

## Analysis of rainfall pattern and extreme events during southwest monsoon season over Varanasi during 1971-2010

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**सार** – इस शोध पत्र में 1971-2010 की अवधि के 40 वर्षों के दैनिक वर्षा आंकड़ों का उपयोग करते हुए दक्षिण पश्चिमी मानसून वर्षा ऋतु (जून-सितंबर) के दौरान ऋतुनिष्ठ, मासिक और दशकीय विश्लेषण के माध्यम से वाराणसी (उत्तर प्रदेश, भारत) में वर्षा की चरम स्थितियों की प्रवृत्तियों और परिवर्तनशीलता का पता लगाने का प्रयास किया गया है। परिणामों से पता चला है कि 1971-2010 के दौरान संचित वर्षा अंततः मानसून वर्षा ऋतु व साथ ही साथ जून, जुलाई अगस्त और सितंबर के महीनों में कम हुई। सामान्यतः सभी कैटेगरी में प्रेक्षित वर्षा परिघटना (बिना वर्षा वाले दिन, 0-2.4 मि. मी. कैटेगरी I; 2.5-64.4, कैटेगरी II, 64.5 से 124.4; कैटेगरी III 124.5 मि. मी. और अधिक) इन सभी महीनों के अध्ययन की समूची अवधि में मानसून वर्षा ऋतु की प्रवृत्ति में कमी की प्रवृत्ति देखी गई है। हालांकि दशकीय विश्लेषण से यह पता चलता है कि प्रायः प्रत्येक कैटेगरी में वर्षा की घटनाओं की सामान्य बारम्बारता में हाल के वर्षों में गिरावट आई है। अगस्त में अलग किस्म के परिणाम देखे गए क्योंकि इस महीने में संचयी वर्षा में कमी आई जबकि हाल के दशक में व साथ ही साथ इस पूरी अवधि में बहुत भारी और अपवाद स्वरूप भारी वर्षा और उसका योगदान काफी बढ़ा है।

**ABSTRACT.** An attempt has been made to detect the pattern of rainfall and examine the trends and variations of extreme events of rainfall over Varanasi (Uttar Pradesh, India) through seasonal, monthly and decadal analysis during southwest monsoon season (June-September) using the daily rainfall data of 40 years period from 1971-2010. The results show that cumulative rainfall during 1971-2010 is overall decreasing in monsoon season as well as in all the months June, July, August and September. In general, the observed rainfall events in all categories (Non rainy day, 0-2.4 mm; Category I, 2.5-64.4; Category II, 64.5 to 124.4; Category III, 124.5 mm or more) have a decreasing trend in all the months and monsoon season over the entire period of study. However, decadal analysis reveals that in general frequency of rainfall events in almost every category is decreasing in recent decade. Different results are seen in August, as cumulative rainfall is decreasing in this month, whereas very heavy and exceptionally heavy rainfall events and their contribution have increased in recent decade as well as over total period.

**Key words** – Rainfall, Trend analysis, Southwest monsoon, Decadal rainfall, Seasonal rainfall.

### 1. Introduction

The changes in total precipitation may be associated with changes in frequency of rainfall events, rainfall intensity, or combination of both (IPCC, 2007). The change in rainfall distribution and its impact on the water resources is one of the important climatic problems. To understand the rainfall pattern changes during recent decade have become important while considering future climate change. Therefore, the analysis of daily rainfall has become important, *viz.*, 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 pattern on regional and local scale.

Several studies on trends of rainfall have been carried out by many scientists over different regions of the world. The variability and extremes of daily rainfall events during the Indian summer monsoon were investigated on the basis of long observational record for the period 1901-1989 (May, 2004). Goswami *et al.* (2006) 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. Francis and Gadgil (2006) shows that the probability of getting intense rainfall between 14° N - 16° N and near 19° N using 37 years (1951-1987) daily rainfall data of summer monsoon. Dash and Hunt (2007) have emphasized on the decrease in mean monsoon rainfall over India although the decreasing trend is small. Pattanaik and Rajeevan (2010) studied the

