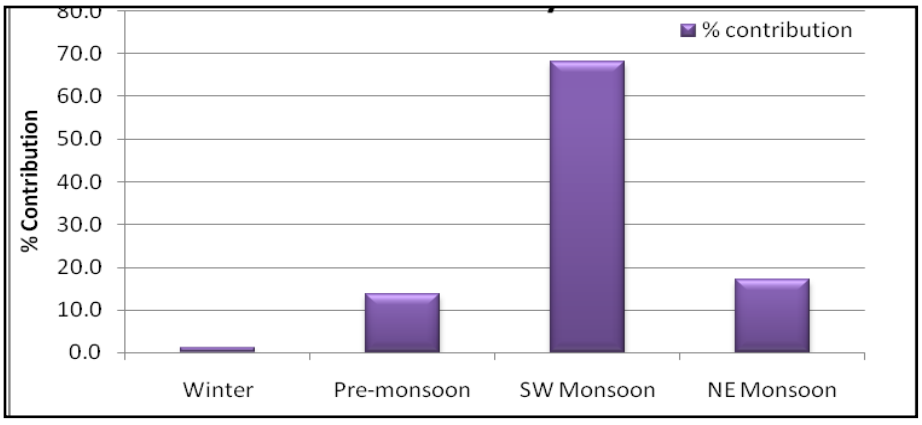


**Fig.1 Percentage contribution of all seasons to annual rainfall**

### 3.2 Annual rainfall trends

Trend analysis shows that there is a long term insignificant decreasing trend in the mean annual rainfall over Kerala during this 141 year period (Fig.2). A significant declining trend in annual rainfall is noticed from 1951 onwards. An annual decrease of 4.8 mm was noticed during the study period of 141 years as against the normal rainfall of 2831 mm whereas a decline of 163.7 mm was noticed during the period of last 91 years as against the normal rainfall of 2844 mm. An increasing trend of 15% in the annual rainfall is noticed in the last decade. A relatively wet period (excess rainfall) was seen in earlier decades from 1900 to 1980 (Fig. 2).

