

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

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(Received 4 November 2011, Modified 19 November 2013)

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सार – इस शोध पत्र में केवल रत्नागिरी स्टेशन के 30 वर्षों (1980 से 2009 तक) के दैनिक वर्षा आँकड़ों का उपयोग करके दक्षिण-पश्चिमी (एस डब्ल्यू) मॉनसून ऋतु (जून से सितम्बर) के दौरान हुई वर्षा के प्रेक्षित प्रवृत्ति एवं परिवर्तनों का विश्लेषण किया गया है। इस विश्लेषण से यह पता चला है कि यहाँ वर्षा में गिरावट आई है परन्तु कुल वर्षा की मात्रा तथा वर्षा वाले दिनों की संख्या में कोई खास प्रवृत्ति नहीं पाई गई है, इस प्रकार मॉनसून ऋतु के दौरान वर्षा की औसत तीव्रता में थोड़ी वृद्धि हुई है परन्तु कोई खास प्रवृत्ति नहीं पाई गई है। इस क्षेत्र में हुई मॉनसून वर्षा की औसत तीव्रता की वृद्धि को सत्यापित करने के लिए वर्षा होने की आवृत्ति की प्रवृत्तियों तथा वर्षा की प्रतिशतता को, भिन्न-भिन्न श्रेणियों की बारिश की घटनाओं में हुई कुल मॉनसूनी वर्षा को, मॉनसून ऋतु के दौरान हुई दशकीय परिवर्तन के साथ मिलाकर विश्लेषण किया गया है। वर्षा के इस रुख से पता चला है कि वर्षा की घटनाओं की आवृत्ति और कुल मॉनसूनी वर्षा की श्रेणी जैसे हल्की, सामान्य, थोड़ी भारी तथा भारी वर्षा की घटनाओं की प्रतिशतता में कमी (परन्तु अत्यधिक कमी नहीं) आई है जबकि वर्षा होने की घटनाओं की बारंबारता तथा कुल मॉनसूनी वर्षा में भारी वर्षा एवं अप्रत्याशित भारी वर्षा वाली घटनाओं से होने वाली वर्षा की प्रतिशतता में 30 वर्षों (1980-2009) के दौरान वृद्धि (परन्तु अत्यधिक वृद्धि नहीं) हुई है। दर्शाता है कि मॉनसूनी वर्षा में वर्षा की औसत तीव्रता में वृद्धि होने से भारी वर्षा से अत्यधिक भारी वर्षा वाली घटनाएं बढ़ी हैं।

दशकीय विश्लेषण से भी पता चला है कि वर्षा की घटनाओं की बारंबारता और कुल मॉनसूनी वर्षा की घटनाओं जैसे-हल्की वर्षा, सामान्य वर्षा, थोड़ी भारी वर्षा एवं भारी वर्षा, की प्रतिशतता में प्रति दशक वृद्धि हुई है। बहुत भारी वर्षा से अत्यधिक भारी वर्षा वाली घटनाओं की बारंबारता से इस क्षेत्र में बाढ़ों, भूस्खलनों की बारंबारता में वृद्धि हुई है और कृषि उत्पाद बर्बाद हुए हैं। अतः इस पर ध्यान देने की आवश्यकता है।

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 $16^{\circ} 59' N$ and Longitude $73^{\circ} 20' E$, 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 is considered in this study as 'category II' with $R \geq 65$ mm/day & $R < 125$ mm/day. The very heavy and exceptionally heavy rainfall events as per IMD are further regrouped as 'Category III' with $R \geq 125$ 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

Broad categories used in this study	IMD classifications of rainfall events	Rainfall (R) in a day (mm)
Non rainy day	No rain	000.0
	Very light rain	0.1 to 2.4
Category I	Light rain	2.5 to 7.5
	Moderate rain	7.6 to 35.5
	Rather heavy rain	35.6 to 64.4
Category II	Heavy rain	64.5 to 124.4
Category III	Very heavy rain	124.5 to 244.4
	Exceptionally heavy rain	> 244.5

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.

