On the Recent Changes in the Characteristics of Rainfall Events Over Kerala

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Abstract **- Fluctuating patterns of precipitation in Kerala and its unending changing character has become very obvious in recent decades. The present study focuses on changes in extreme rainfall events and determining the significant changes in the frequency and duration of rainfall events over Kerala during monsoon period. High resolution daily gridded rainfall data (0.250× 0.250) from 1950–2018 is obtained from India Meteorological Department IMD, Pune. The analysis suggested significant increase in heavy intensity rainfall events in recent decade with a sharp decrease in low intensity rainfall events. The analysis also shows that during monsoon season, short spell rain events with low intensity have increased whereas long spell rain events with low intensity have decreased in number. Results further shows that the short spell rainfall events with heavy intensity is found to have an increasing trend while, long spell of heavy intensity rainfall event have shown a noticeable increase specifically in the Idukki district whereas a decrease is noticed in Malappuram district during 1981-2018.**

Index Terms - Climate Variations. Extreme Events. Rainfall. Significant Trend

INTRODUCTION

It is notable that Indian summer monsoon rainfall (ISMR) is an essential source of water supply vital for agriculture, industrial production and household in the country. Since Indian economy mainly depends on agriculture, monsoon season is a great concern for the Indian farmers where rainfall influences agriculture in a grand manner (Parthasarathy 1984).Not only that, the presence and fluctuation of precipitation to a large magnitude along with temperature decides which crops can be grown in various areas among the world. An interruption in monsoon may lead to shortage of water availability (Lal 2000). Due to the variation in frequency and duration of rain events during monsoon season, the impact of environmental change and their changeability has been examined by numerous researchers in various fields. However, most of the studies are based on the change in trend in the extreme rainfall events. A few investigations have tended to the significant issue of patterns in precipitation over India since the last century. For example, Goswami et al. (2006) have shown that there is a significant increasing trend in extreme rainfall events over Northern India during 1951-2000.Spatial and temporal variation of monsoon rainfall over India for 1871-1988 were analyzed by Subbaramayya and Naidu (1992) and they have reported that, during late 19^{th} century and 1960s, a decreasing trend is found in the central and western parts of Indian subdivisions. The later trend was reversed in the early 1970s. Ramesh and Goswami (2007) showed decreasing trends in both early and late monsoon rainfall and number of rainy days over India for the period 1951-2003.Sushama et.al (2015) studied dry spell characteristics over India based on IMD and APHRODITE datasets. Rajeevan et.al (2008) have examined variability and long trend patterns of extreme precipitation occasions over central India shows significant inter-annual and inter-decadal variations in addition to a statistically significant long term trend of 6% per every decade.Dash et.al (2009) showed that the frequencies of moderate and low downpour days considered over the whole nation have essentially diminished in the last 50 years.

As compared to other states in India, no such study has been conducted on the maritime state Kerala whose geography is divine with pleasant climate. Monsoon in Kerala are broadly divided into two; namely southwest monsoon (June- September) and the northeast monsoon (December–February).Simon and Mohankumar (2004) have found that the state can be divided into three rainfall region with each having a similar covariance structure of annual rainfall. It is also found that Northern Kerala of 10^0 N receives more rainfall (65% of the annual rainfall during the south-west monsoon period) than southern Kerala of 10^0 N (25–30% of annual rainfall during the pre-monsoon and the north-east monsoon periods). Although the mean and standard deviation of daily rainfall over the Kerala regions in India are comparatively homogeneous, trends in seasonal extremes are not regular throughout the state (Pal and Tabba 2009). Krishnakumar et.al (2009) studied the precipitation drifts over Kerala region in twentieth century where the analysis suggested a significant decrease in southwest monsoon rainfall while increase in post monsoon season over the State of Kerala. Rainfall variability and trend at regional level for Kerala state during the last 100 years is examined by Nair et.al (2014) and they have noticed that the precipitation variety in northern and southern districts of Kerala has large deviations on various timescales.Since the climate is changing at a much fast pace, it is important to know not only the change in trend in the frequency but also in the duration of rainfall events in different intensities over Kerala as Kerala is under the threat of extreme climate shift. Hence the present study is aimed at analyzing

- the recent changes in the extremes rainfall events.