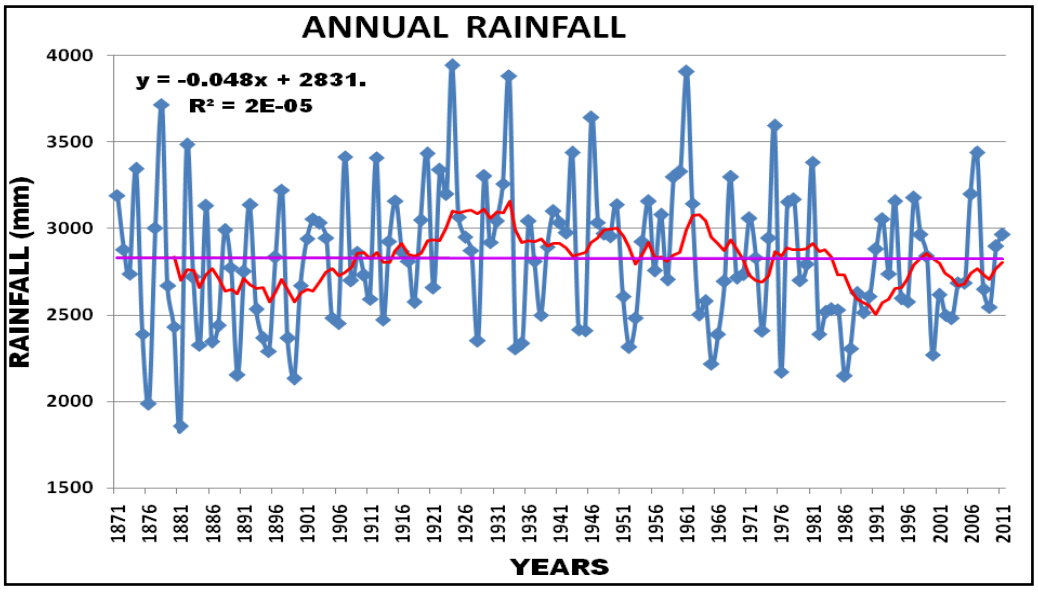


**Fig.2 Long term variability of annual rainfall**

### 3.3 Seasonal rainfall trends

**Winter (January –February)**

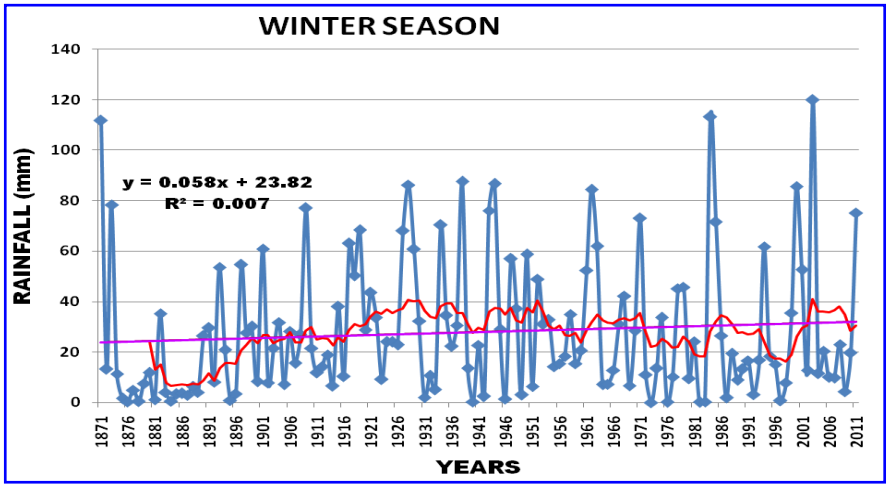


**Fig.3 Long term variability of rainfall during winter season**

10 year moving average indicates that the winter rainfall had a decreasing trend upto 1911-20 later half , while increasing trend thereafter till 1951 (fig.3). Decreasing trend existed from 1971 to 2001 and during last decade winter rainfall was increasing. Overall, an increase of 5.8 mm was noticed during the study period of 141 years as against a normal of 23.82 mm.

**Pre-monsoon season (March – May)**

Pre-monsoon rainfall depicts three epochs of high rainfall during 1930-1940, 1950-1960 and 2000-2010 (fig.4).There was an overall insignificant increase of pre-monsoon rainfall of 23.5 mm was noticed as against the normal of 373.6 mm during the study period of 141 years. A decline in decadal pre-monsoon rainfall was noticed up to early 1900s, 1940s, and 1960s and later half of 1970s till 2000.

