Observed trends and variations in rainfall events over Ratnagiri (Maharashtra) during southwest monsoon season

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ABSTRACT. The observed trends and variations in rainfall during southwest (SW) monsoon season (June to September) of individual station Ratnagiri, have been analyzed by using 30 years (1980-2009) daily rainfall data. The analysis revealed decreasing but not significant trend in total amount of rainfall and number of rainy days, with increasing but not significant trend in average intensity of rainfall during rainy days of monsoon season. To verify this increase in average intensity of monsoon rainfall over the region, the trends in frequency of occurrence of rainfall events and percentage (%) contribution of rainfall events, to total monsoon rainfall in different categories of rainfall event, along with decadal variation during monsoon season are analyzed. The trend shows that frequency of occurrence of rainfall events and % contribution of rainfall events to total monsoon rainfall in category of light, moderate, rather heavy and heavy rainfall events decreased (but not significantly), whereas frequency of occurrence of rainfall events and % contribution of rainfall events to total monsoon rainfall in category of very heavy to exceptionally heavy rainfall events increased (but not significantly) during 30 years (1980-2009) over Ratnagiri indicating that increase in average intensity of monsoon rainfall is contributed by very heavy to exceptionally heavy rainfall events.

Decadal analysis also shows that frequency of occurrence of rainfall events and % contribution of rainfall events to total monsoon rainfall in category of light, moderate, rather heavy and heavy rainfall events have decreased per decade. Whereas in category of very heavy to exceptionally heavy rainfall events it has increased per decade. This increased frequency of very heavy to exceptionally heavy rainfall events over the region may lead to an increase in frequency of floods, landslides and spoil agricultural crops and hence requires attention.

Key words – Trends, Heavy rainfall, Frequency, SW monsoon.
1. Introduction

West Coast of India receives copious rainfall during southwest (SW) monsoon season (June to September), with orography playing crucial role being windward side of the Western Ghats (Rao, 1976). Ratnagiri district is located on the west coast of Maharashtra and is part of Konkan region, with Arabian Sea to its west and Western Ghats to its eastern side. Heavy to very heavy rainfall is a feature of weather over the region during monsoon season. Ratnagiri being coastal station at Latitude 16° 59' N and Longitude 73° 20' E, receives average annual rainfall 320 cm, of which more than 90% occurs during SW monsoon season.

Secular changes in precipitation have attracted many researchers in context of climate change. It is now widely accepted that changes in total precipitation can be associated with changes in frequency of rainfall events, the amount of rainfall per event (Intensity), or combination of both (IPCC, 2007). Understanding precipitation changes in both climate variability and climate extremes during recent decade have become important under future climate change. To achieve this understanding, the analysis of daily rainfall has become mandatory, namely evaluation of changes in frequency of rainfall events are due to changes in number of heavy or light rainfall events over the region, (Karl and Knight, 1998; Trenberth et al., 2003). Therefore, it is important to monitor closely, the rainfall trends and variations on regional and local scale.

So far, several studies on trends of rainfall have been carried out by many scientists over different regions of the world. Over Indian region there have been some recent studies by Goswami et al. (2006); Rupa kumar et al. (2006); Guhathakurta and Rajeevan (2007); Pattanaik and Rajeevan (2010) and Guhathakurta et al. (2010). Goswami et al. (2006) by using daily rainfall data set from 1951 to 2000, observed significant rising trends in the frequency of extreme rainfall events and significant decreasing trend in the frequency of moderate rainfall events over central India during summer monsoon season. Rupa kumar et al. (2006), concluded that extreme precipitation shows substantial increase over a large area, particularly over west coast of India and central India. Guhathakurta and Rajeevan (2007) studied trends in rainfall pattern over India and observed significant increasing trend in annual rainfall for sub-division Konkan and Goa. Pattanaik and Rajeevan (2010) using daily rainfall for 55 years (1951-2005) data recently studied variability of extreme rainfall events over India during SW monsoon season and observed that frequency of rainfall events and percentage (%) contribution to total monsoon rainfall show significant increasing trend in the category of extreme rainfall events over the west coast and central parts of India. Guhathakurta et al. (2010), observed increasing trend in the frequency of heavy rainfall events over few numbers of stations in Konkan and Goa and adjoining west coast of India. All these studies described long term trends and were for country as whole or sub-divisional based, very few studies have been carried out on regional and local scale. In order to have a better understanding of rainfall behaviour as an indicator of climate change, daily rainfall series must be analyzed on regional and local scale. Hence an attempt has been made to study observed trends and variations of rainfall during SW monsoon season for individual station Ratnagiri using recent 30 years (1980-2009) daily rainfall data.