- changes in intensity and duration of various rainfall events

For this, the manuscript is arranged in the following way such that Section 2 describes the available observed data and the method adopted for the analysis of trends.Section 3 outlines some key focuses and shows the results from the examination and the conclusions for the study is penned in the Section 4.

DATA AND METHODOLOGY

The study area is located in the Southwestern Malabar Coast of India.Geographically, it lies between latitudes 8.18^0 N and 12.48^0 N and between longitudes 74.52^0 E and 77.22^0 E covering 14 districts.The complete catchment region of the state Kerala is 38,863 Km^2 which is situated between Arabian Sea to the west and Western Ghats to the east. Kerala is generally partitioned into 3 climatically particular areas incorporating the eastern highlands, the focal midlands and the western lowlands. Kerala receives average annual rainfalls of 3107mm and annual temperature differs from 25^0C - 27.5^0C in the western lowlands to 20^0C - 22.5^0C in the eastern highlands. The state receives maximum rainfall during monsoon period (June to September).Kerala's downpours are generally the consequence of regular rainstorm. The study area and topographical location of the districts are given in Figure 1.

STUDY AREA

Figure 1 Map showing districts of Kerala

In this study, daily rainfall (mm) data set over India from 1950 – 2018 is obtained from the Indian Metrological Department (IMD), Pune(Pai et.al 2014). From the Indian domain, Kerala state is extracted through MATLAB and GIS. In this study, we focus on frequency analysis of rainfall over Kerala on a spatial and temporal scale, using($0.25^0\times$ 0.25^0Lat/Long) during the monsoon season from 1950- 2018. In order to study seasonal changes, we divided the whole data set from 1950- 2018 into two eras namely 1950-1980 (era1) and 1981–2018 (era2).The trend in the frequency of rainfall is studied by using Mann Kendall Test and fitted the Gamma distribution by using gridded data.

Mann Kendall Test:

Mann Kendall Test is a non parametric method used to test and model trends.It is appropriate for monotonic trend.Mann Kendall Statistics provides an indication of whether a trend exists and whether the trend is positive or negative.It is defined as

$$S = \sum_{i=1}^{n-1} \sum_{j=i+1}^{n} sgn(x_j - x_i)$$

The application of trend test is done to a time series x_i that is ranked from $i = 1,2,.....n-1$ and x_j,which is ranked from $j = i=1,2,.....n$.Each of the data point x_i is taken as a reference point which is compared with the rest of the data points x_j so that,

$$Sgn(x_j - x_i) = \begin{cases} +1, & (x_j - x_i) > 1 \\ 0, & (x_j - x_i) = 0 \\ -1, & (x_j - x_i) < 1 \end{cases}$$

The variance statistic is given as

$$Var(S) = \frac{\{n(n-1)(2n+5) - \sum_{p=1}^{q} t_p(t_p-1)(2t_p+5)\}}{18}$$

where t_i is considered as the number of ties upto sample i.
The test statistic $Z_c$is compared as

$$Z_c = \begin{cases} \frac{S-1}{\sqrt{Var(S)}}, S > 0 \\ 0 \quad\quad\quad, S = 0 \\ \frac{S+1}{\sqrt{Var(S)}}, \ S < 0 \end{cases}$$

Z_c here follows a standard normal distribution.A positive (negative)value of Z signifies an upward (downward)trend.A significance level α is also utilised for testing either an upward or downward monotone trend (a two tailed test).If Z_c appears greater than $Z_{\frac{\alpha}{2}}$, then the trend is considered as significant (Kendal 1975).