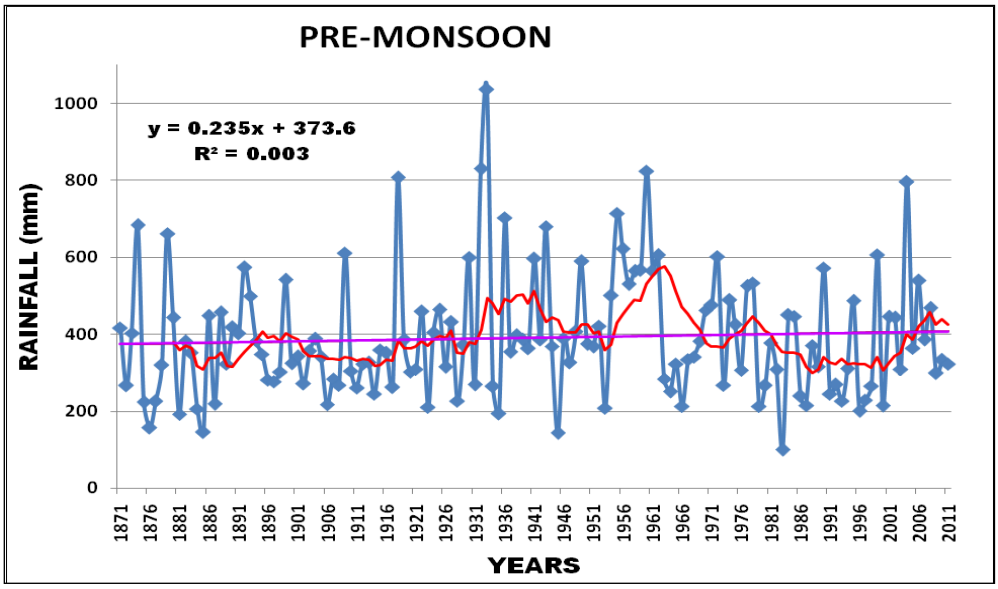


**Fig.4 Long term variability of rainfall during pre-monsoon season**

**Southwest monsoon (June–September)**

10 year moving average indicates that the Southwest monsoon rainfall had a decreasing trend upto 1900, thereafter sharp increase is noticed during 1900-1910, 1920s, 1940s, 1960s and later half of 1970s & 1980s, 1990s (fig.5) . All other period show declining trend. Overall, a decrease in rainfall of 109 mm was noticed during the study period of 141 years as against a normal of 2002 mm. The Southwest monsoon rainfall was decreasing at the rate of 10.9 mm per decade.

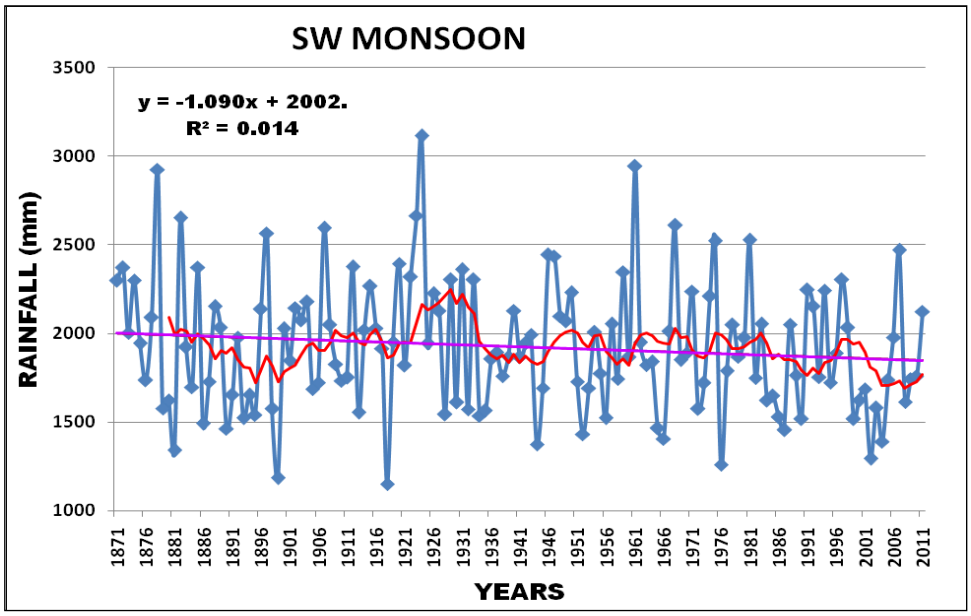


**Fig.5 Long term variability of rainfall during southwest monsoon season**

**Post-monsoon (October–December)**

Post-monsoon rainfall depicts four epochs of high rainfall during 1910s, 1930-40, later half of 1970s and 1990s onwards (fig.6) .Trend line analysis infers that the post-monsoon rainfall was significantly increasing at the rate of 7.4 mm per 10 years and 10 year moving average shows that such trend was persistent except during 1960s, 1970s and early half of 1980s. Overall an increase of 74.7 mm was noticed during the study period of 141 years as against a normal of 431.3 mm (fig.7).

