Trends in seasonal precipitation extremes – An indicator of ‘climate change’ in Kerala, India

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SUMMARY

Recent news on the occurrence of off-seasonal natural disasters, such as pre-monsoon drought and post-monsoon flooding in India, and particularly in the peninsular region, highlight the urgent need to look at the patterns of change in seasonal extremes at the local level. Kerala, the south-western state of the Indian peninsula, comprising of a total of six gridded areas, was chosen for this study focusing on the variability and changes in rainfall extremes in the different seasons. Since other studies by the authors have focused on the monsoon season, this paper considers the winter, spring and autumn seasons only. A set of indices derived from the daily rainfall time series is defined and used to examine the changes in extreme rainfall through assessing long-term trends by non-parametric Mann–Kendall technique. The trends are determined over the period of 1954–2003, which are also tested for significance. The results show that there are large intra-regional differences in the trends in different seasons. Local changes were found different from the large spatial scale averages in Kerala. Winter and autumn extreme rainfall were found having an increasing tendency with statistically significant changes in some regions indicating more occurrences of winter and autumn floods. On the other hand the spring seasonal extreme rainfall showed decreasing trends, which together with increasing frequency of the dry days is mainly affecting the total seasonal precipitation, which mainly point towards the vulnerability of Kerala to increasing probability of water scarcity in the pre-monsoon time and a delaying monsoon onset. Overall, the results of this study are good indicators of local climate changes over the five decades that will assist in seasonal forecasting and risk management.

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Introduction

Temporal changes in discrete random extreme events are becoming important in climate change scenario studies because of their socio-economic impacts. The risk of extreme events is difficult to predict but their impacts could be severe. To outline the change in rainfall extremes in a certain region, it is necessary to look at the historical trends of statistical properties of seasonal rainfall extremes. An increase of extreme events has been reported in the monsoon season over central India (Goswami et al., 2006). Also, rainfall with more than 10 years and up to 50 years of return periods has been reported occurring in Kerala, the south-western state of Indian peninsula (Pal and Al-Tabbaa, 2007). Kerala is a very important region for India since a large part of India’s agro-economy is concentrated there. Although Kerala is one of very few highest monsoon rainfall regions in India, along with the North-Eastern Indian states, and receives the first monsoon showers every year, significant amount of precipitation in the other seasons is also important from an agricultural point of view. Furthermore, increasing off-monsoon seasonal floods and thunderstorms in some parts of Kerala, and also in the neighbouring state of Karnataka in peninsular India (De et al., 2005), make it important to look at the change in extreme rainfall in the other seasons as well.

Assessment of other seasonal extreme rainfall changes in Indian region is scarce in the literature. Only Revadekar and Kulkarni’s (2007) recently published work on winter monsoon extremes and their relation with ENSO in South–East peninsular India in the months of October–December provides some information. However, they did not consider other important seasons such as spring (March–May) and autumn (October–November) in their study. The authors have found that spring precipitation makes a very important contribution to annual rainfall variabilities and changes in India and that extreme rainfall plays a dominant role in deciding the seasonal rainfall strength (Pal and Al-Tabbaa, submitted for publication). Therefore, in addition to the winter season (December–February), spring and autumn seasonal precipitations are also considered in this study to investigate whether there have been any significant changes in the extreme rainfall in Kerala over the second half of the 20th century. Previous analyses by the authors found that the average autumn and winter rainfall in Kerala does not seem to show any significant trends but that the
spring rainfall does (unpublished work). Since the changes in short-duration extreme events do have the potential to indicate long-term seasonal climatic changes (Keim and Cruise, 1998), winter and autumn extremes are also examined here. Six separate gridded regions comprising of the whole state of Kerala are studied. Fig. 1 shows the position of the Kerala state in India and the gridded regions in Kerala (orange colour) considered in this study. Gridded regional analysis will help us to identify the spatial changes at very small scales, which will provide the local information on the changing climate that is not usually extracted from the aggregated spatial mean (Bardossy and Hundecha, 2003). Collectively, this work aims at characterising the singular events that have the potential to help in defining and assessing the associated risks, and developing mitigation and adaptation strategies in the state of Kerala.