**TABLE 1**  
**Categorization of rainfall events based on daily rainfall**

IMD classification		IMD classification regrouped for this study	
Rainfall categories	Daily Rainfall (mm)	Rainfall categories	Daily Rainfall (mm)
No rain	0	Non rainy day	0.0 to 2.4
Very light rain	0.1 to 2.4		
Light rain	2.5 to 7.5	Category I	2.5 to 64.4
Moderate rain	7.6 to 35.5		
Rather heavy rain	35.6 to 64.4	Category II	64.5 to 124.4
Heavy rain	64.5 to 124.4		
Very heavy rain	124.5 to 244.4	Category III	124.5 mm or more
Extremely heavy rain	≥ 244.5		

frequency of rainfall events and percentage contribution to total monsoon rainfall using daily rainfall data for 55 years (1951-2005) and found significant increasing trend in the extreme rainfall events (divided into six different categories from 'light' to 'exceptionally heavy' depending on the amount of rainfall in a day as per IMD) over the west coast and central parts of India. Guhathakurta *et al.* (2010), observed increasing trend in the frequency of heavy rainfall events (according to India Meteorological Department if the rainfall of that is 64.5 mm or more) over few numbers of stations in Konkan and Goa and adjoining west coast of India. There have been several studies on daily extreme rainfall as per IMD criterion over the region based on station and grid point rainfall data (Sen Roy and Balling, 2004; Joshi and Rajeevan, 2006; Goswami *et al.*, 2006; Ghosh *et al.*, 2009; Dash *et al.*, 2009; Guhathakurta *et al.*, 2011). All these studies described long term trends and were for country as whole or sub-divisional based, while few studies have been carried out on regional and local scale (Rakehecha and Soman, 1994; Saseendran *et al.*, 1995; Prasad and Agrawal, 1996, Desai *et al.*, 1996; Sinha Ray and Srivastava, 2000; Sonar, 2014, Guhathakurta, 2014; Mohanty *et al.*, 2014; Kumar and Jaswal, 2014).

In order to have a better understanding of rainfall behaviour as an indicator of climate change and also for proper mitigation and sustainable development of a given place, the micro-scale studies are appreciated (Bhatla and Tripathi, 2014). It is preferable to analyse daily rainfall data on regional or local scale 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 objective of the present study is to examine the observed trends and variations of

extreme events of rainfall as well as changes in the rainfall pattern over Varanasi during southwest monsoon season using the daily rainfall data of 40 years period from 1971-2010. Varanasi (25° 20' N, 83° 0' E) has been chosen for this study as it lies in the subtropical region where the monsoon trough exists and we may expect a high degree of variability in rainfall events. Being situated at the tropic of Cancer, its temperature reaches as high as 45 °C with humidity too during summers. Monsoons usually come in middle of June or late June for about two months with torrential rains and high humidity accompanying it. The paper is presented in four sections. Section 2 describes the Data and Methodology used in this study. Trends of rainfall events and their decadal variations are analysed and discussed in section 3. Conclusions are presented in section 4.

## 2. Data and methodology

The daily rainfall data for the 40 years (1971-2010) period during monsoon season (June - September) was used for the analysis of rainfall pattern and extreme rainfall events over Varanasi station. The above said daily rainfall data was obtained from India Meteorological Department, Pune. The rainfall events are categorised according to the classification defined by IMD into No rain, very light rain, light rain, moderate rain, rather heavy rain, heavy rain, very heavy rain and exceptionally heavy rain depending on the amount of rainfall received in a day and further regrouped into four broad categories Non rainy day, Category-I, Category-II and Category-III as defined 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 ( $rf \geq 2.5$  and  $rf < 64.5$ , where 'rf' is daily rainfall

amount) *i.e.*, light, moderate and rather heavy rainfall events as per IMD classification are regrouped into 'Category-I'. Daily rainfall 64.5 to 124.4 mm ( $rf \geq 64.5$  and  $rf < 124.5$ ), *i.e.*, Heavy rainfall events as per IMD classification is considered in this study as 'Category-II'. Daily rainfall 124.5 mm or more ( $rf \geq 124.5$  mm/day), *i.e.*, very heavy and extremely heavy rainfall events as per IMD are further regrouped as 'Category-III' (<http://www.imd.gov.in/doc/termglossary.pdf>).