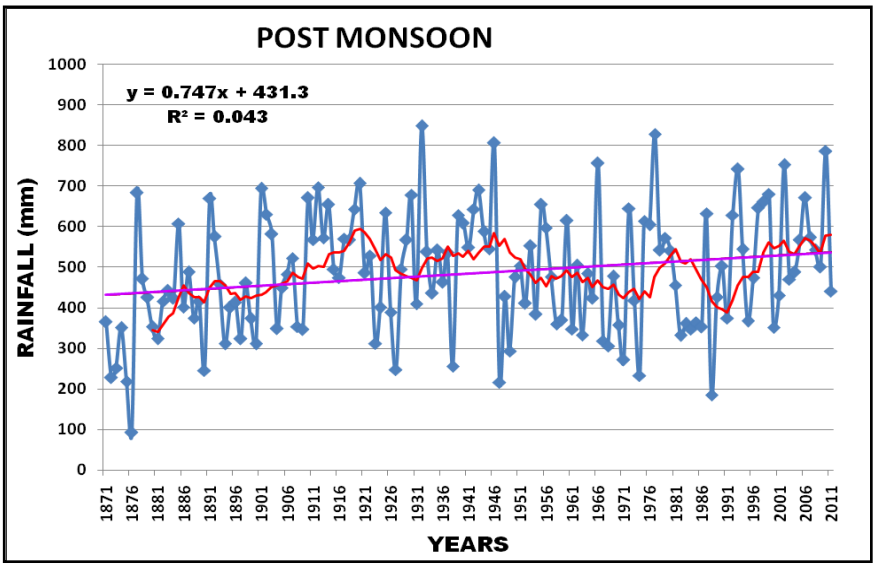


**Fig.6 Long term variability of rainfall during post monsoon season**

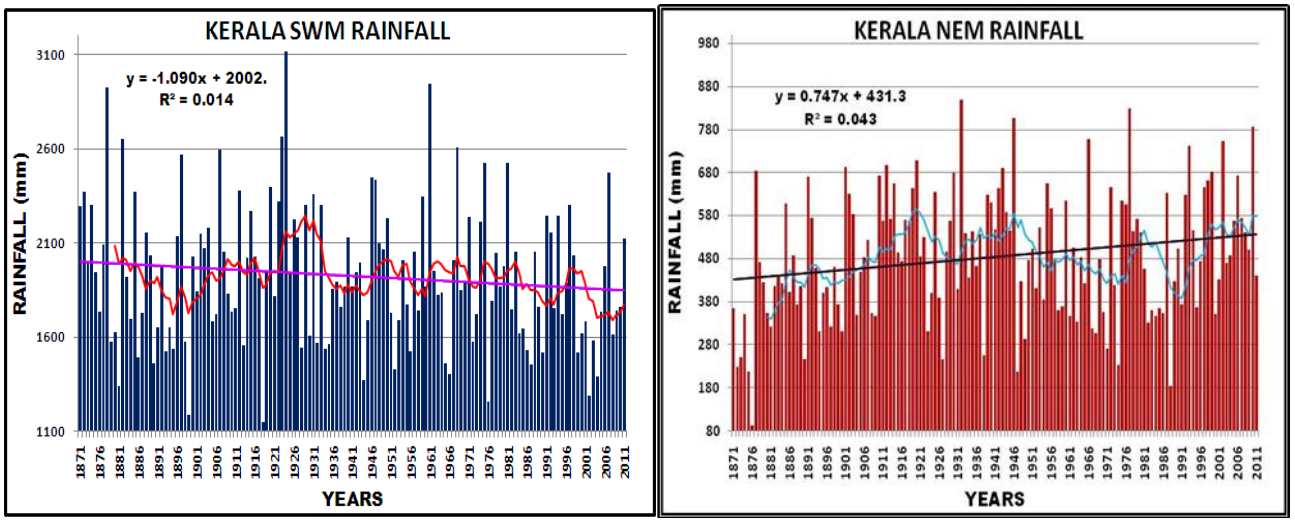


**Fig.7 Comparison of long-term variability of both South West Monsoon and North east Monsoon rainfall**

### 3.4 Monthly rainfall trend

Decade-wise mean of monthly and seasonal rainfall contribution to annual rainfall is tabulated in table 2. It shows that there is a significant decreasing trend in monthly rainfall of June and July, while rainfall of January and December showed an insignificant decreasing trend. Rainfall during February, March, September, October and November showed a significant increasing trend, where as that during April, May & August showed an insignificant increasing trend. There was a decrease of (28 % to 22.4%) rainfall contribution of June and decline from 23 to 18.4% in the contribution of July rainfall to the annual rainfall over a period of time 141 years.

