MAUSAM, **69**, 4 (October 2018), 577-588

551.577.3 : 551.553.3 (540.27)

Trend and variability of hourly intensity of rainfall over eastern and northern part of Uttar Pradesh during 1969-2014

SHASHI KANT

Meteorological Centre, BPI Airport, Bhubaneswar, Odisha – 751 020, India

(*Received 17 February 2017, Accepted 7 August 2018*)

e mail : onlineskmishra@gmail.com

सार - अब यह विचार व्यापक रूप से स्वीकार किया जा चुका है कि दुनिया के तापमान के औसत मान में बढ़ोत्तरी हुई है, जिसकी मुख्य वजह मानव जनित स्रोतों के माध्यम से ग्रीन हाउस गैसों का प्रमुख रूप से जलवायविक उत्सर्जन है । भीषण बाढ़, तूफान और सूखे जैसी मौसम की चरम घटनाओं की घटना की आवृत्ति में परिवर्तन से भी ग्लोबल वार्मिंग देखी जा सकती है। जलवायु परिवर्तन के विषय पर अंतरराष्ट्रीय मंचों से विचार-विमर्श किया जा रहा है। इस संदर्भ में जलवायु परिवर्तन पर अंतरराष्ट्रीय पैनल (IPCC) की रिपोर्ट्स महत्वपूर्ण है। जलवायु परिवर्तन और भूमंडलीय उष्णीकरण के दौर में इस अध्ययन का उद्देश्य वर्षा के प्रति घंटा आंकड़ों के द्वारा उत्तर प्रदेश के चयनित चार स्टेशनों अर्थात बरेली, लखनऊ, इलाहाबाद और बाबतपुर (वाराणसी एयरपोर्ट) की वर्षा की प्रवृत्ति और तीव्रता का पता लगाना है। इन स्टेशनों को उत्तर प्रदेश के पूर्वी और उत्तरी भाग का प्रतिनिधित्व करने के लिए और बेहतर डेटा की उपलब्धता के आधार पर चयन किया गया है। सबसे पहले प्रति घंटा 1969 से लेकर 2014 के लिए सभी चार स्टेशनों की वर्षा डेटा की जांच की है। प्रति घंटा डेटा के प्रतिशतक स्टेशनों में से प्रति घंटा वर्षा के विभिन्न तीव्रताओं को परिभाषित करने के लिए गणना की है। अलग प्रतिशतक समूहों के आधार पर, वर्षा की तीव्रता को बहुत हल्का दौर, हल्का दौर, मध्यम दौर, तीव्र दौर, बहुत तीव्र दौर, अत्यंत तीव्र दौर, असाधारण तीव्र दौर में वर्गीकृत किया गया है। प्रत्येक प्रतिशतक समूह के लिए, वार्षिक, मासिक, JJAS (मानसून) आवृत्ति वितरण तैयार किया गया है। आवृत्ति वितरण प्रवृत्ति का विश्लेषण टी परीक्षण, पी मान, ढाल और आर वर्ग के माध्यम से किया गया है। प्रवृत्ति के सांख्यिकीय महत्व की जांच को टी परीक्षण द्वारा किया गया है।यह पाया गया है कि में विभिन्न तीव्रताओं की वर्षा वार्षिक, मासिक, JJAS (मानसून) के सभी चार स्टेशनों के लिए सांख्यिकीय रूप से महत्वपूर्ण नहीं है। इससे इस बात का निष्कर्ष निकाला जा सकता है कि जलवायु परिवर्तन के इस दौर में भी उत्तर प्रदेश के पूर्वी और उत्तरी भाग में वर्षा क़ी प्रति घंटा प्रवृत्ति और तीव्रता में कोई परिवर्तन नहीं आया है।