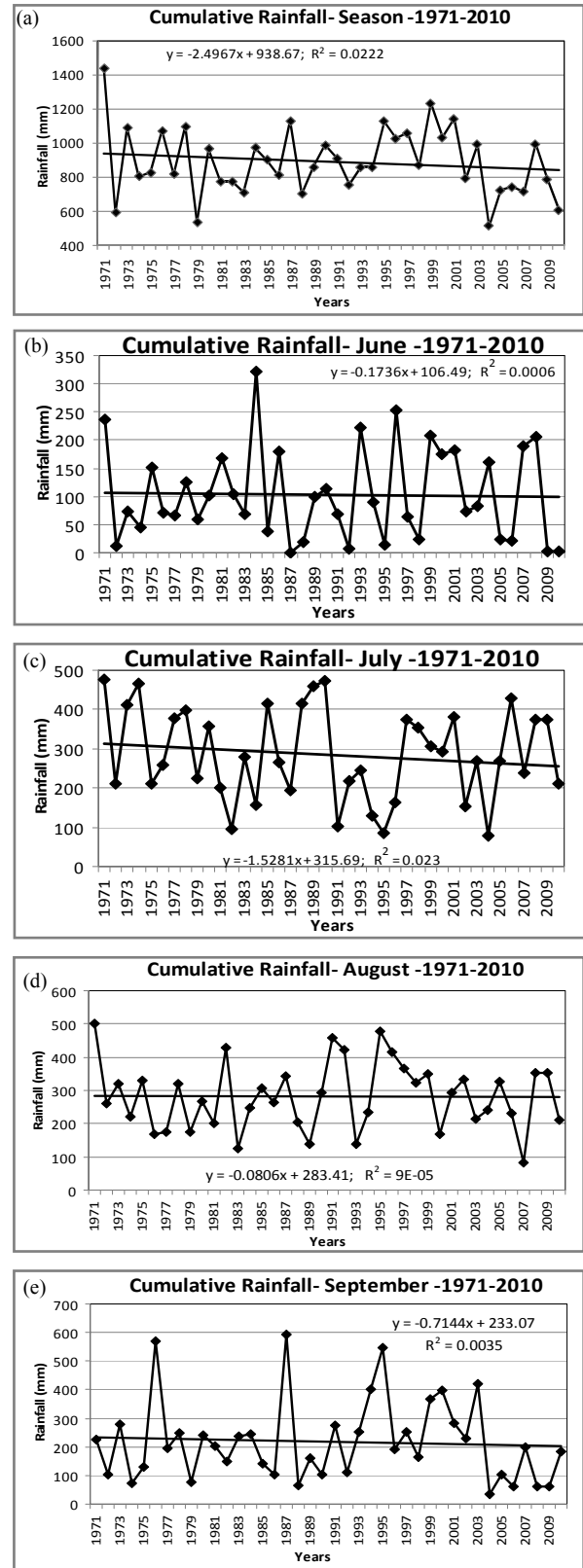
As per IMD criteria, rainfall  $\geq 2.5$  mm/day is considered as rainy day. The same criteria is considered for this study and used to calculate total rainfall amount. The 'frequency of rainfall event' is defined as the number of days or occasions when rainfall occurred in a particular category of rainfall as identified in Table 1, in each year. The ratio of total rainfall in a category, to 'Total rainfall amount' calculated in percentage is taken as Percentage (%) contribution of rainfall in that category. Here, 'Total rainfall amount' is the amount of rainfall received in all the three rainfall categories (rainy days), *i.e.*, Category-I, Category-II and Category-III, each year. Since focus of the present study is to analyse the changes in the frequency of extreme rainfall events, therefore, frequency and rainfall in Category-I, Category-II and Category-III only has been considered, whereas, the rainfall received in 'Non rainy day' category has not been considered as their contribution and impact on agriculture and social activities are not much important. The trends of rainfall are analyzed using linear regression method and the statistical significance of trend is tested by Man Kendall rank statistics (WMO, 1966) over all series of data at 95% significance level.