Gamma Distribution:
A random variable x is said to follow gamma distribution,if its probability density function is given by

$$f(x,\alpha,\beta) = \begin{cases} \frac{1}{\beta^{\alpha}\Gamma\alpha} x^{\alpha-1} e^{-\frac{x}{\beta}}, & x \geq 0 \\ 0 \ , & otherwise \end{cases}$$

Where,

- $\Gamma\alpha = \int_0^{\infty} t^{x-1}e^{-t}\,dt$ is a gamma function
- α is the shape parameter
- β is the rate parameter

Here gamma distribution is used to find the threshold values of precipitation per day.The precipitation values corresponding to parameters of gamma distribution < 0.4 and > 0.99 probabilities are considered as low and heavy rain days respectively.The limiting values for a moderate rain day lie within 0.4 and0.99. Short spell rain events are defined as those having continuous rainfall with intensity $\geq$ 2.5mm/d for less than 4 consecutive days.Similarly long spell rain events are those when rainfall occurs for more than or equal to 4 consecutive days(Dash et al. 2011).

RESULTS AND DISCUSSION

In the subsequent section, the recent changes in the rainfall characteristics viz duration and frequency are analyzed along with the significant difference in the rainfall distribution.Symbolic colors are used to demonstrate the trends which are referenced in the separate inscriptions.

Recent Changes In The Rainfall Distribution
Figure (2) shows the significant difference of rainfall between the year 1950-1980 and 1981-2018 over Kerala. This figure indicates significant changes in the distribution of rainfall in almost all the regions of the state. A noticable significant decrease in rainfall in most of the regions of Kerala is seen except northern part of Kannur district (northern Kerala) where 3-4mm/day of rainfall increase is found. All the districts of central part of Kerala are observed to have low rainfall over the range 1-4mm/day. Among all the districts, Kannur (northern Kerala) is noticed to have the highest rainfall increase whereas the least rainfall is seen over the western part of Thiruvananthapuram (southern Kerala 7-8mm/day). Few stations of Kozhikode and Malapuram also show a decrease of 6-7mm/day. The rainfall is found to increase in the Idukki district over the range 1-3mm/day.
The above discussion might reveal a climate change signal whose causes are still unknown. The climate change signal can also bring lot of changes in the distribution of rainfall and skewness in the frequency of rainfall. Hence, in the next section, we make an attempt to study the change in trends in the frequency and duration of the rainfall events.

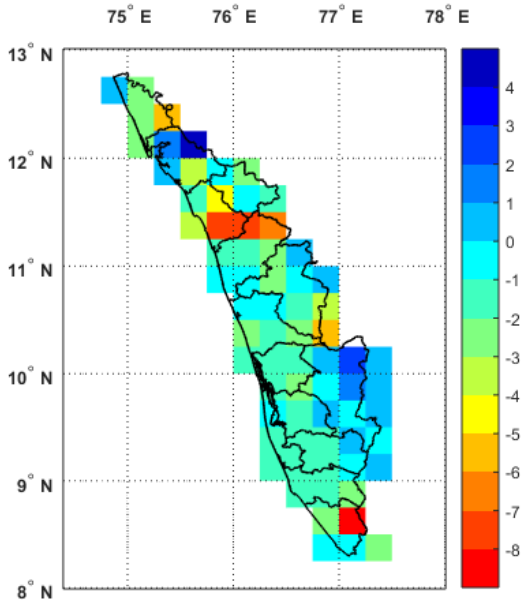

Figure 2 Difference in the magnitude of precipitation between 1950-1980 and 1981-2018.

Trend Analysis In The Frequency Of Rainfall Distribution

In the next section, the trend in low and heavy intensity rainfall events are discussed. The analysis of trend in the frequency of low intensity rainfall over Kerala is shown in figure 3 for era1(1950-1980)((figure 3a) and era 2(1981-2018) (figure 3b) respectively.The trend in heavy intensity rainfall is shown in figure 4 for era1(1950-1980)((figure 4a) and era 2(1981-2018) (figure 4b) respectively The blue grid represents the increasing trend while the red grid represents the decreasing trend.