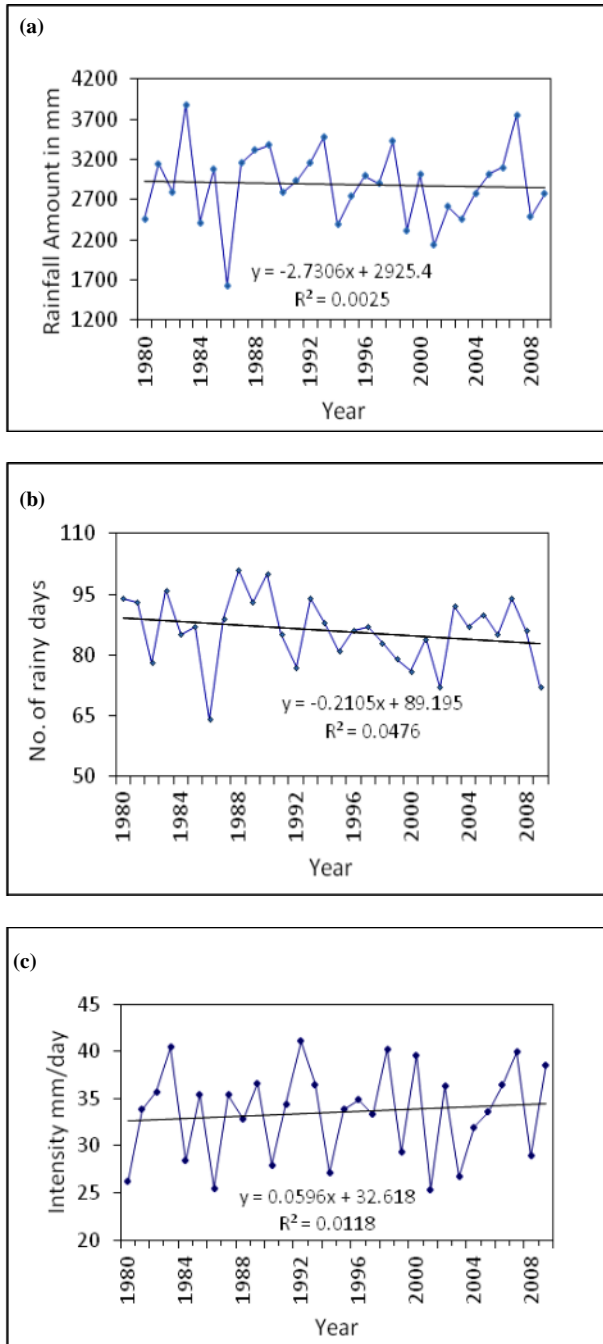
The trends of rainfall are analyzed using linear regression method and the significance of trend is tested using *t*-test of regression statistics for 95% confidence level. Here the *p*-value is compared to the significance level (0.05) and rejecting the null hypothesis when *p*-value is less than the significance level. That is if $p \leq 0.05$ the test is significant and if $p > 0.05$ the test is not significant. The above methodology is used to examine the trends in rainfall amount, number of rainy days, average intensity of rainfall, along with trends in frequency of occurrence of rainfall event and percentage (%) contribution of rainfall events to total rainfall during monsoon season for

different categories of rainfall events as identified in Table 1.

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 Fig. 1(c), shows 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



Figs. 1(a-c). Trends for (a) Total Amount of rainfall (b) Number of rainy days and (c) Average intensity of rainfall with linear trend line during monsoon season over Ratnagiri for the period 1980-2009

rainfall events to total rainfall for different categories of rainfall events (as given in Table 1) are further analyzed.

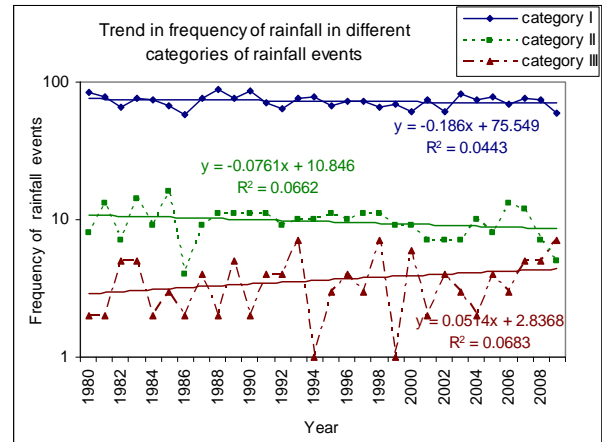


Fig. 2. Trends in frequency of rainfall in different categories of rainfall event with linear trend line, during monsoon season over Ratnagiri for the period 1980-2009