### 3. Result and analysis

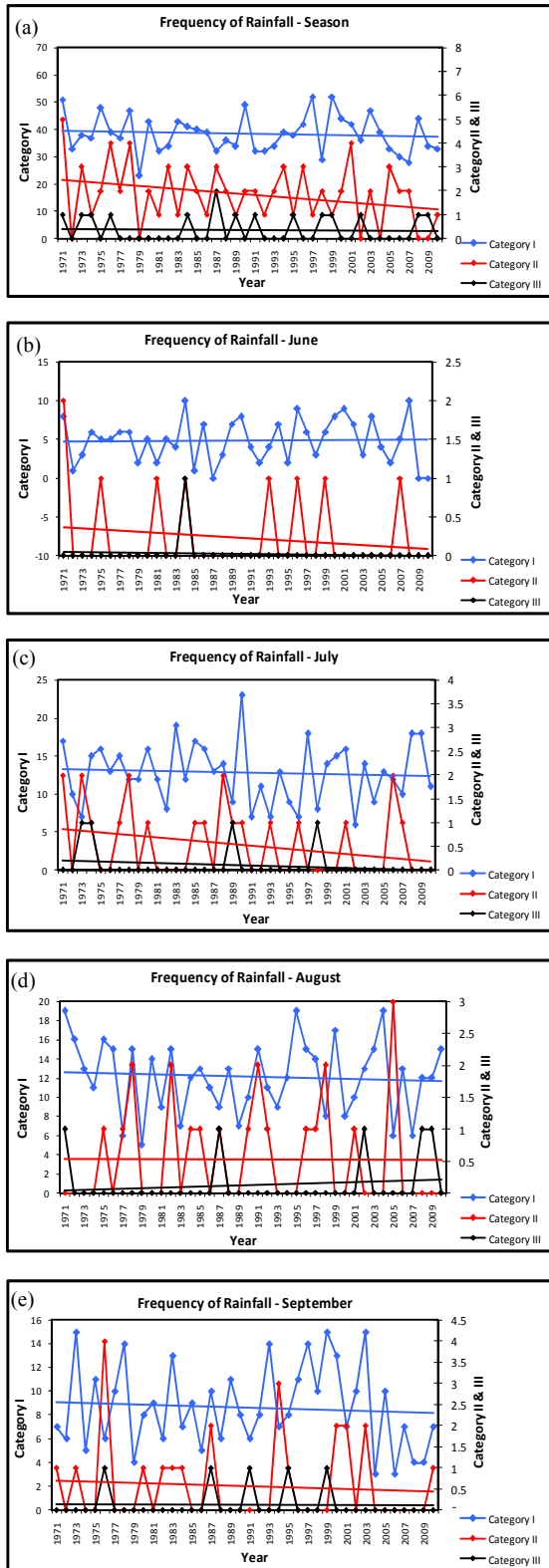
#### 3.1. Seasonal and monthly trends in cumulative rainfall

The trend analysis of seasonal (June-September) and monthly (June, July, August and September) rainfall over Varanasi is carried out for the study period 1971-2010 and shown in Figs. 1(a-e). The analysis has also been done for the four embedded decades, *viz.*, 1971-1980 (D1), 1981-1990 (D2), 1991-2000 (D3) and 2001-2010 (D4).

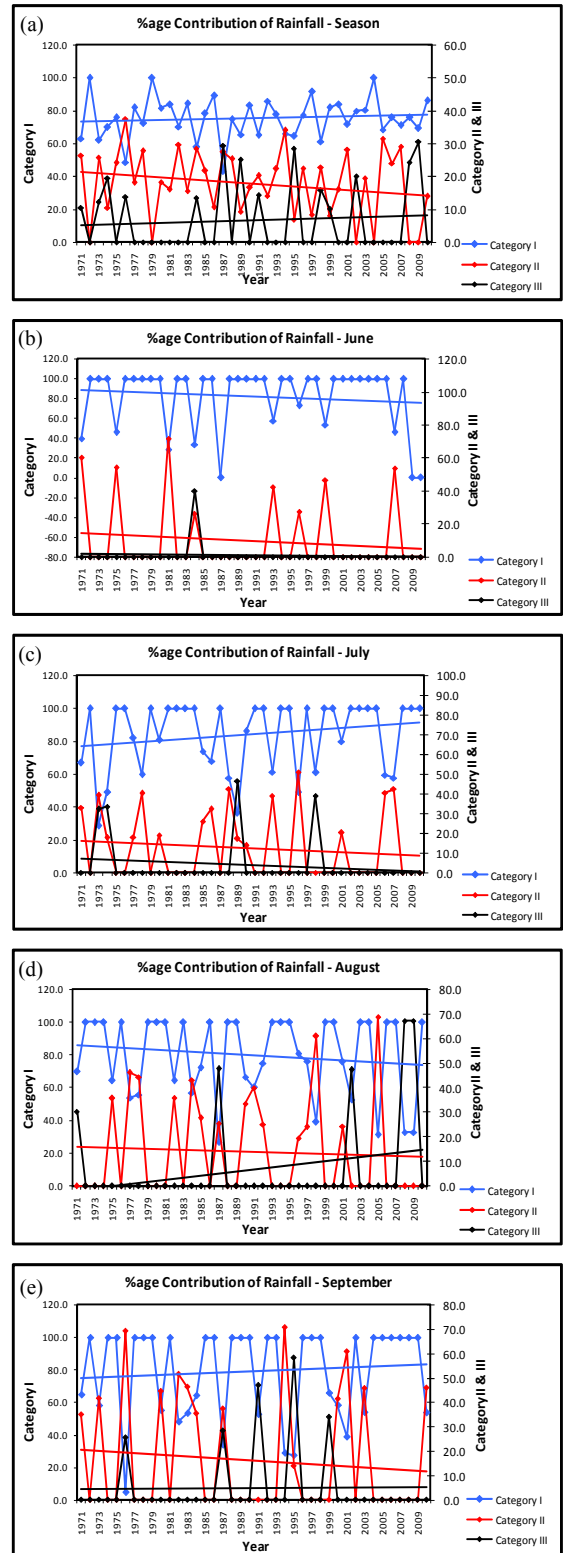
Fig. 1(a) shows the variations in the seasonal rainfall during the period 1971-2010. The regression equation depicts a very small decreasing trend of the order of 2.5 mm/year. The highest cumulative rainfall of 1438.7 mm is observed in the year 1971 and lowest 511.3 mm is observed in 2004. The trend in the month of June for entire study period 1971-2010 is not noticeable, although, it is towards negative side [Fig. 1(b)]. There is