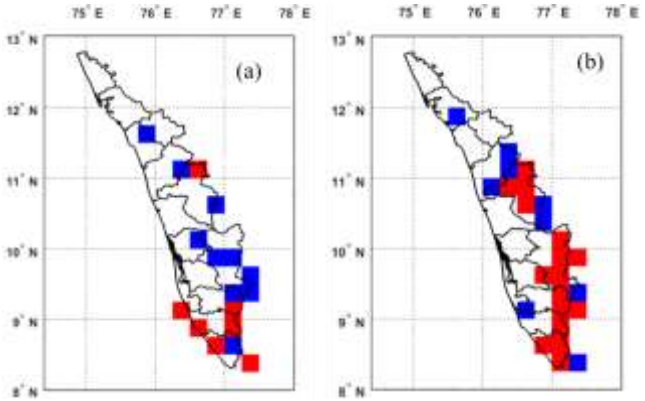

Figure 3: Trend in low intensity rainfall events for era 1 (a) and era 2 (b)

In era1,few regions in the south of Kerala viz of Thiruvananthapuram,Kollam,Pathananthitta is found to have decreasing trend.Some parts of Alappuzha which is a coastal area and some parts of Palakkad are also noticed to have decreasing trend(shown in red dots) in low intensity rainfall events.A significant increasing trend is found in the Idukki and Ernakulamdistrict.Over rest of the regions (Kottayam,Kasargod,Kannur and Thrissur) no significant trend is noticed.In the low intensity distribution in the recent decades, it can be seen that the southern part of Kerala shows a significant decreasing trend.

In era 2, Ernakulam,Thrissur ,Kozhikode,Wayanad and Kasargod shows no trends in the low intensity rainfall during monsoon period.There is a significant increasing trend in the district Idukki and Thiruvananthapuram.A similar significant increasing trend is found in the Palakkaddistrict of the state..A decreasing trend is found over few pockets of Kottayam .

A marked difference in the behaviour of trend can be noted in the district Idukki where it shows significant increasing trend(shown in blue dots) and decreasing trend in era 1 and era 2 respectively. There is a significant increasing trend in the district Kannur in era 2, while in era 1, no trend can be found.From this section, we can see that, posterior to 1980's a drastic change could be seen in the different regions of Kerala especially in Idukki and Palakkad where the low intensity rainfall trend is found decreasing in recent decades.

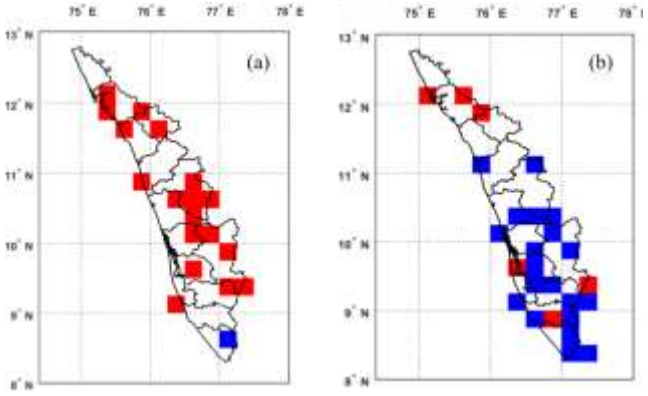

Figure 4: Trend in heavy intensity rainfall events for era 1 (a) and era 2 (b)