ABSTRACT. It is now widely accepted question that average value of the world temperature has gone up because of climatologically significant emission of greenhouse gases by means of anthropogenic sources. Global warming may be witnessed by changes in the frequency of occurrence of the extreme weather events such as severe floods, storms and drought. The topic of climate change is being discussed on international platforms. With this reference reports of Intergovernmental panel on climate change (IPCC) are important. In this era of climate change and global warming, we set the objective of this study to find out the trend and intensity of rainfall in the selected four stations, *viz*., Barielly, Lucknow, Allahabad and Bapatpur (Varanasi Airport) of Uttar Pradesh (UP), India based on hourly rainfall data. These stations are selected on better data availability and to represent eastern and northern part of UP. Firstly hourly rainfall data of all four stations ranging from 1969 to 2014 is examined. The percentile of hourly data is calculated to define various intensities of hourly rainfall of the stations. Based on different percentiles groups, intensity of the rainfall is classified into very light spell, light spell, moderate spell, intense spell, very intense spell, extremely intense spell , exceptionally intense spell. For each percentile group, yearly, monthly, JJAS (monsoon) frequency distribution is prepared. Frequency distribution trend is analyzed by means of t-test, p-value, slope and R square. Statistical significance of the trend is done by t-test. It is found that the rainfall of different intensities in yearly, monthly, JJAS (monsoon) for all the four stations is not statistically significant. From this it may be infer that even in the era of climate change, the trend and intensity of hourly rainfall in the eastern and northern parts of UP is not changed.

Key words – Hourly rainfall data, Trend analysis, Percentile method, Frequency analysis.

1. Introduction

According to Census of India 2011, approximate seventy percent of the population of India lives in villages (www.censusindia.gov.in). In rural areas main employment is agriculture and cultivation. Agriculture is mainly depends on the precipitation and rainfall. Besides this drinking water and other water demanding activities are primarily depend on the rainfall. Therefore, rainfall pattern, extreme rainfall events etc. are very important.

Rainfall study is an important research area in meteorology, hydrometeorology and hydrology (Syafrina *et al*., 2015; Guhathakurta *et al*., 2005; Taxak *et al*., 2014; Ananthakrishnan and Rajan, 1987; Roy and Balling, 2007; Coumou and Rahmstorf, 2012).

We refer to latest IPCC report (2014) (Hijioka *et al*., 2014), it is pointed out that "Over India, the increase in the number of monsoon break days and the decline in the number of monsoon depressions are consistent with the overall decrease in seasonal mean rainfall. But an increase in extreme rainfall events occurred at the expense of weaker rainfall events over the central Indian region and in many other areas. If we consider the whole South Asia, the seasonal mean rainfall shows inter-decadal variability, noticeably a declining trend with more frequent deficit monsoons under regional in homogeneities. In South Asia, the frequency of heavy precipitation events is increasing, while light rain events are decreasing".

The topic of climate change is being discussed on international platforms. With this reference, reports of Intergovernmental panel on climate change (IPCC) are important. Many possible sources are being pointed out for the global warming (IPCC 2007 - Parry *et al*., 2007); (IPCC 2007 - Field, 2007); IPCC 2013; IPCC 2014; Jones and Moberg, 2003; Menne and Williams, 2005; Muschinski and Katz, 2013; Trenberth *et al*., 2007; Hansen *et al*., 2010; Rohde *et al*., 2012; Groisman *et al*., 2005; Alexander *et al*., 2006). Human activities are playing a major role in the extreme events (Min *et al*., 2011).

The climate of India is dominated by monsoon systems. During the northern hemispheric summer, southwesterly winds bring moisture from the Indian Ocean and give heavy rains across India during June to September. The climate of India is broadly divided into four seasons, primarily demarcated by the seasonality in rainfall: (*i*) Winter (January and February); (*ii*) Pre-monsoon (March to May); (*iii*) Southwest monsoon (June to September); (*iv*) Post-monsoon (October to December). On an average, India receives 105 cm of rainfall in a year out of which summer monsoon (or southwest monsoon) contributes nearly 75-80% to the annual rainfall at many parts of the country. A salient feature of monsoon rainfall is the movement of depressions/storms originating over Bay of Bengal or Arabian Sea. However, the northern tip of India receives a substantial amount of rainfall during winter season on the account of western disturbances. Pre-monsoon rainfall activity or thunderstorm activity prevails over some parts of India such as northeast India. Southeast peninsula experiences its wettest season during October to December or post-monsoon season.