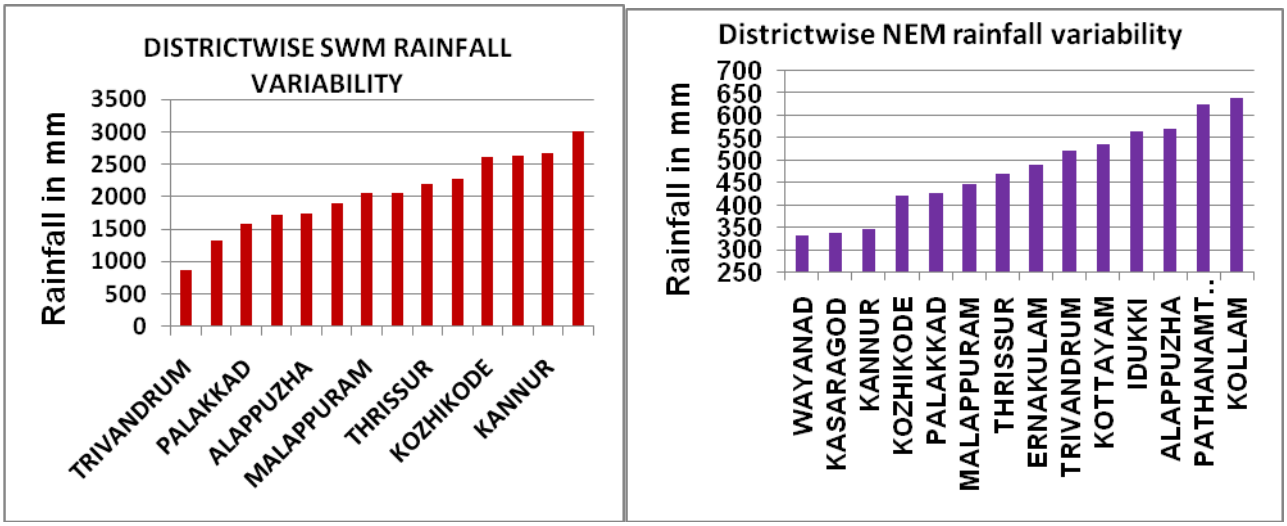


**Fig. 8 District-wise comparison of Southwest Monsoon and Northeast Monsoon Rainfall**

In contrast, the contribution of rainfall during August (12.9 –15.1%) and September (7.3–9.6%) is increasing. Notable increasing trends were noticed during October and November, while during December more or less steady value 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 seasons, trend during winter is stable over Kerala (table 2). The above phenomenon was more significant in recent decades. However, change in rainfall during the monsoon season is steady, while it is unsteady in remaining months.

**Table 2: Decade-wise monthly and seasonal contribution of rainfall (%) to annual from 1871 to 2010 over Kerala**

| % contri-bution | 1871-1880 | 1881-1890 | 1891-1900 | 19401-1910 | 1911-1920 | 1921-1930 | 1931-1940 | 1941-1950 | 1951-1960 | 1961-1970 | 1971-1980 | 1981-1990 | 1991-2000 | 2001-2010 |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| Jan | 0.4 | 0.2 | 0.2 | 0.6 | 0.5 | 0.5 | 0.4 | 0.6 | 0.2 | 0.5 | 0.2 | 0.5 | 0.2 | 0.3 |
| Feb | 0.5 | 0.2 | 0.7 | 0.5 | 0.5 | 0.8 | 0.5 | 0.6 | 0.6 | 0.7 | 0.6 | 0.6 | 0.7 | 0.7 |
| Mar | 0.7 | 0.8 | 1.7 | 1.2 | 0.9 | 1.7 | 1.4 | 1.6 | 1.4 | 1.5 | 1.0 | 1.4 | 0.9 | 1.9 |