**Database and methodology**

Lack of long-term daily precipitation time series restricts the empirical analysis of the extreme precipitation changes in the precipitation distribution. High resolution (1° × 1° Lat/Long) gridded daily rainfall datasets comprising of 53 years of data (1951–2003) covering the whole Indian region was collected from the National Climate Center, Indian Meteorological Department, Pune (http://www.imdpune.gov.in/). The daily time series for the six grids of Kerala was then extracted from this database for the 50 years (1954–2003) of analysis done here. Gridded rainfall data sets are useful for regional studies on the climate variability and changes. The high resolution gridded daily rainfall data base for India was developed based on interpolation of the daily rainfall data from 1803 stations in India having at least 90% data availability during the period of 1951–2003 (Rajeevan et al., 2005, 2006). Standard quality control was performed in order to minimise the risk of generating spatial or temporal inhomogeneities in the gridded data. A comparison with similar global gridded rainfall revealed that this database is better in accurate representation of spatial and temporal rainfall variations in India (Rajeevan et al., 2006).

The analysis of the precipitation extremes was based on the indices developed under the World Climate Research Programme on Climate Variability and Predictability Working Group on Climate Change Detection (Peterson et al., 2002; Peterson, 2005). Some of these indices have been previously used in the analyses of the trends in global and regional climates (Bardossy and Hundecha, 2003; Alexander et al., 2006). Selective indices used here for the seasonal analyses are demonstrated in Table 1. Seasonal extreme indices were calculated on a yearly basis for the entire 50 years (1954–2003) of study for all the areas under investigation in Kerala. The base period considered here was 1961–1990. Before moving onto the extremes, changes in seasonal total rainfall in the wet days and changes in the frequency of the dry days are also examined and discussed in the first two sub-sections below.

All the trends for each index were determined using non-parametric Mann–Kendall test, which were also tested for significance at 95% level (Wilks, 1995; Onoz and Bayazit, 2003; Luo et al., in press). Since there are chances of outliers to be present as the extreme rainfall events, non-parametric Mann–Kendall test is useful because its statistic is based on the sign of differences, not directly on the values of the random variable and therefore the trends determined is less affected by the outliers. The Mann–Kendall test

![Fig. 1. Location of Kerala state in India (orange colour grids mark the study regions considered). The numerical numbers in the grid points represent 1° × 1° grids as follows, 1 = 11.5N, 75.5E; 2 = 11.5N, 76.5E; 3 = 10.5N, 75.5E; 4 = 10.5N, 76.5E; 5 = 9.5N, 76.5E and 6 = 8.5N, 76.5E [from Rajeevan et al., 2006]. (For interpretation of the references to colour in this figure legend, the reader is referred to the web version of this article.)](image-url)
is applicable to the detection of a monotonic trend in a time series with no seasonal or other cycle. The test is based on the statistic $S$, which is calculated using the formula

$$S = \sum_{j=1}^{n-1} \sum_{k=j+1}^{n} \text{sgn}(x_j - x_k)$$

(1)

$$\text{sgn}(x_j - x_k) = \begin{cases} +1 & \text{if } x_j - x_k > 0 \\ 0 & \text{if } x_j - x_k = 0 \\ -1 & \text{if } x_j - x_k < 0 \end{cases}$$

(2)

where $n$ is the number of observed data series, $x_j$ and $x_k$ are the values in periods $j$ and $k$, respectively, $j > k$. For $n \geq 10$, the sampling distribution of $S$ is as follows. $Z$ follows the standard normal distribution:

$$Z = \frac{S - \frac{n(n-1)}{2}}{\sqrt{\text{VAR}(S)}}$$

(3)

where $\text{VAR}(S)$ is determined as

$$\text{VAR}(S) = \frac{1}{18} \left[ n(n-1)(2n+5) - \sum_{p=1}^{q} t_p (2t_p - 1)(2t_p + 5) \right]$$

(4)

where $q$ is the number of tied groups and $t_p$ is the number of data values in the $p$th group. If $|Z| > Z_{1-\alpha/2}$, null hypothesis is rejected and a significant trend exists in the time series. $Z_{1-\alpha/2}$ is the critical value of $Z$ from the Standard Normal Table, for 95% confidence the value of $Z_{1-\alpha/2}$ is 1.96. A positive value of $Z$ indicates an upward trend and a negative value of $Z$ indicates a downward trend.