**Figs. 1 (a-e).** Cumulative rainfall for period 1971-2010 for (a) Season (b) June (c) July (d) August and (e) September



**Figs. 2(a-e).** Frequency of rainfall events in different categories, over Varanasi for the period 1971-2010 during (a) monsoon season (b) June (c) July (d) August and (e) September



**Figs. 3(a-e).** Percentage contribution to rainfall amount ( $\geq 2.5$  mm) in different categories of rainfall events with linear trend line, over Varanasi for the period 1971-2010 during (a) monsoon season (b) June (c) July (d) August and (e) September

TABLE 2

Trend values for frequency and percentage contribution of rainfall events to total rainfall amount in different categories over Varanasi for the period 1971-2010 during monsoon season, June, July, August and September

Decade	Frequency of rainfall events in category			Avg. Percentage contribution in category		
	I	II	III	I	II	III
Season	-0.0615	-0.0313*	-0.0027*	0.10	-0.20	0.07*
June	0.0057	-0.0070*	-0.0012*	-0.35*	-0.25*	-0.05*
July	-0.0223	-0.0170*	-0.0053*	0.37	-0.20*	-0.17*
August	-0.0224	-0.0007*	0.0046*	-0.30*	-0.10*	0.40*
September	-0.0225	-0.0067*	-0.0008*	0.21*	-0.20*	0.02*

\* indicate significance at 95% confidence level

wide range of fluctuations with maximum cumulative rain of 320.9 mm in the year 1984 and minimum cumulative rain of 0 mm in the year 1987 found in the month of June. A decreasing trend in monthly cumulative rainfall, although of small magnitude (of the order of 1.5 mm per year) is observed as shown in Fig. 1(c) for the month of July for the entire period under consideration, *i.e.*, 1971-2010. The fluctuations in cumulative rainfall are clearly visible from the Fig. 1(c) and found to be ranging from 475.7 mm (1971) to 76.7 mm (2004).

The interannual variation of monthly cumulative rainfall for the month of August during period 1971-2010 is shown in Fig. 1(d). The analysis shows a negligible decrease at a rate of 0.1 mm/year is present. However, the variations during this period are large with minimum cumulative rainfall of 81.8 mm in year 1971 to maximum 501.4 mm in year 2007. A decreasing trend of very small magnitude of the order of 0.7 mm per year is observed as shown in Fig. 1e for the month of September for the entire period under consideration, *i.e.*, 1971-2010. The maximum cumulative rainfall of 591.3 mm is recorded in 1987 and minimum cumulative rainfall of 33.3 mm is recorded in 2004, therefore the range of variation is largest in this month. Also the cumulative rainfall is seen to be below 40 years average (218.4 mm) for the consecutive 7 years since 2004.

### 3.2. Seasonal and monthly trends in frequency of rainfall events

Figs. 2(a-e) shows the variations in the frequency of rainfall events and their trends using three different categories as defined in Table 1 for the entire period of study (1971-2010) over Varanasi during the southwest monsoon season (June - September) as well as in the months of June, July, August and September separately. Trend line equations were not shown in the Figs. 2(a-e),