| Apr | 3.5 | 3.0 | 5.9 | 3.4 | 3.0 | 3.4 | 4.5 | 3.7 | 5.1 | 3.6 | 4.1 | 4.0 | 3.4 | 4.6 |
| May | 9.1 | 8.3 | 7.4 | 7.2 | 8.4 | 7.3 | 10.6 | 8.8 | 12.0 | 8.2 | 9.1 | 7.8 | 6.6 | 9.3 |
| Jun | 28.2 | 28.3 | 26.7 | 23.3 | 25.7 | 23.3 | 20.6 | 24.3 | 24.4 | 19.6 | 21.4 | 26.7 | 25.4 | 20.8 |
| Jul | 23.5 | 22.9 | 22.2 | 25.5 | 21.0 | 24.2 | 22.8 | 21.8 | 21.0 | 26.5 | 23.2 | 18.4 | 21.8 | 20.5 |
| Aug | 12.9 | 13.4 | 13.4 | 12.6 | 11.2 | 14.9 | 14.4 | 13.1 | 10.8 | 14.9 | 14.0 | 15.1 | 13.8 | 11.3 |
| Sep | 9.0 | 7.3 | 5.6 | 8.0 | 8.3 | 8.3 | 6.8 | 7.9 | 7.2 | 9.3 | 8.0 | 10.0 | 7.9 | 9.6 |
| Oct | 7.4 | 9.4 | 11.2 | 10.9 | 11.6 | 8.7 | 11.2 | 8.9 | 10.5 | 9.8 | 9.6 | 9.0 | 11.7 | 13.7 |
| Nov | 3.6 | 5.2 | 4.2 | 5.4 | 6.9 | 5.4 | 5.9 | 6.4 | 5.7 | 3.8 | 7.4 | 5.3 | 6.4 | 6.4 |
| Dec | 1.1 | 1.1 | 0.9 | 1.5 | 1.8 | 1.3 | 1.0 | 2.2 | 0.9 | 1.7 | 1.2 | 1.3 | 1.3 | 0.8 |
| Winter | 0.9 | 0.3 | 0.9 | 1.0 | 1.1 | 1.3 | 0.9 | 1.2 | 0.8 | 1.2 | 0.8 | 1.1 | 0.9 | 1.0 |
| Pre Mon | 13.4 | 12.0 | 14.9 | 11.8 | 12.4 | 12.4 | 16.4 | 14.2 | 18.6 | 13.3 | 14.2 | 13.3 | 10.8 | 15.8 |
| SWM | 73.6 | 71.9 | 67.8 | 69.4 | 66.3 | 70.8 | 64.6 | 67.1 | 63.4 | 70.2 | 66.6 | 70.1 | 68.9 | 62.3 |
| Post Mon | 12.1 | 15.8 | 16.3 | 17.8 | 20.3 | 15.5 | 18.1 | 17.4 | 17.2 | 15.3 | 18.3 | 15.5 | 19.3 | 20.9 |