Generally, information on rainfall climatology is available for time scales such as monthly, seasonal or annual rainfall, which is derived from the daily rainfall amounts recorded at individual stations. By using daily rainfall data, variations in the rainfall patterns at the time scales such as monthly, seasonal or annual have been a focus of the scientific literature for many years. It is also important to know the climatic features of rainfall on shorter time scales such as daily, hourly and even minute-wise, for the management of drainage systems, agricultural operations and soil erosion studies, etc. The mean diurnal cycle of rainfall in terms of short-duration precipitation can provide interesting insights on the local rainfall characteristics that may have important implications for efficient water resource management.

Many studies are going on to study the patterns of rainfall based on hourly time scale. Recently many such studied are reported (Syafrina *et al*., 2015; Deshuai *et al*., 2016). Syafrina *et al*. (2015) studied historical trend of hourly extreme rainfall in peninsular Malaysia. They analyzed hourly rainfall data (1975-2010) across the Peninsular Malaysia for trends in hourly extreme rainfall events. The analyses were conducted on rainfall occurrences during the northeast monsoon (November-February) known as NEM, the southwest monsoon (May-August) known as SWM and the two inter-monsoon seasons, *i.e*., March-April (MA) and September-October (SO). At the station level they calculated several extreme rainfall indices. For the purpose of the trend analysis authors used linear regression; no serial correlation was detected from the Durbin-Watson test. Ordinary kriging was used to determine the spatial patterns of trends in seasonal extremes. Their results showed that the total amount of rainfall received during NEM is higher compared to rainfall received during inter-monsoon seasons. However, it was also estimated that the intense rainfall is observed during the inter-monsoon season with higher hourly total amount of rainfall. Many such studies are available in the literature. Studies on daily rainfall analysis are much popular.

However, many studies available on hourly rainfall data over the Indian region also, describes diurnal variation during summer monsoon season or a particular season in India (Ananthakrishnan and Rajan, 1987; Roy and Balling, 2007; Roy, 2009; Deshpande *et al*., 2012). Ananthakrishnan and Rajan (1987) studied several characteristics of the south-west monsoon rainfall of the low latitude stations of Cochin (coastal) and Minicoy (island) by using the histograms of these stations for the ten year period 1973-1982. They found that both stations exhibit diurnal variations of rainfall with maximum activity in the post-midnight hours and minimum in the afternoon hours. The amplitude of the diurnal variation

TABLE 1

Station details and data availability

Station name	Station index No.	Lat.	Long.	Years for which data is available
Bareilly	42189	28.3670	79.4304	1970-2012
Allahabad	42475	25.4358	81.8463	1969-2014
Lucknow	42369	26.8467	80.9462	1969-2014
Babatpur (Varanasi Airport)	42479	25.4507	82.8560	1970-2014

TABLE 2

Climatology of Stations

Station name	Average annual rainfall (mm)	Average annual min temp. in degree Celsius	Average annual max. temp. in degree Celsius	Remark, If any
Bareilly	1136.9	4.8*	44.4	Average for 30 years
Allahabad	744.1	4.8*	45.8	
Lucknow	917.3	3.6	44.6	
Babatpur (Varanasi Airport)	989.0	4.4*	44.7*	

* 29 years average (Source: Climatological Normals 1981-2010, IMD)

TABLE 3

The classification of hourly rainfall based on percentile

S. No.	Terminology	Percentile
1.	Very light spell	upto 50
2.	Light spell	50-75
3.	Moderate spell	75-90
4.	Intense spell	90-95
5.	Very intense spell	95-97.5
6.	Extremely intense spell	97.5-99.9
7.	Exceptionally intense spell	>99.9

TABLE 4

Station-wise percentile values (in mm)

Station name	percentile values (in mm)					
	50	75	90	95	97.5	99.9
Bareilly	1.0	3.5	9.9	15.7	23.9	63.1
Allahabad	0.8	2.8	7.6	13.0	20.0	62.6
Lucknow	0.9	3.0	8.2	13.9	21.0	60.2
Babatpur (Varanasi Airport)	0.8	2.8	8.2	13.5	20.2	62.9

TABLE 5

Station-wise intensity classification (in mm)

S. No.	Terminology	Bareilly	Allahabad, Lucknow, Babatpur (Varanasi Airport)
1.	Very light spell	<1.0	<1.0
2.	Light spell	4.0	3
3.	Moderate spell	10	8
4.	Intense spell	16	14
5.	Very intense spell	24	20
6.	Extremely intense spell	63	61
7.	Exceptionally intense spell	>63	>61

increases for rain events of increasing intensities. The integrated duration of the seasonal rainfall is about 250 hr at Cochin and 110 hr at Minicoy. Half the total rain from heavy falls is received in a fifth of the total duration; half the total duration accounts for only a fifth of the total rain from light falls.