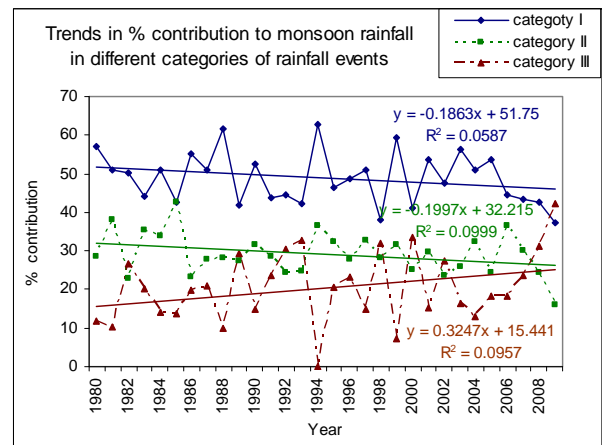
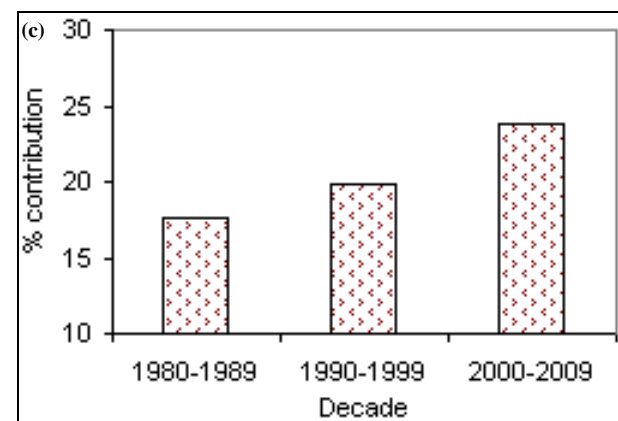
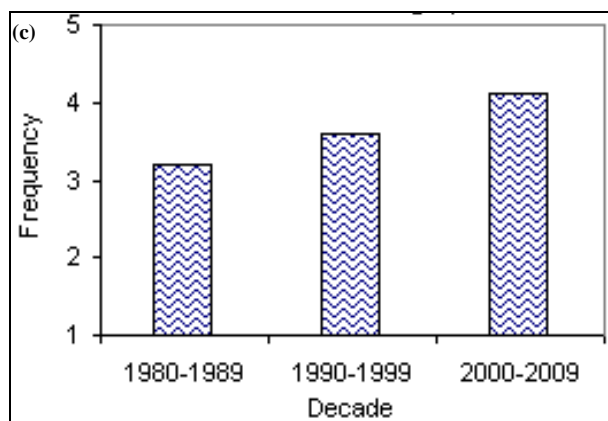
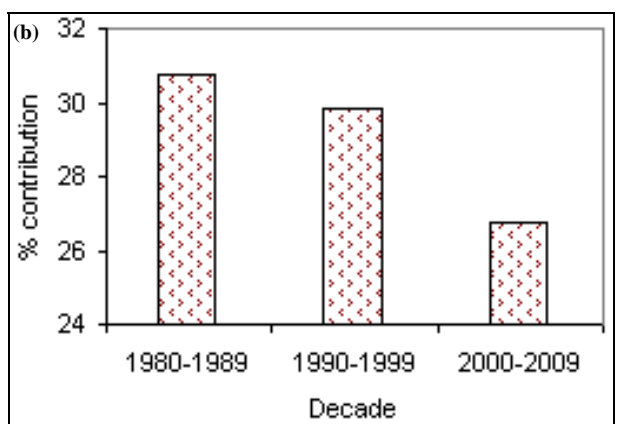
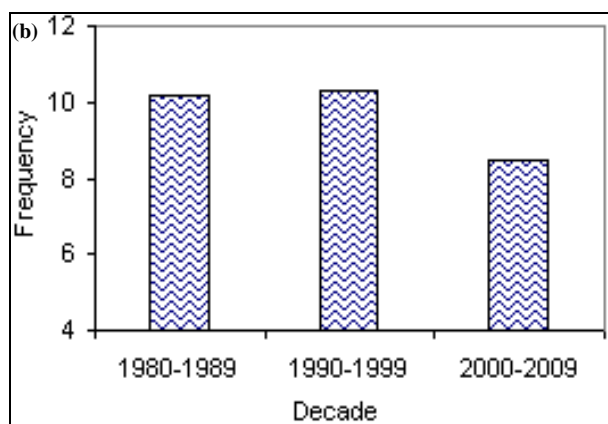
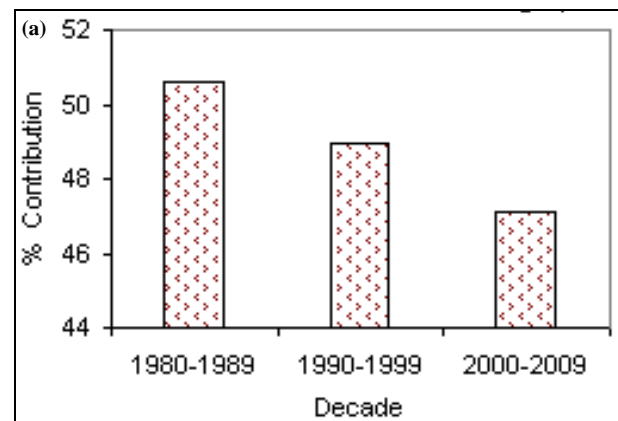
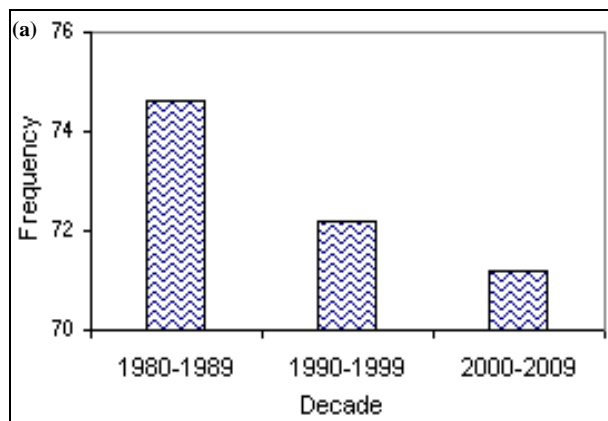