The spatial variation of heavy intensity rainfall over Kerala from 1950 - 1980 (era 1) and 1981 - 2018 (era 2) is shown in figure (4).The figure shows the significant trend of heavy intensity rainfall during monsoon season (JJAS). In era 1, there is a significant decreasing trend(shown in red dots) of heavy intensity rainfall in most of the region in Kerala. In fact, no trend is found in the Kollam and Kasargod district.Only southern region of Thiruvananthapuram shows significantly increasing trend in rainfall during 1950-1980. As compared to the other districts in Kerala, most of the region in Palakkad is found to have significantly decreasing trend. In the central part of the state, a decreasing trends are observed in the(kottayam,Ernakulam,Thrissur)districts.Only few stations of Malapuram district shows decreasing trend while most of the places of Wayanad shows decreasing trend.Heavy intensity rainfall is also decreasing significantly over the district Kannur and Kozhikode.

In era 2 (1981 – 2018), we can see a major shift in the distribution of rainfall pattern. Here the central and southern regions shows significant increasing trend(shown in blue dots) in the heavy intensity rainfall events. Kollam district indicates both increasing (central part) and decreasing (eastern and western parts) trend. Few stations of northern region of Kerala (Kasargod, Kannur, Wayanad) shows decreasing trend while Kozhikode shows an increasing trend. A noticeable change can be seen over southern and central regions of Kerala as compared to era1. We noticed that the increase was sharper during the period 1981 – 2018.

Trend Analysis In The Duration Of Rainfall Distribution

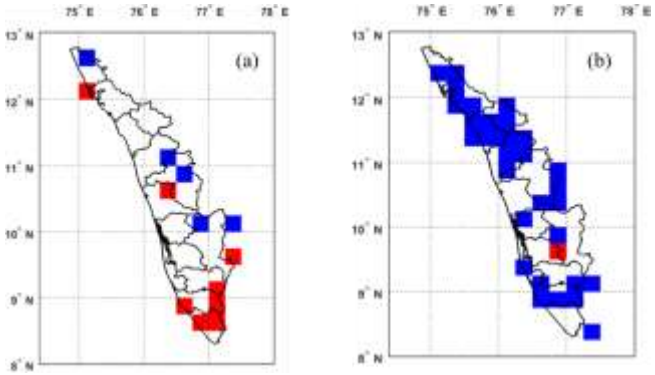

Figure 5: Trend in low intensity short spell rainfall events for era 1 (a) and era 2 (b)

Figure 5 pinpoints the low intensity short spell rainfall events over Kerala during 1950 – 1980 (figure 5a) and 1981 – 2018 (figure 5b).For the period 1950 – 1980, southern Kerala shows significant decreasing trend(shown in red dots). Few pockets of Thrissur, Palakkad, Kannur and Kasargod also exhibited a significant declining trend. The four districts namely Idukki, Palakkad, Malapuram and Kasargod indicate an increasing trend. There is no trend in the district Kozhikode, Wayanad, Alappuzha, Kottayam and Ernakulam. While summing up, we cannot find a uniform pattern of either increased or decreased trend of low intensity short spell rainfall during 1950 – 1980.In era 2, an increasing trend(shown in blue dots) is found in all the districts of Kerala except Kottayam. In view of above, it can be seen that, the low intensity short spell rain events are increasing over Northern Kerala in the recent era.

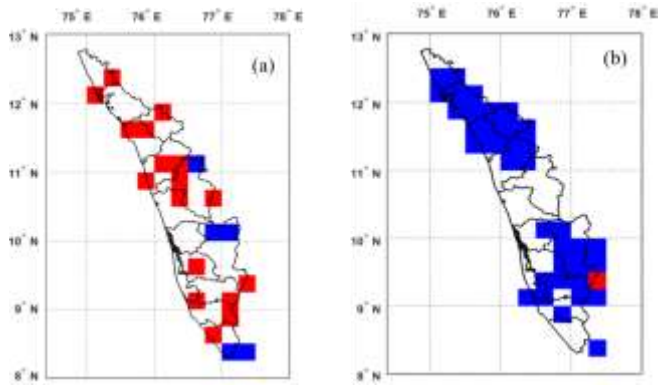

Figure 6: Trend in heavy intensity short spell rainfall events for era 1 (a) and era 2 (b)