Roy and Balling (2007) studied and analyzed the spatial patterns in the diurnal cycle of precipitation over the Indian subcontinent. They assembled hourly precipitation data for 78 stations spread across the Indian subcontinent for the period 1980 to 2000. On the basis of the results of the first harmonic, we found the presence of a distinct diurnal cycle over most of the Indian subcontinent for frequency, total and intensity of precipitation events. The standardized amplitudes, indicative of the strength of diurnal cycle over a region, are strongest in peninsular India, with greater than 80% explained variance. The diurnal spatial patterns are broadly a result of the interaction of local orography and convectional processes. The time of maximum precipitation along the west coast is predominantly concentrated a few hours after midnight to predawn hours. The interiors of the subcontinent generally experience late afternoon to early evening showers, which may be attributed to local convective processes. The time of maximum for total amount of precipitation are mostly about half an hour to 1 hr before the time of maximum for the frequency. The overall patterns of diurnal cycle were also found to be robust against interannual variations, in the form of ENSO and La Ni˜na years.

Deshpande *et al*. (2012) also studied the hourly rainfall data recorded at 72 Self Recording Raingauge Stations (SRRG) for the period 1969-2006 are utilized to study the characteristic features of hourly rainfall and diurnal variations of rainfall in India. They examined temporal changes in the short duration (less than 12 hr) rainfall extremes. They analyzed the time distribution of a heavy rain spell of 24 hr duration, which is an important component in water resources management and flood control studies. They also studied different aspects of hourly rainfall such as, average number of rain hours in a year, empirical probability distribution functions. Their analysis indicated that many stations in India have