When district-wise normal rainfall is analyzed, it is seen that there is north-south variability in monthly rainfall pattern. Fig. 8 depicts that north Kerala receives more rainfall during SWM season, while it is reverse during post monsoon season, Fig 9. Shows monthly variability of rainfall with July and June as wettest month for north Kerala, where as June, July and October comes in this category for south Kerala.

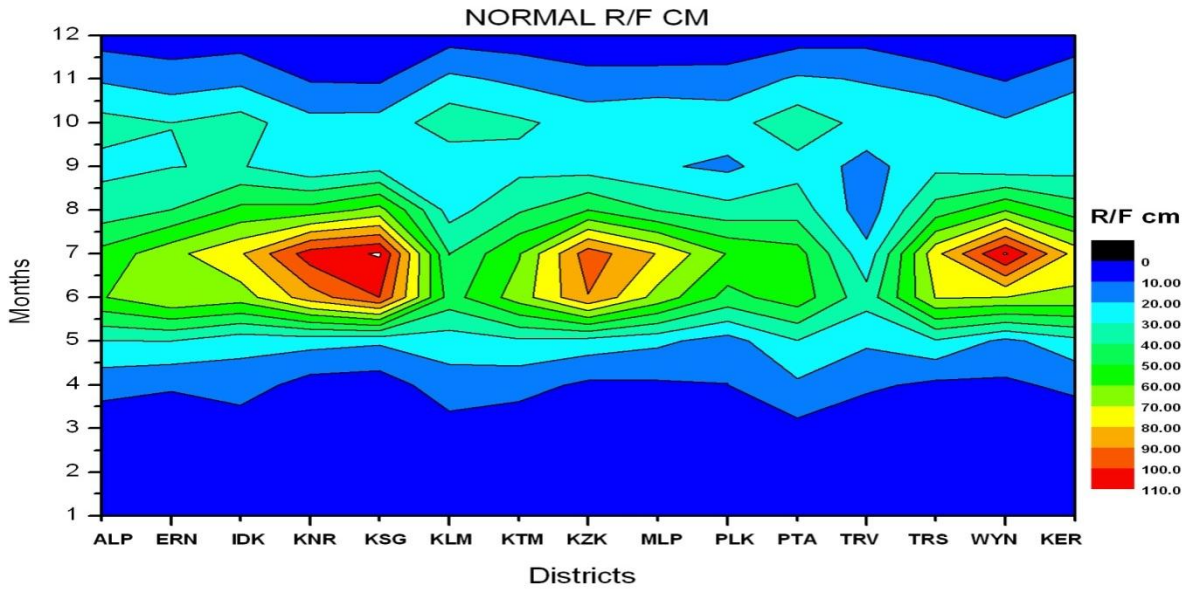


**Fig. 9 Variability in monthly rainfall of all districts of Kerala**

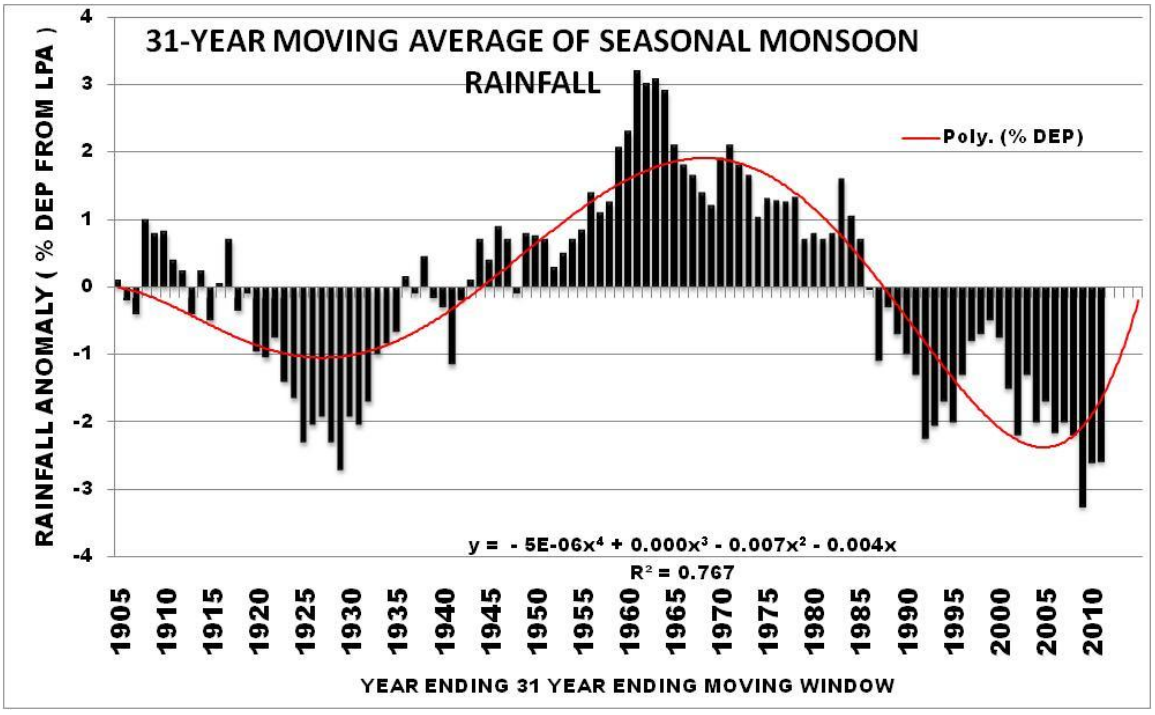


**Fig. 10 31 years' moving average of Southwest monsoon rainfall anomaly**

### 3.5 Decade-wise annual and seasonal rainfall trends

Table 3 depicts decade-wise percentage departure of annual and seasonal rainfall, frequencies of excess and deficit years. When rainfall is less than or more than one standard deviation, then that year is taken as deficient or excess rainfall year. It is noticed that in some decades, when monsoon season is considered, there is clustering of wet or dry

years. During the wet decade 1871–1880, there were four excess rainfall years. During the dry period of 1881–1900 and 1891- 1900 three deficient years each were observed. The decade 1901–1910 was predominantly a normal rainfall decade with only one excess year and no deficit year. During the next four decades of the wet period, ten excess years and 5 deficit years have been found. In the dry period of 1951–2010, there were 11 deficit years and seven excess years were observed. During the period of 141 years, when annual rainfall is considered, the number of deficit years was more (24) than the number of excess years (20). When season's rainfall is considered, excess years were more than deficit years or they are more or less equal for all seasons. Figure 10 depicts that epochal variability of rainfall with thirty one years' moving average for southwest monsoon season is presently in the below normal epoch of its natural variability.