The main objective of present study is to analyze the observed changes in rainfall over Ratnagiri for 30 years period (1980-2009) during SW monsoon season, which may provide the local information about the changing trends of monsoon rainfall and help to identify the recent climate change on local scale over the region. The structure of paper is as follows, section 2 describes the Data and Methodology used in this study. Trends of rainfall events and decadal variations were analyzed & discussed in section 3 under Results and discussion. Conclusions are presented in section 4.

2. Data and methodology

The daily rainfall data of Ratnagiri station for the 30 years (1980-2009) period during monsoon season (June - September) is used for this study. The daily rainfall data from year 1980 to 2006 was obtained from National Data Centre (NDC), IMD Pune, and daily rainfall from 2007 to 2009 was obtained from Ratnagiri observatory. As per IMD classification, the rainfall events are divided in different categories from 'Light' to 'exceptionally heavy', depending on the amount of rainfall in a day. The same classification of rainfall is used for this study with four broad categories as given in Table 1. Daily rainfall 0.0 to 2.4 mm/day is considered as Non Rainy day category, rainfall 2.5 to 64.4 mm (rounded as 65 mm/day), i.e., light, moderate and rather heavy rainfall events as per IMD classification are regrouped into 'category I' with R < 65 mm /day (where 'R' = Rainfall). Rainfall 64.5 to 124.4 mm (rounded as 125 mm/day), i.e., Heavy rainfall events as per IMD classification are considered in this study as 'category II' with R ≥ 65 mm/day & R < 125 mm/day. The very heavy and exceptionally heavy rainfall events as per IMD are further regrouped as 'Category III' with R ≥ 125 mm/day.

As per IMD criteria, rainfall ≥ 2.5 mm/day is considered as rainy day. The same criteria is considered for this study and used to calculate rainfall amount,
TABLE 1
Classification of rainfall events based on daily rainfall amount

<table>
<thead>
<tr>
<th>Broad categories used in this study</th>
<th>IMD classifications of rainfall events</th>
<th>Rainfall (R) in a day (mm)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Non rainy day</td>
<td>No rain</td>
<td>0.000.0</td>
</tr>
<tr>
<td></td>
<td>Very light rain</td>
<td>0.1 to 2.4</td>
</tr>
<tr>
<td>Category I</td>
<td>Light rain</td>
<td>2.5 to 7.5</td>
</tr>
<tr>
<td></td>
<td>Moderate rain</td>
<td>7.6 to 35.5</td>
</tr>
<tr>
<td></td>
<td>Rather heavy rain</td>
<td>35.6 to 64.4</td>
</tr>
<tr>
<td>Category II</td>
<td>Heavy rain</td>
<td>64.5 to 124.4</td>
</tr>
<tr>
<td>Category III</td>
<td>Very heavy rain</td>
<td>124.5 to 244.4</td>
</tr>
<tr>
<td></td>
<td>Exceptionally heavy rain</td>
<td>&gt; 244.5</td>
</tr>
</tbody>
</table>

number of rainy days, and average intensity of rainfall. 'Rainfall amount' is total amount of rainfall occurred on rainy days (each year) during monsoon season (June-September). The 'Number of rainy days' is the total number of days with rainfall (greater than or equal to 2.5 mm/day) during monsoon season each year. 'Average intensity of rainfall' during rainy days (rainfall greater than or equal to 2.5 mm/day) considered for this study is calculated as total amount of rainfall occurred during rainy days of monsoon season (each year) divide by total number of rainy days (each year) during monsoon season. The 'frequency of rainfall event' is defined as the number of days or occasions in particular category of rainfall event as identified in Table 1. Percentage (%) contribution of rainfall in each category of rainfall event as identified in Table 1, is calculated as percentage of total rainfall in each category of rainfall event (each year) in proportion to total rainfall occurred during rainy days (each year) of monsoon season.