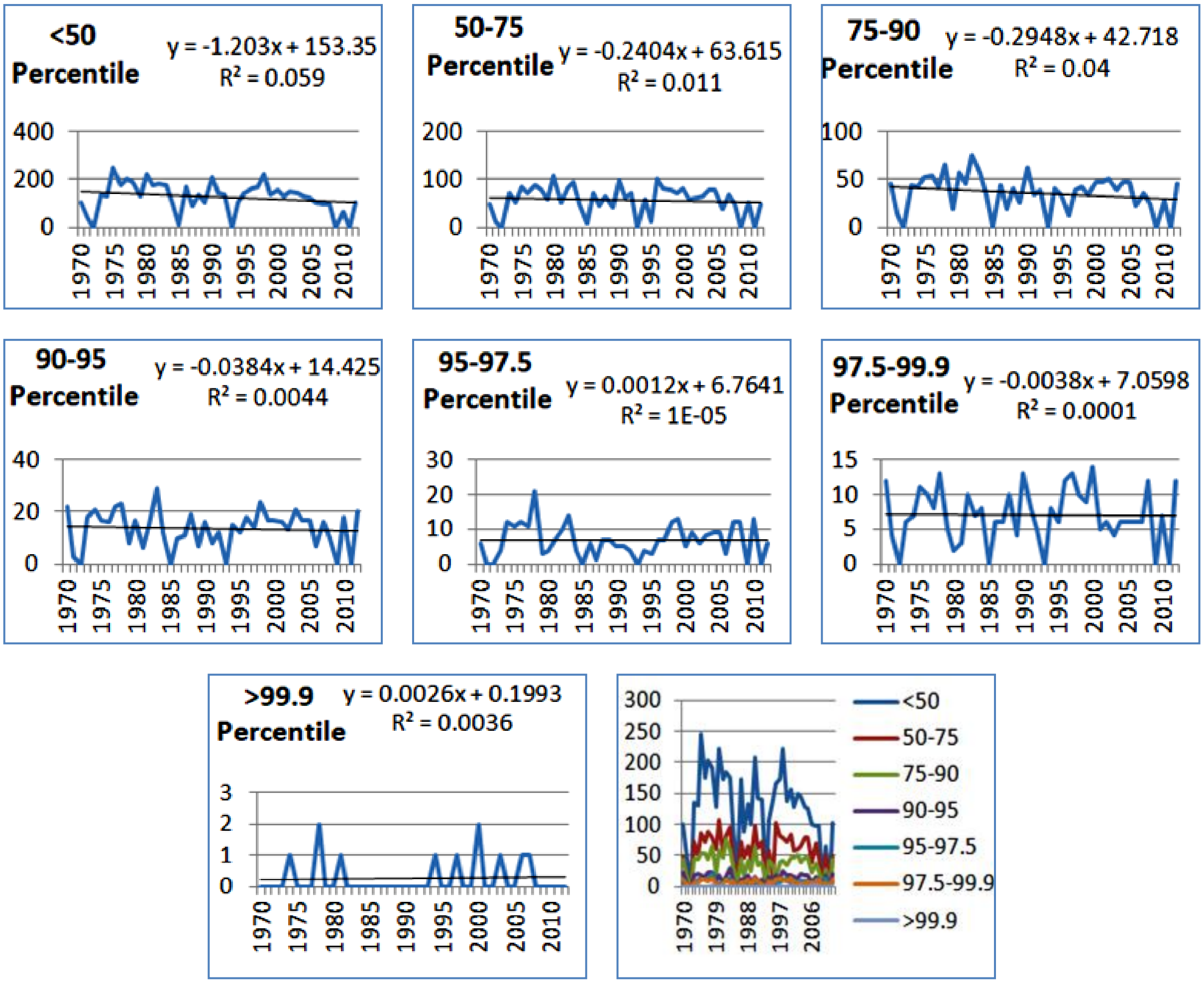

Fig. 1. Yearly analysis for the station (42189)

recorded more than 10 cm of rainfall in an hour's duration. Such stations are located along the west coast, foothills of Himalayas and along the tracks of monsoon disturbances. Extreme rainfall events of various duration (3-12 hr) show increasing trends, significant at 5% level, at many stations located in central India and peninsular India except for southern part of west coast. Time distribution of hourly rainfall shows that, on average, 25% of the daily rainfall can be received in just 3 hr, while 80% can occur in 12 hr during the heavy rain spells of 24 hr duration. They examined some characteristic features of short duration rainfall at some Indian stations and also the temporal changes in their characteristics during the period 1970-2003. Along with the two aspects discussed above, namely, diurnal variation of rainfall and time distribution of rainfall during heavy spells, other important aspects of hourly rainfall, such as number of rain hours during a year, frequency distribution of hourly rainfall, contribution of the daytime rainfall to monsoon rainfall & spatio-temporal changes in the extreme rainfall of durations less than 12 hour, etc. have also been examined in this study. For more literature on hourly rainfall data, we can refer to (Syafrina *et al.*, 2015; Guhathakurta *et al.*, 2005; Taxak *et al.*, 2014; Ananthakrishnan and Rajan, 1987; Roy and Balling, 2007; Muschinski and Katz, 2013).

Accordingly, the main objectives in this paper is to examine:

(*i*) By using hourly rainfall data classify the intensity of rainfall by the method of percentile.

(*ii*) To find out the station-wise the monthly, yearly frequency and JJAS (Total) of each category of intensity.

(*iii*) Yearly, Monthly trend of rainfall for all the years and all the stations. Trend for SW monsoon season (JJAS).

(*iv*) To test whether the trends are statistically significant or not.