### Results

The results of the trend assessments are summarised in the following headings. The figures discussed in the sections below show three-panel map of trends in various gridded regions in Kerala for the three seasons analysed. Only the grids under study are shown in those figures. Symbolic colours are used to indicate the trends, which are mentioned in the respective captions.

**Long-term changes of seasonal total precipitation (PREP_ST)**

The trends in total precipitation from the wet days (the days with precipitation $\geq 1$ mm) show seasonal variabilities, as seen in Fig. 2. The spatially averaged trends in different seasons over the whole of Kerala are shown in Fig. 3. The most apparent feature of the results in Fig. 2 is that trends in seasonal precipitations over the study period are not consistent throughout the state (except spring season) even though the mean and standard deviation of daily rainfall over these regions is more or less homogeneous (see Table 2). This intra-regional variability for the precipitation indices is possibly because of small spatial correlations for precipitation because of topographical differences (Fig. 4). Fig. 2 also shows that two extreme northern regions of Kerala show positive tendencies in winter seasonal precipitation and, four locations show negative tendencies, while none are significant. On the other hand, spatially averaged winter seasonal rainfall show positive tendency in Kerala, spring precipitation has statistically significant decreasing trends throughout the state, as in Fig. 3. Furthermore, although positive tendencies were noticed everywhere in Kerala

### Table I

Extreme rainfall indices (DP = daily precipitation amount).

<table>
<thead>
<tr>
<th>Index</th>
<th>Description</th>
<th>Units</th>
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<tbody>
<tr>
<td>PREP_ST</td>
<td>Seasonal total precipitation from wet days (DP $\geq 1$ mm)</td>
<td>mm</td>
</tr>
<tr>
<td>TDD</td>
<td>Seasonal total number of dry days (DP &lt; 1 mm)</td>
<td>Days</td>
</tr>
<tr>
<td>R95p</td>
<td>Seasonal total precipitation from DP &gt; 95th percentile of the wet days</td>
<td>mm</td>
</tr>
<tr>
<td></td>
<td>(based on the period 1961–1990)</td>
<td></td>
</tr>
<tr>
<td>R99p</td>
<td>Seasonal total precipitation from DP &gt; 99th percentile of the wet days</td>
<td>mm</td>
</tr>
<tr>
<td></td>
<td>(based on the period 1961–1990)</td>
<td></td>
</tr>
<tr>
<td>RX1 day</td>
<td>Seasonal maximum precipitation in 1 day</td>
<td>mm</td>
</tr>
<tr>
<td>RX5 day</td>
<td>Seasonal maximum precipitation in five consecutive days</td>
<td>mm</td>
</tr>
<tr>
<td>RXF</td>
<td>Extreme frequency, i.e. number of days with rainfall &gt;95 percentile in the</td>
<td>days</td>
</tr>
<tr>
<td></td>
<td>season</td>
<td></td>
</tr>
<tr>
<td>RXP</td>
<td>Extreme percent, i.e. proportion of total seasonal rainfall from all events</td>
<td>%</td>
</tr>
<tr>
<td></td>
<td>above the average long-term 95th percentile</td>
<td></td>
</tr>
</tbody>
</table>

Fig. 2. Trends of seasonal total precipitations from the wet days (PREP_ST) in various gridded regions in Kerala in 1954–2003.
(except grid 4), no region has statistically significant trend for the autumn precipitation (Fig. 2). The spatially averaged trends in PREP_ST in autumn season in Kerala also show positive tendencies (Fig. 3). Hence the above results indicate that the trends corresponding to large scaled spatial averages are not representative of the local regional changes, and therefore are not recommended to use in local projects.

Long-term changes of seasonal total number of dry days (TDD)

The winter season has the maximum number of dry days in Kerala. Spatially averaged trends of TDD in various seasons are shown in Fig. 3. The figure indicates whether possible increase or decrease in water stress is experienced in different seasons in Kerala, which is important for natural vegetation and crop growth. It could be noticed in Fig. 3 that the number of dry days are significantly increasing in spring season, which is a clear indication of severe water stress in this season. The increasing frequency of dry days in spring season could be another indication of delayed monsoon onset in Kerala. Spatially averaged trends of total number of dry days in winter and autumn seasons have decreasing tendency, which are possibly contributing to increase in total precipitation from the wet days (PREP_ST), as in Figs. 2 and 3.