Figure 6 represents trends in heavy intensity short spell rain events over Kerala in era 1 and era2. Here we examined the significant trend of short spell which is defined as the duration of heavy precipitation or consecutive 3 days of heavy intensity rainfall over Kerala. In era 1, most of the parts of Kerala show a significant decreasing trend(shown in red dots). Only few stations of Thiruvananthapuram, Idukki and Palakkad indicates an increasing trend(shown in blue dots). The trend test revealed no statistically significant trend at the district Ernakulam. Southern parts of Thiruvananthapuram shows significantly increasing trend whereas northern Thiruvananthapuram shows decreasing trend. In era 2, almost all the districts in Kerala shows significant increasing trend. Few pockets of eastern parts of Idukki district is found to have significant decreasing trend. No trend is found over the district Thrissur of Kerala.

The above discussion reveals that few stations of Idukki is found to have decreasing trend in both era 1 and era 2.A prominent change can be seen in northern and southern Kerala in era 2 as compared to era 1.The three districts namely Kozhikode,Wayanad and Kannur showed a major deflection. This indicates that Kerala is experiencing a major climate shift with dramatic increase in the climate extremes. This increase was very much clear in the year 2018 rainfall scenario over Kerala which resulted in severe flooding in 13 out of 14 districts in the State. As per IMD data, Kerala received 2346.6 mm of rainfall from 1 June 2018 to 19 August 2018 in contrast to an expected 1649.5 mm of rainfall. This rainfall was about 42% above the normal.

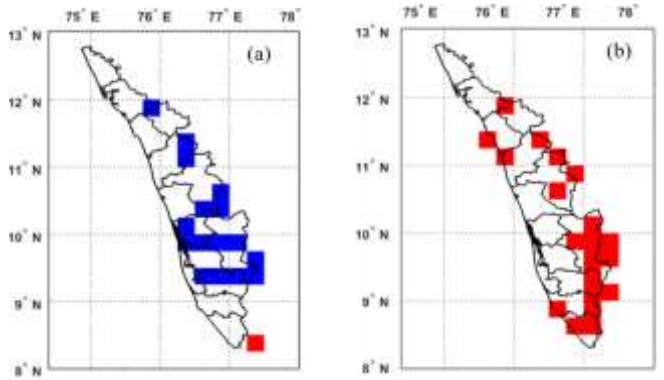

Figure 7: Trend in low intensity long spell rainfall events for era 1 (a) and era 2 (b)

Figure 7 shows the trends corresponding to the low intensity long spell rainfall events over Kerala during monsoon period.It is clear from the figure that the trends in both the era's showed exactly opposite character in the two stages. For the period 1950-1980,most of the areas shows a statistically significant increasing trends in the low intensity long spell rainfall events, whereas interestingly, no significant trends are noticed in the districts Thiruvananthapuram, Kollam, and Kasargod.A general tendency of increasing trend of low intensity long spell was found in the central region of Kerala.
In era 2,there is a significant decreasing trend(shown in red dots) in most of the regions in Kerala.A decreasing trend is covered mostly in the eastern parts of Kerala.No trend is found in Alapuzha, Ernakulam , Thrissur and Kasargod districts. In both era's, Kasargod found to remains the same with no trend.From the above discussion, it is found that in the monsoon period, an exactly opposite results were noticed for low intensity long spell rainfall events. A prominent change can be seen in Thiruvananthapuram, where there is no trend in era 1, while in era 2, a decreasing trend is seen. In era 1 , most of the areas of Ernakulam shows an increasing trend while no trend is found over there during 1981 – 2018.Similarily, for the period 1950-1980,Idukki had an increasing trend, but after 1980's , it shows a significant decreasing trend. There is a decreasing trend in low intensity rainfall in most of the districts in Kerala during recent decades.