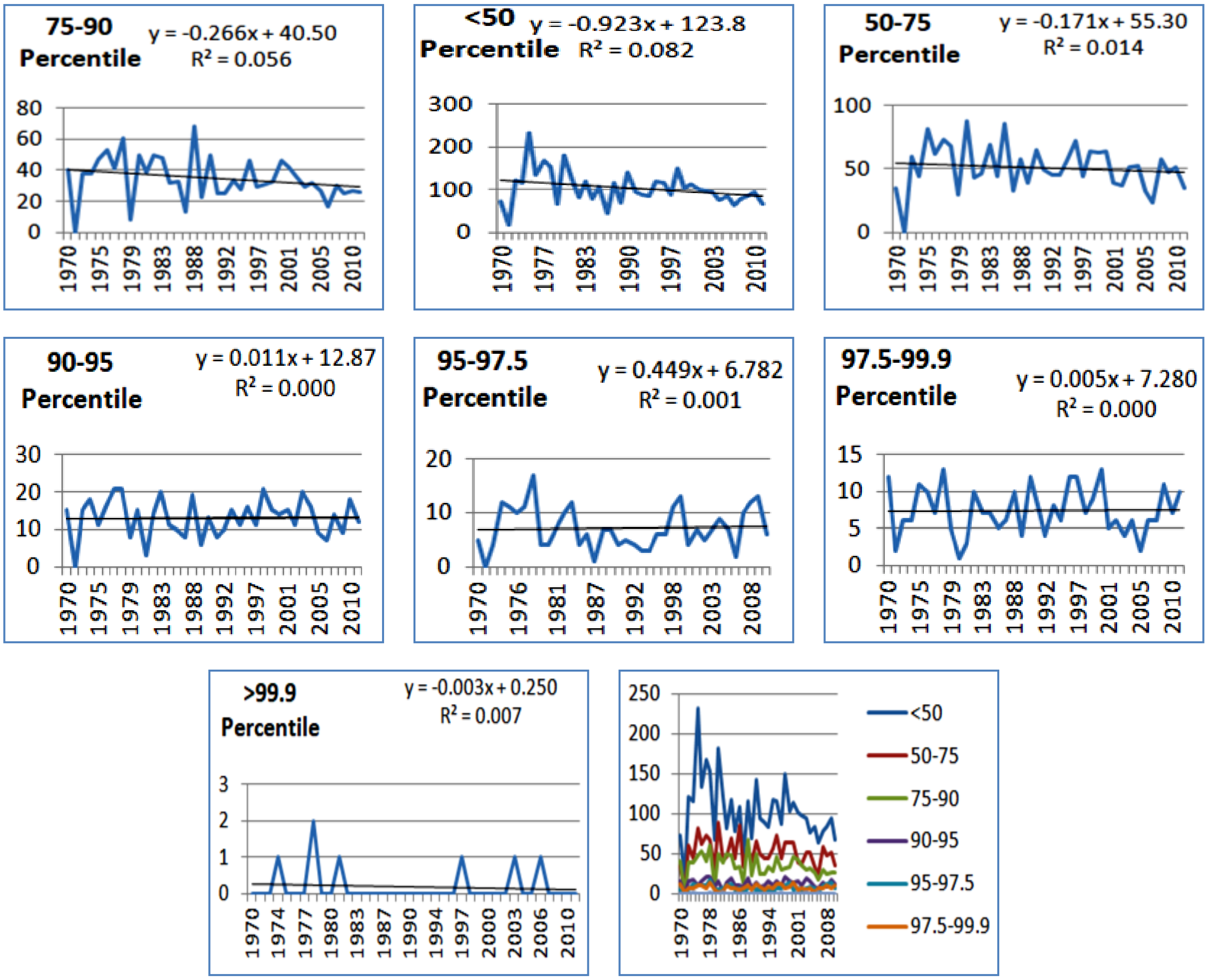

Fig. 2. Monsoon analysis 42189

2. Data and methodology

2.1. *Study area*

Uttar Pradesh (26.8467 N, 80.9462 E) is a biggest state in northern part of India. We have selected Uttar Pradesh (UP) as our domain of study. We have selected four major stations namely Bareilly, Allahabad, Lucknow and Babatpur (Varanasi Airport) from UP. These stations are selected on better data availability and to represent eastern and northern part of UP. The station-wise hourly rainfall data is collected from National Data Centre (NDC), India Meteorological Department (IMD), Pune, India. The detail about four stations including availability of hourly data is shown in Table 1.

The climatology of these stations is also listed in the Table 2 to get an insight the standard normal's for these stations.

2.2. *Techniques and tools*

We used the percentile method for classification of the intensity. As a matter of fact there is no standard definition of the percentile. However, percentiles are an important parameter in the statistical tools similar to other tools like quartiles and deciles. However, when data is arranged in descending or ascending order, it can be divided into various parts such as quartiles, deciles and percentiles. Collectively these are known as quantiles. Anyhow all these tools are extension of median formula.