**Table 3 Decade-wise mean of % departure from normal, frequency of excess and deficit rainfall years over Kerala from 1871 to 2010.**

| Decade | Winter | | | Pre-monsoon | | | Southwest monsoon | | | Post monsoon | | | Annual | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | % Dep from normal (decade mean) | Excess r/f years | Deficit r/f years | % Dep from normal | Excess r/f years | Deficit r/f years | % Dep from normal | Excess r/f years | Deficit r/f years | % Dep from normal | Excess r/f years | Deficit r/f years | % Dep from normal | Excess r/f years | Deficit r/f years |
| 1871-1880 | -13.8 | 2 | 2 | -2.6 | 2 | 3 | 8.4 | 4 | 0 | -29.0 | 1 | 4 | 0.3 | 2 | 2 |
| 1881-1890 | -68.7 | 0 | 1 | -19.6 | 0 | 4 | -2.1 | 2 | 3 | -14.6 | 0 | 2 | -7.3 | 1 | 4 |
| 1891-1900 | -15.2 | 0 | 1 | 0.7 | 1 | 0 | -7.3 | 1 | 3 | -11.3 | 1 | 3 | -7.0 | 0 | 4 |
| 1901-1910 | 6.7 | 2 | 0 | -13.4 | 1 | 1 | 3.2 | 1 | 0 | 4.9 | 2 | 0 | 1.2 | 1 | 0 |
| 1911-1920 | 10.8 | 2 | 0 | -7.2 | 1 | 0 | 0.8 | 2 | 2 | 22.8 | 4 | 0 | 3.6 | 2 | 0 |
| 1921-1930 | 44.6 | 3 | 0 | -2.9 | 1 | 2 | 12.6 | 4 | 1 | -2.2 | 2 | 2 | 8.2 | 3 | 1 |
| 1931-1940 | -1.1 | 2 | 1 | 22.8 | 3 | 1 | -2.1 | 2 | 1 | 8.7 | 1 | 1 | 3.2 | 2 | 2 |
| 1941-1950 | 33.8 | 4 | 0 | 9.1 | 3 | 1 | 4.7 | 2 | 1 | 8.1 | 3 | 2 | 6.1 | 2 | 2 |
| 1951-1960 | -14.9 | 0 | 0 | 36.2 | 5 | 1 | -5.6 | 1 | 2 | 1.6 | 1 | 0 | 1.3 | 2 | 1 |
| 1961-1970 | 19.6 | 2 | 0 | -3.7 | 2 | 1 | 2.8 | 2 | 2 | -11.1 | 1 | 3 | -0.3 | 2 | 2 |
| 1971-1980 | -13.5 | 1 | 2 | 5.1 | 1 | 1 | -0.2 | 1 | 1 | 8.8 | 2 | 2 | 1.9 | 1 | 2 |
| 1981-1990 | -0.2 | 2 | 2 | -13.0 | 1 | 2 | -6.9 | 1 | 3 | -18.3 | 1 | 2 | -9.6 | 1 | 3 |
| 1991-2000 | -6.6 | 2 | 1 | -21.8 | 1 | 4 | 1.2 | 1 | 1 | 12.9 | 4 | 0 | -0.1 | 0 | 1 |
| 2001-2010 | 1.5 | 1 | 0 | 12.2 | 1 | 0 | -10.4 | 1 | 2 | 19.4 | 3 | 0 | -2.1 | 1 | 0 |

## 4 Conclusions

It is concluded from the present study that there is significant decrease (10.9 mm in 10 years) in southwest monsoon rainfall while there is increase (7.5 mm in 10 years) in post monsoon rainfall. Rainfall decline is more significant in June and July but not so in August and September. The percentage rainfall contribution during the southwest monsoon has declined whereas there is increasing trend during pre- and post-monsoon seasons. The above phenomenon is more significant in the recent decades. There is a significant increasing trend in monthly rainfall during February, March, October and November. A decrease of (28 % to 22.4%) rainfall contribution of June and a decline from 23 to 18.4% in the contribution of July

rainfall to the annual rainfall is noticed over a period of 141 years. A prominent north-south variability in monthly and season rainfall pattern is also observed, viz. north Kerala receives more rainfall during southwest monsoon season, while it is reverse during post monsoon season.

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