while their trend values were presented separately in Table 2. A trend value marked with ‘\*’ indicates its significance at 95% confidence level. Analysis of number of rainfall events in Category-I shows a slight decreasing trend [Fig. 2(a)] in the monsoon season. Significant decreasing trend is observed for events under Category-II and Category-III. Analysis of rainfall events in the month of June [Fig. 2(b)] shows a slight increasing rate for rainfall events under Category-I, whereas Category-II and Category-III show significant decreasing trend. It is also seen that only one event in Category-III, which occurred in 1984, is responsible for its decreasing trend, whereas, in Category-II, highest frequency of magnitude 2 is seen in 1971. In the month of July [Fig. 2(c)] variations in frequency of rainfall events in all the three categories shows no significant trend. The similar characteristic is exhibited by Fig. 2(e), where number of events show decreasing trend in all the three categories in the month of September. However, in both July and September months, the trend for frequency of rainfall events in Category-II and Category-III is statistically significant. In the month of August [Fig. 2(d)], the rainfall events under Category-III show a significant increasing trend, however, events under Category-I and Category-II show a significant decreasing trend.

### 3.3. Seasonal and monthly trends in percentage contribution of rainfall events

The percentage contribution of rainfall received in each category to the total rainfall amount (cumulative rainfall when daily  $rf \geq 2.5$  mm) during the entire period of study (1971-2010) for the monsoon season (June-September) and also for monsoon months, *i.e.*, June, July, August and September over Varanasi [Figs. 3(a-e)] is analysed. Trend line equations were not shown in the Figs. 3(a-e) just for the sake of clarity; however, their trend values were presented separately in Table 2. A trend

TABLE 3

Decadal analysis of frequency of rainfall events in different categories (as defined in Table 1) and their average percentage (%) contribution to total rainfall amount ( $\geq 2.5$  mm) during monsoon season over Varanasi for the period 1971-2010

Decade	Frequency of rainfall events in category			Avg. Percentage (%) contribution in category		
	I	II	III	I	II	III
1971-1980	396	23	4	72.3	21.4	6.4
1981-1990	380	19	4	71.7	20.4	7.9
1991-2000	394	18	4	75.9	16.7	7.4
2001-2010	366	14	3	76.9	15.2	8.0

TABLE 4

Decadal analysis of frequency of rainfall events in different categories (as defined in Table 1) and their average percentage (%) contribution to total rainfall amount ( $\geq 2.5$  mm) during June over Varanasi for the period 1971-2010

Decade	Frequency of rainfall events in category			Avg. Percentage (%) contribution in category		
	I	II	III	I	II	III
1971-1980	47	3	0	75.7	24.3	0.0
1981-1990	47	2	1	69.4	18.8	11.8
1991-2000	51	3	0	76.6	23.4	0.0
2001-2010	48	1	0	88.8	11.2	0.0

TABLE 5

Decadal analysis of frequency of rainfall events in different categories (as defined in Table 1) and their average percentage (%) contribution to total rainfall amount ( $\geq 2.5$  mm) during July over Varanasi for the period 1971-2010

Decade	Frequency of rainfall events in category			Avg. Percentage (%) contribution in category		
	I	II	III	I	II	III
1971-1980	133	9	2	71.0	20.6	8.5
1981-1990	143	6	1	75.3	17.4	7.3
1991-2000	109	2	1	86.0	7.8	6.2
2001-2010	127	4	0	87.2	12.8	0.0

value marked with ‘\*’ indicates its significance at 95% confidence level. The analysis of Fig. 3(a) shows that the trend for the Category-I and Category-III have significant increasing trend, whereas, the Category-II shows a decreasing trend. The analysis of percentage contribution of rainfall in these categories in the month of June [Fig. 3(b)] shows an overall decreasing trend (all significant). However, the comparison between Fig. 3(b) and Fig. 2(b) reveals that the rainfall events in Category-I have increased; however, their intensities have reduced. In

Fig. 3(c) a growth in percentage contribution of rainfall in recent time in Category-I events is seen, whereas, Category-II and Category-III show significant decreasing trend. This indicates the increase in intensities of rainfall events in Category-I in the month of July. In the month of August [Fig. 3(d)] the percentage contribution of rainfall events in Category-I and Category-II has significant decreasing tendency, whereas, it has significant increasing tendency for rainfall events in Category-III. Fig. 3(e) is very similar to Fig. 3(a), where the percent contribution

TABLE 6

**Decadal analysis of frequency of rainfall events in different categories (as defined in Table 1) and their average percentage (%) contribution to total rainfall amount ( $\geq 2.5$  mm) during August over Varanasi for the period 1971-2010**

Decade	Frequency of rainfall events in category			Avg. Percentage (%) contribution in category		
	I	II	III	I	II	III
1971-1980	130	4	1	82.1	12.4	5.5
1981-1990	106	6	1	72.7	20.9	6.4
1991-2000	128	7	0	80.5	19.5	0.0
2001-2010	121	4	3	64.8	11.2	24.0

from rainfall events in Category-I and Category-III show significant increasing trend, whereas Category-II shows a significant decreasing trend. The comparison between Fig. 3(e) and Fig. 2(e) reveals that light, moderate, rather heavy, very heavy and exceptionally heavy rain has decreased in frequency but their intensities has increased in the month of September.