3. Results and discussion

3.1. Trends in rainfall amount, number of rainy days and intensity of rainfall

To understand the rainfall pattern over the region in past 30 years (1980-2009) during SW monsoon season, the trends in amount of rainfall, number of rainy days and average intensity of rainfall during monsoon season have been analyzed, as shown in Figs.1(a-c). Trend analysis for amount of rainfall on rainy days during monsoon season shown in Fig. 1(a), indicate slight decreasing but not significant (p = 0.7939) trend at 95% confidence level. Trend for Number of rainy days, Fig. 1(b), show negative trend, which is also not statistically significant (p = 0.2529) at 95% confidence level. Whereas average intensity of rainfall on rainy days during monsoon season shown in Fig. 1(c), indicate increasing but not significant (p = 0.5675) trend at 95% confidence level. This indicates that, the amount of rainfall, number of rainy days during monsoon season have decreased, whereas average intensity of rainfall on rainy days during monsoon season increased over Ratnagiri during 30 years (1980 - 2009). In order to verify the above result more specifically, i.e., decrease in amount of rainfall, number of rainy days and increase in average intensity of rainfall on rainy days during monsoon season, the trends in frequency of occurrence of rainfall and percentage contribution of
rainfall events to total rainfall for different categories of rainfall events (as given in Table 1) are further analyzed.

3.2. Trends in frequency of occurrence of rainfall in different categories of rainfall events

Trends in frequency of occurrence of rainfall for three categories of rainfall events as given in Table 1 are shown in Fig. 2. Frequency of occurrence of rainfall (R) in category I, i.e., R < 65 mm/day shows decreasing but not significant trend (p = 0.2645) at 95% confidence level, also frequency of occurrence of rainfall events in category II, i.e., R ≥ 65 mm/day & R < 125 mm/day shows decreasing but not significant trend (p = 0.1701) at 95% of confidence level. This indicates that frequencies of occurrence of light, moderate, rather heavy and heavy rainfall events have decreased (but not significantly) over
Figs. 4(a-c). Decadal variation in frequency of rainfall events for (a) category I, $R < 65$ mm/day (b) category II, $R \geq 65$ mm/day and $R < 125$ mm/day (c) Category III, $R \geq 125$ mm/day, during SW monsoon season over Ratnagiri for the period 1980-2009.

Ratnagiri during monsoon season. Whereas, frequency of occurrence of rainfall in category III, i.e., $'R' \geq 125$ mm/day shows increasing but not significant trend ($p = 0.1632$) at 95% confidence level. The similar results were obtained by Rupa Kumar et al. (2006) and Guhathakurta et al. (2010); using long term data for the period (1961-1990) & (1901-2005) respectively. They observed that frequency of extreme rainfall events were increased, mostly in Konkan, Goa and adjoining west coast of India. Thus, the trend analysis shows that

Figs. 5(a-c). Decadal variation in avg. percentage contribution to monsoon rainfall for (a) category I, $R < 65$ mm/day (b) Category II, $R \geq 65$ mm/day & $R < 125$ mm/day (c) category III, $R \geq 125$ mm/day, during SW monsoon season over Ratnagiri for the period 1980-2009.
Decadal variation in frequency of rainfall events and average percentage (%) contribution of rainfall events to total rainfall in different categories of rainfall events (as identified in Table 1) during monsoon season over Ratnagiri for the period 1980-2009

<table>
<thead>
<tr>
<th>Decade</th>
<th>Frequency of rainfall events in category</th>
<th>Avg. Percentage (%) contribution in category</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>I</td>
<td>II</td>
</tr>
<tr>
<td>1980-1989</td>
<td>746</td>
<td>102</td>
</tr>
<tr>
<td>1990-1999</td>
<td>722</td>
<td>102</td>
</tr>
<tr>
<td>2000-2009</td>
<td>712</td>
<td>85</td>
</tr>
</tbody>
</table>

3. Decadal variation in frequency of rainfall events and percentage contribution to total rainfall

Decadal variation of rainfall in different categories of rainfall events (as given in Table 1) for frequency of rainfall events and percentage contribution to total rainfall during monsoon season over Ratnagiri is depicted in Table 2 and represented graphically as shown in Figs. 4(a-c) & Figs. 5(a-c). Frequency of rainfall events and percentage contribution of rainfall events to total rainfall in category I, i.e., 'R' < 65 mm/day decreased per decade, as shown in Figs. 4(a) & 5(a). In decade 1980-1989 the frequency of rainfall events was 746 events per decade and average percentage contribution was 50.6%. In decade 1990-1999 the frequency of rainfall events decreased to 722 events per decade but average percentage contribution decreased to 48.9% of total monsoon rainfall. In decade 2000-2009 frequency of rainfall events further decreased to 656 events per decade and average percentage contribution further decreased to 47.1% respectively, as shown in Table 2.