Fig. 3. Trends in percentage (%) contribution to monsoon rainfall in different categories of r/f events with linear trend line, during monsoon season over Ratnagiri for the period 1980-2009

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

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

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

TABLE 2

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

Decade	Frequency of rainfall events in category			Avg. Percentage (%) contribution in category		
	I	II	III	I	II	III
1980-1989	746	102	32	50.6	30.8	17.6
1990-1999	722	102	36	48.9	28.9	19.9
2000-2009	712	85	41	47.1	27.6	23.9

frequencies of light, moderate, rather heavy and heavy rainfall events are decreasing, whereas very heavy to exceptionally heavy rainfall events are increasing over Ratnagiri during monsoon season in 30 years (1980-2009). This increase in frequency of very heavy to exceptionally heavy rainfall events over the region is likely to increase the frequency of floods, landslides and soil erosion etc, hence requires more attention.

3.3. Trends in percentage contribution to total rainfall in different categories of rainfall events

Trends in the percentage (%) contribution of rainfall events to total rainfall in three categories (as given in Table 1) of rainfall event during monsoon season are shown in Fig. 3. The % contribution of rainfall event in category I, *i.e.*, 'R' < 65 mm/day show decreasing but not significant trend ($p = 0.1970$), also the % contribution of rainfall event in category II, *i.e.*, 'R' ≥ 65 mm/day & 'R' < 125 mm/day shows decreasing but not significant trend ($p = 0.0889$). Whereas, the % contribution of rainfall events to total monsoon rainfall in category III, *i.e.*, 'R' ≥ 125 mm/day show increasing but not significant trend ($p = 0.0963$) at 95 % confidence level. Thus, the trend analysis shows that % contribution of rainfall to total monsoon rainfall in category of light, moderate, rather heavy and heavy rainfall events have decreased, whereas in category of very heavy to exceptionally heavy rainfall events, the % contribution to total monsoon rainfall have increased during period 1980-2009. The similar results were obtained by Pattanaik and Rajeevan (2010); observed that frequency of rainfall events and % contribution to total monsoon rainfall show significant increasing trend in category of extreme rainfall events over west coast of India, but the data used by them was for the period 1951-2005. Thus, increase in average intensity of rainfall shown in Fig. 1(c), is contributed by very heavy to exceptionally heavy rainfall events over the region during SW monsoon season.

3.4. 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 in 'category I' 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 with percentage contribution to 48.9% of total monsoon rainfall. In decade 2000-2009 frequency of rainfall events and average percentage contribution further decreased to 712 events per decade and 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.*, for 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.

Acknowledgements

For this study, I am grateful and would like to express my gratitude and special thanks to Shri K. S. Hosalikar, Sc. 'E', for encouragement, support and valuable guidance. I am thankful to Dr. D. M. Rase, IMD, Pune, for encouragement and valuable guidance. I am also grateful to National Data Centre, IMD, Pune, for providing the rainfall data for this study. Finally I would like to thank Shri R. J. Mane, AM-II, Mrs. Sushma Nair S.A. and Shri D. S. Varadkar, S.A. of RMC Mumbai for their kind co-operation.

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