#### 3.4. Decadal analysis of frequency of rain events and their contribution

The whole period of study 1971-2010 is divided into four decades 1971-1980, 1981-1990, 1991-2000 and 2001-2010 for further study of the rainfall distribution and its variation in reference to previously defined (Table 1) three categories of rainfall events and their percent contribution to total rainfall amount and decadal analysis is performed over the monsoon season and its four constituent months June, July, August and September (Tables 3-7).

The decadal analysis of frequency of rainfall events and their contribution to total rainfall amount in each category is carried out for the monsoon season (Table 3). In all the three categories number of rainfall events has decreased in the recent decade. In Category-I the highest frequency is observed in D1 (396 events per decade) and lowest in D4 (366 events per decade), however, the decrease in frequency of events in recent decade D4 in comparison to D3 is 7.1% (28 events). In Category-II again D1 receive maximum number of events (23 per decade) and D4 receives lowest number of events (14 per decade). The decrease in recent decade D4 is 22% (4 events) as compared to D3. In Category-III, the number of events per decade are maintained at 4 in D1, D2 and D3 which falls to 3 in D4, thereby registering a 25% decrease. The scenario of per cent contribution of rainfall events to total rainfall is entirely different in Category-I as highest contribution come from D4 which corresponds to lowest

frequency of events. The recent decade D4 observes an increase of 1% in contribution to total rainfall as compared to D3. The lowest contribution was recorded in D2 (71.2%). However, in Category-II the contributions from different decades are varying in the same way as frequencies are changing. An increase in the recent decade is recorded in the percentage contribution of events in Category-III, thus making D4 highest contributing decade (8.0%) and D1 lowest contributing decade (6.4%).

A decrease in the frequency of rainfall events in all the three categories is observed in the recent decade in the month of June (Table 4). In Category-I, the maximum frequency of 51 events per decade was observed in D3, which declined to 48 events per decade in D4. Category-II observed a decrease from D3 (3 events per decade) to D4 (1 event per decade), whereas, Category-III recorded only 1 event in D2, which shows the scarcity of events in this category. Contrary to frequency, the percentage contribution in the Category-I has increased by 12.2% in the recent decade, showing increase in the intensities of rainfall events in this category in the recent decade. The contribution in the Category-II has reduced by 12.2% in accordance with the decreased frequency of rainfall events. There is no contribution to total rainfall from Category-III in decades D3 and D4 because of non occurrence of any event in this period, however, 11.8% contribution is observed in D2.

Decadal changes in the frequency of rainfall events and their contribution to total rainfall is shown in Table 5 for the month of July. In Category-I, there is increase in the frequency in recent decade D4 (by 18 events) as compared to D3, which records the lowest frequency of 109 events per decade, however highest frequency 143 events per decade is observed during D2. In Category-II, there is increase in the frequency in recent decade D4 (by 2 events) as compared to D3, which records the lowest frequency of 2 events per decade, however highest

TABLE 7

Decadal analysis of frequency of rainfall events in different categories (as defined in Table 1) and their average percentage (%) contribution to total rainfall amount ( $\geq 2.5$  mm) during September over Varanasi for the period 1971-2010

Decade	Frequency of rainfall events in category			Avg. Percentage (%) contribution in category		
	I	II	III	I	II	III
1971-1980	86	7	1	60.3	32.8	6.9
1981-1990	84	5	1	66.4	25.0	8.6
1991-2000	106	6	3	62.8	17.8	19.4
2001-2010	70	5	0	72.1	27.9	0.0

frequency 9 events per decade is observed during D1. Further, frequency of events in Category-III gradually decrease from decade D1 (2 events) to recent decade D4 (0 events). In Category-I the percentage contribution to total rainfall gradually increase from D1 with lowest contribution of 71.0% to D4 with highest contribution of 87.2%. Whereas in Category-II the percentage contribution increased in the recent decade D4 (12.8%) by recording an increase of 5.0% over decade D3 (7.8%) which records lowest contribution. In Category-III the percentage contribution gradually decreased from highest contributor D1 (8.5%) to D4 (0%).