Results corresponding to every individual grid in Kerala are different from the spatial average results above. The trends for every individual region are displayed in Fig. 5. The figure shows that the number of winter dry days has no significant trend in most places except only the region at the highest elevation (grid 2) that exhibits significantly decreasing number of dry days in Kerala. Also that, the other north most region (grid 1) shows decreasing tendency in the number of dry days. This could be one of several reasons for the increase in winter precipitation in these two northern regions, as discussed in the previous section. The spatial distribution of the regions indicates that the famous port and agricultural district Kozhikode/Calicut, is situated in grid 1 (see Fig. 4). In spring, most of the areas have been undergoing water stresses since they have statistically significant increasing trends of the number of dry days; whereas, interestingly, no significant trends are noticed in the north most regions (grids 1 and 2) in Kerala. Also in autumn, 33% of the total area under investigation shows a significant decrease in the number of dry days, the areas are located at the highest elevation (grid 2) and at the southern coastal part of Kerala (grid 6). Grid 1, the other northern part of Kerala also shows decreasing tendency of TDD in autumn, like winter. Exactly opposite results were noticed for the total number of wet days in the various seasons (not shown) meaning

Table 2

<table>
<thead>
<tr>
<th>Regions</th>
<th>Mean</th>
<th>SD</th>
</tr>
</thead>
<tbody>
<tr>
<td>Winter</td>
<td>Spring</td>
<td>Autumn</td>
</tr>
<tr>
<td>1 11.5N,75.5E</td>
<td>0.4</td>
<td>3.8</td>
</tr>
<tr>
<td>2 11.5N,76.5E</td>
<td>0.4</td>
<td>2.3</td>
</tr>
<tr>
<td>3 10.5N,75.5E</td>
<td>0.5</td>
<td>4.3</td>
</tr>
<tr>
<td>4 10.5N,76.5E</td>
<td>0.4</td>
<td>2.7</td>
</tr>
<tr>
<td>5 9.5N,76.5E</td>
<td>1</td>
<td>5.27</td>
</tr>
<tr>
<td>6 8.5N,76.5E</td>
<td>1</td>
<td>4.5</td>
</tr>
</tbody>
</table>
that there is an increasing tendency of rainfall occurring more frequently in the winter and autumn seasons and less frequently in spring in Kerala.

Trends of extreme precipitations

Indices R95p and R99p

The remaining six indices in Table 1 give a direct measure of extreme precipitation in the various seasons. Figs. 6 and 7 show the trends corresponding to the total precipitation above 95th and 99th percentile. The percentile rainfall values were averaged over 1961–1990, i.e. the base line set by WMO to separate 24-h daily rainfall extremes in every year of the 50 years of study. All the extreme rainfall amounts in a year are then summed up to get R95p and R99p for every year. Fig. 3 displays the spatially averaged trends and variabilities of the various seasonal R95p and R99p in Kerala. It is noted in the figure that, both the cases exhibit no trends in the winter season. A decreasing tendency of R95p index in spring season is noticed while no trends were found in R99p index. In autumn season, however, total amount of extreme precipitation above 95 percentile show increasing tendency for both the cases although none was statistically significant.

The results corresponding to the gridded regions were variable and sometimes different from that of spatial average. While in winter, trends corresponding to both the indices show no tendencies, decreasing tendencies in R95p index are observed in spring but no trend in R99p index was found in spring season. Therefore, it is noted that, together with statistically significant increases in the number of dry days and decrease in extreme precipitations, the spring season tends to go through severe water stresses, which is a familiar phenomenon these days in Kerala. Furthermore, while increasing tendency in R95p in autumn season is almost everywhere in Kerala, only a single region (grid 5) shows an increasing...
tendency and other grids have no trends for the case of R99p index. Hence, increase in extreme rainfall tends to exhibit a higher number of flash floods in the autumn season, which is also an emerging scenario in some parts of Kerala (De et al., 2005); for example, the place Kochi (see Fig. 4) and its near by regions, which fall under the grid 5.