In 'category II', i.e., 'R' ≥ 65 mm/day & 'R' < 125 mm/day the frequency of rainfall events and percentage contribution to total monsoon rainfall also decreased per decade as shown in Figs. 4(b) & 5(b). In decade 1980-1989 the frequency of rainfall events was 102 events per decade and average percentage contribution was 30.8%. In decade 1990-1999 the frequency of rainfall events remains same, i.e., 102 events per decade but average percentage contribution decreased to 28.9%. In decade 2000-2009 the frequency of rainfall events further decreased to 85 events per decade and average percentage contribution to total rainfall decreased to 27.6% as shown in Table 2.

In case of rainfall events in category III, i.e., 'R' ≥ 125 mm/day showed decadal rise in both frequency of
rainfall events and average percentage contribution to total monsoon rainfall, Figs. 4(c) & 5(c). In decade 1980-1989 the frequency of rainfall events in category III was 32 events per decade and average percentage contribution to total monsoon rainfall was 17.6 %, which increased in decade 1990-1999 to frequency of rainfall 36 events per decade and percentage contribution to total monsoon rainfall 19.9%, indicating 2.3% of rise per decade. In decade 2000-2009 frequency of rainfall events further increased to 41 events per decade and average percentage contribution to total monsoon rainfall increased to 23.9%, indicating 4% of rise per decade.

Thus, above analysis shows that frequency of rainfall events and average percentage contribution to total monsoon rainfall have decreased per decade for category I and category II, i.e., light, moderate, rather heavy and heavy rainfall events, whereas frequency of rainfall events and percentage contribution of rainfall events to total monsoon rainfall in category III, i.e., very heavy rainfall to exceptionally heavy rainfall events for SW monsoon season have increased per decade over Ratnagiri during 1980-2009.

4. Conclusion

The study shows some important results in trends and decadal variations of rainfall, for different categories of rainfall events during monsoon season over Ratnagiri during the period 1980-2009. The results from this study are location dependent and conclusions below are valid only for the study region.

The conclusions emerged from this study are:

(i) Monsoon rainfall showed decreasing (not significant) trend in total amount of rainfall and number of rainy days, whereas average intensity of rainfall during rainy days showed increasing (not significant) trend over Ratnagiri during period 1980-2009.

(ii) Trends analysis in frequency of occurrence of rainfall events in category I and category II of rainfall events, i.e., light, moderate, rather heavy and heavy rainfall events showed decreasing (not significant) trend, whereas in category III, frequency of occurrence of very heavy to exceptionally heavy rainfall events showed increasing (not significant) trend over Ratnagiri during SW monsoon season for period 1980-2009.

(iii) The results also show that percentage contribution of rainfall events to total monsoon rainfall, in category I & category II, i.e., light, moderate, rather heavy, and heavy rainfall events have decreasing (not significant) trend, whereas in category III, i.e., very heavy to exceptionally heavy rainfall events the percentage contribution to total monsoon rainfall have increasing (not significant) trend.

(iv) Decadal variation analysis showed that frequency of rainfall events and percentage contribution to total monsoon rainfall in category I and category II, i.e., light, moderate, rather heavy and heavy rainfall events have decreased per decade, whereas in category III, i.e., very heavy to exceptionally heavy rainfall events, the same have increased per decade over Ratnagiri for SW monsoon season during period 1980-2009.

(v) The results from the present study revealed that increase in frequency of very heavy to exceptionally heavy rainfall events over the region, indicate rise in average intensity of rainfall during monsoon season. This increase in frequency of very heavy to exceptionally heavy rainfall events over the region, may lead to an increase in the frequency of flash floods, landslides and spoil agricultural crops. Hence a close monitoring of these very heavy to exceptionally heavy rainfall events, is essential for proper planning of disaster management authorities and other concerned agencies.

The results from this study could be valuable inputs for assessing regional and local impact of climate change and form basis for determining likely changes in rainfall during monsoon season over Ratnagiri.

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