Table 6 describes the variations in the frequency of rainfall events and their contribution to total rainfall in different categories for the month of August. In Category-I the highest frequency of events is observed in decade D1 (130) which decreased to lowest frequency level in decade D2 (106). However, recent decade D4 (121) observed a decrease of 7 events over the decade D3 (128). In Category-II, decade D3 (7) recorded highest frequency which decreased to 4 events in the recent decade D4. In Category-III, the lowest frequency 0 is observed in D3, which increased to 3 in recent decade D4. Percentage contribution by events in recent decade D4 (64.8%) is the lowest in Category-I, whereas highest contribution is recorded in D1 (82.1%). In Category-II also the decade D4 (11.2%) has recorded the lowest contribution. Thus in both Category-I and Category-II recent decade has decreased in contribution. However, in Category-III, decade D3 (0%) has recorded the lowest contribution, which increased to highest contribution in recent decade D4 (24.0%).

Table 7 shows the decadal rainfall pattern for the month of September. In Category-I, a sharp decrease is observed from decade D3 (106) being highest frequency to decade D4 (70) being the lowest. Again in Category-II, the decrease in recent decade D4 (5) is seen. The highest

frequency in this category is 7 in D1. In Category-III, decrease in the number of events is noticed in the recent decade D4 (0), whereas, highest frequency is recorded in D3 (3). Percentage contribution from rain events in Category-I is increased in recent decade D4 (72.1%) from D3 (62.8%). Similar increase is observed in Category-II from D3 (17.8%) to D4 (27.9%), whereas highest contribution recorded in decade D1 (32.8%). Contrary to Category-I and Category-II, a decrease in percentage contribution in recent decade D4 (0) is seen against D3 (19.4%).

The monsoon rainfall is the average over many sporadic weather events at spatial scales between 100 and 1000 km, which can give to up to 400 mm of rainfall on a single day (Stephenson *et al.*, 1999). Such extreme daily rainfall events are due to convection associated with monsoon depressions, mid-tropospheric cyclones, local convection, thunderstorms and other mesoscale phenomena which may not associate with monsoon circulation and organized convection (Dash *et al.*, 2009). The increasing (decreasing) trend of extreme rainfall events may be due to increase (decrease) number of intensified mesoscale convections which are caused by western disturbance and westward waves on the esaterlies (Dash *et al.*, 2009).

#### 4. Conclusions

The cumulative rainfall during 1971-2010 shows an overall decreasing trend in monsoon season as well as in all the months June, July, August and September. The seasonal rainfall is seen to be below normal (218.4 mm) for consecutive 7 years since 2004. The year 1971 is found to be the wettest year (1438.7 mm) and 2004 driest year (511.3 mm).

In general, the observed rainfall events in all categories have a decreasing trend in all the months and



monsoon season over the entire period of study (Dash *et al.*, 2009; Guhathakurta, 2014), whereas, in some cases the percentage contribution to total rainfall amount has shown increasing trend. The frequency of heavy rainfall events (Category-II) and their contribution to total rainfall is consistently found to be decreasing. In July the decrease in the frequency of rainfall event in Category-I is associated with an increase in its percentage contribution to total rainfall amount, which could be interpreted as increase in the intensity of rainfall events in Category-I. The percentage contribution of very heavy and exceptionally heavy rainfall events has increased in the months of August and September, however, in September the intensity of events has also increased. Study during the monsoon season clearly shows that in the recent period larger contribution is made from smaller number of events in Category-I and Category-III, therefore it may be concluded that intensity of rainfall events has increased in recent times in these rainfall categories.

A decrease in frequency of rainfall events in almost every category is observed in recent decade, the exception found only in the month of July (Category-I and Category-II) and August (Category-III). However, the percentage contribution to total rainfall amount is found increased mainly in Category-I and hence an increase in intensities in this category in June, September and season is interpreted. Overall, August shows quite peculiar behaviour, as cumulative rainfall is decreasing whereas very heavy and exceptionally heavy rainfall events and their contribution have increased in recent decade as well as over total period. The limitation of the study is that the number are too less in Category-III to draw any conclusion. However, to see the changes in the extreme events (extremely heavy rainfall events) the Category-III is considered.

Climate change impact and evidences are not same over the entire globe. Increasing or decreasing trends in seasonal, monthly and decadal rainfall are indicated by many research findings, but such trends vary spatially and temporally. Therefore, it is important to monitor closely, the rainfall trends and variations on regional and local scale.

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