*Indices RX1 day and RX5 day*

These indices indicate whether there are changes in the amount of precipitation received in the day with the highest precipitation and the amount of precipitation received in a 5-day scenario per year with the highest precipitation, respectively. These indices give an indication of the trends in precipitation amounts usually coming from extreme weather occurrences. Trends in spatially averaged RX1 day and RX5 day indices for various seasons are shown in Fig. 3. Fig. 3 displays that winter and autumn extremes are increasing in Kerala and spring extremes are decreasing, which are affecting the seasonal totals, as also mentioned before.

Fig. 8 depicts the trends corresponding to these two indices in various seasons and a number of gridded regions in Kerala. Trends in both the indices showed coherent tendencies; therefore the results corresponding to both are displayed in a single figure (Fig. 8). Winter extremes have increasing trends in northern most regions in Kerala (grids 1 and 2), which must have affected the seasonal total, as discussed in Long-term changes of seasonal total precipitation (PREP_ST). For the spring, the extreme precipitation is decreasing everywhere while the trend corresponding to grid 4 is statistically significant. In addition, the autumn extremes show increasing trends except a decrease in southern coastal tip of Kerala.

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*Fig. 5.* Trends of total number of dry days (TDD) in various seasons in different gridded regions in Kerala in 1954–2003.

*Fig. 6.* Trends of seasonal total precipitation from daily rainfall >95th percentile from the wet days (based on the period 1961–1990) in different gridded regions in Kerala in 1954–2003.
The extreme frequency index (RXF) examines changes in the number of extreme events and was calculated by counting the number of events in a year with intensities above a threshold. The extreme percent (RXP), on the other hand, is the proportion of total seasonal rainfall from all events above the same threshold. A long-term (1961–1990) 95th percentile of the daily rainfall intensity in the monsoon months was used as the threshold to separate the extreme events, which varies significantly from year to year and also spatially in Kerala. The trends of extreme rainfall frequencies corresponding to different regions in Kerala in all the seasons showed no significant trends but only one region (grid 3) in spring season that showed significantly negative trend in extreme rainfall frequency (not displayed); whereas, trends corresponding to extreme rainfall percent (RXP) are different from that of RXF, as shown in Fig. 9. Fig. 9 also shows that, while winter extreme rainfall proportion has no trend like RXF, around 50% of the spatial area of Kerala is undergoing decreasing trends in RXP in the spring season, which is also true for the averages (not shown). Furthermore, autumn extreme rainfall proportion has increasing trends and they are statistically significant in two grid-ded regions in eastern Kerala (grids 2 and 5), which are at the proximity of western ghat mountains. Therefore, in addition to grid 5, as discussed in Indices R95p and R99p, significant increasing trend in total contribution from the extreme autumn rainfall in some parts of Kerala is an indication of more flooding in the autumn season.

Collectively, although not always statistically significant, winter and autumn rainfall extremes are always showing increasing tendencies of floods and spring showing increasing tendency of water
stress. In addition, it can now be seen that extremes plays one of the most important roles in the seasonal rainfall changes wherein tendencies of the changes have high local variabilities in Kerala, which implies that the regional assessment of climatological variables is needed for the local developments.

Conclusions

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. A change in the regional circulation pattern because of temperature changes might be the cause of differences in spatial variations. Kerala has positive trends in the winter total precipitation, extreme amount, and intensity, and negative trends in the frequency of the dry days, which are always true especially for the higher elevation and north most regions. In contrast, Kerala is undergoing a significant decrease in the spring precipitation in all the regions. The index related to dry days, TDD, showed a more significant increasing trend in the spring season in almost the entire state of Kerala and negative trends in the winter and autumn in small specific parts. As for the extremes, the spring season shows negative significant trends in amount, intensity and frequency. The state of Kerala as a whole has a tendency to increase in autumn rainfall, while percent contribution from the extremes is significant in two gridded regions of interest. This entire work, together with the authors’ previous work for the monsoon season are expected to help to define and assess the risk of flooding and droughts, agricultural planning and other developments associating with the mitigation and adaptation strategies for climate change in the state of Kerala.

References