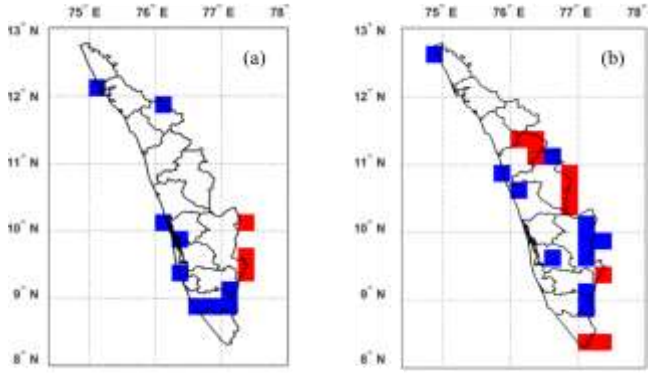

Figure 8: Trend in heavy intensity long spell rainfall events for era 1 (a) and era 2 (b)

Figure 8 depicts the contribution of heavy intensity long spell rainfall events over different zones of Kerala. In era 1, we can see the districts Kollam,Pathanamthitta, Alapuzha and Ernakulam shows significant increasing trends(shown in blue dots) in the number of heavy rain days. Similar increasing trends are noted in Wayanad and Kasargod.Only a few pint- sized part of eastern regions of Idukki shows a decreasing trend(shown in red dots). Infact, there are no significant trends in the districts Palakkad, Malapuram and Kozhikode. After1980's, Malapuram district showed a marked decreasing trend whereas Idukki increases considerably during monsoon period. Similar decreasing trends are observed in Thiruvananthapuram, Idukki, Palakkad and Malapuram whereas district such as Kollam Kottayam, Thiruvananthapuram and Kasargod indicates some increases.Alapuzha,Ernakulam and Kannur do not show any significant trend during 1980 – 2018.Hence the result shows that over the entire state, long spell of heavy intensity rain have remarkable increase in Idukki whereas decreased in Malapuram district during 1981 -2018.

CONCLUSIONS

The present investigation centers around the examination of changing characteristics of heavy and low intensity long and short rainfall events over Kerala during monsoon period, for the period from 1950 – 2018 using $0.25^0 \times 0.25^0$ high resolution daily rainfall data. In order to examine the change in trends in the frequency and duration of rainfall events, the state Kerala is divide into two era's namely era 1(1950-1980) and era 2 (1981 – 2018) respectively. It is found that environmental change sign can likewise acquire part of changes the distribution of precipitation and skewness in the recurrence of precipitation.

The primary characteristics of the monsoon rainfall over Kerala for the period1950-2018 are summarized below,

- Result shows that a significant decreasing trend in low intensity rainfall event is found in recent decades while there is a significant increasing trend in heavy intensity rainfall events.
- During 1981 – 2018, short spell of both low and heavy intensity rainfall event have shown an increasing trend.
- A noticeable change can be seen in northern and southern Kerala in era 2(1981-2018) for short spell of heavy intensity rainfall distribution. This demonstrates Kerala is encountering a significant atmosphere move with sensational increment in the atmosphere limits.
- It is found that the long spell of low intensity rainfall events shows exactly opposite result in which most of the parts of Kerala shows decreasing trend in era 2,while in era 1,an increasing trend is found.
- As a whole ,It is observed that there is not much significant change seen in the long spell of heavy intensity rainfall trend.
- A prominent change is seen in the district idukki which shows an increasing trend in the long spell of Heavy intensity rainfall events during recent decades.
- Over all ,we observed that the short spell of both heavy and low intensity rainfall have an increasing trends during 1981-2018, while the long spell of low intensity rainfall is found to have decreasing trend.

From the results,it can be concluded that the pattern may adversely influence Kerala in future with floods and dry seasons. Intense atmosphere changes and continuous atmosphere calamities are antagonistically influencing the vocation of the individuals.

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