It must be noted that median divides a series into two parts. If we followed this approach then the relation between different quantiles may be established, For example:

First Quartile (Q_1) = P_{25},

Second Quartile (Q_2) = P_{50} = D_2,

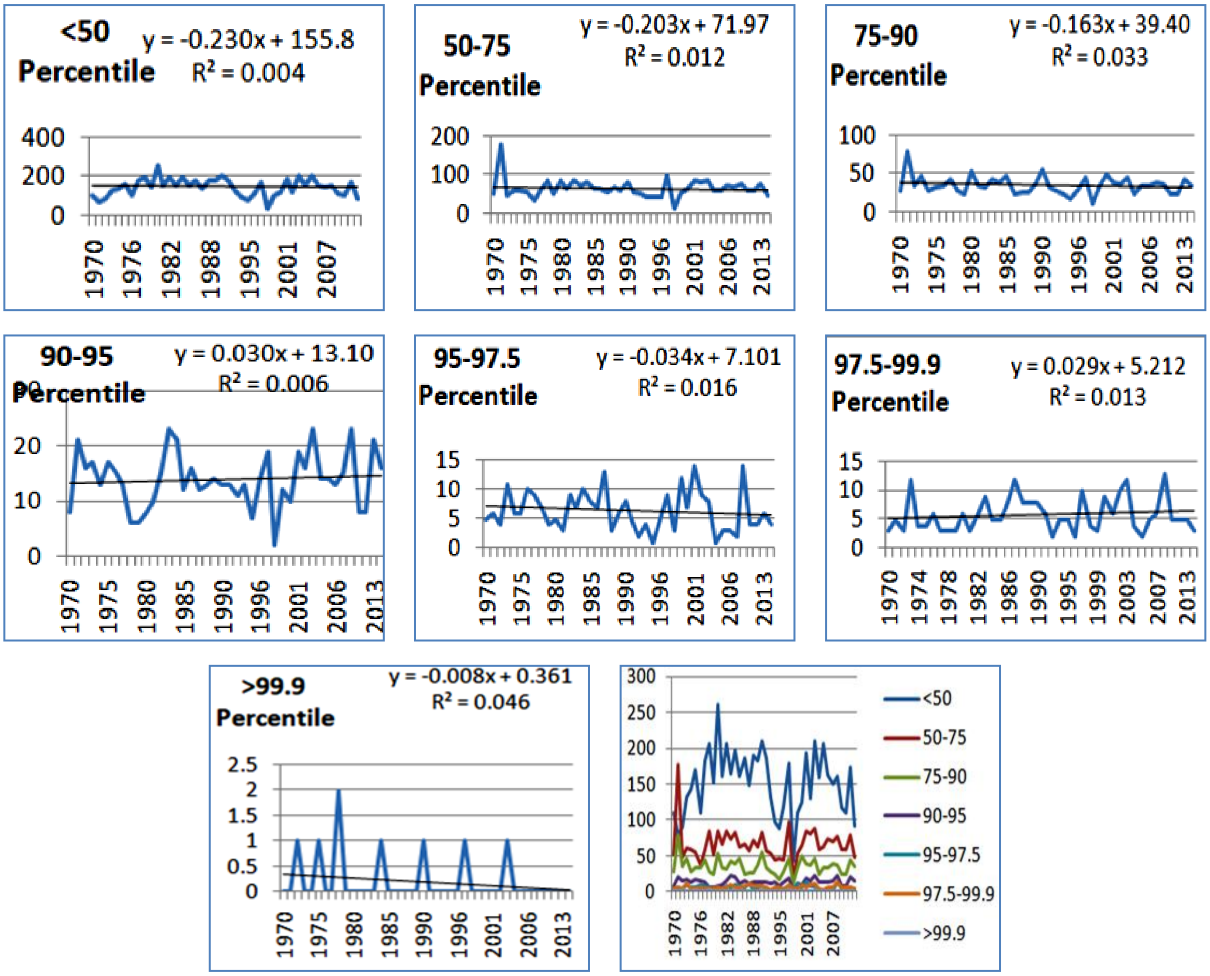

Fig. 3. Yearly analysis 42479

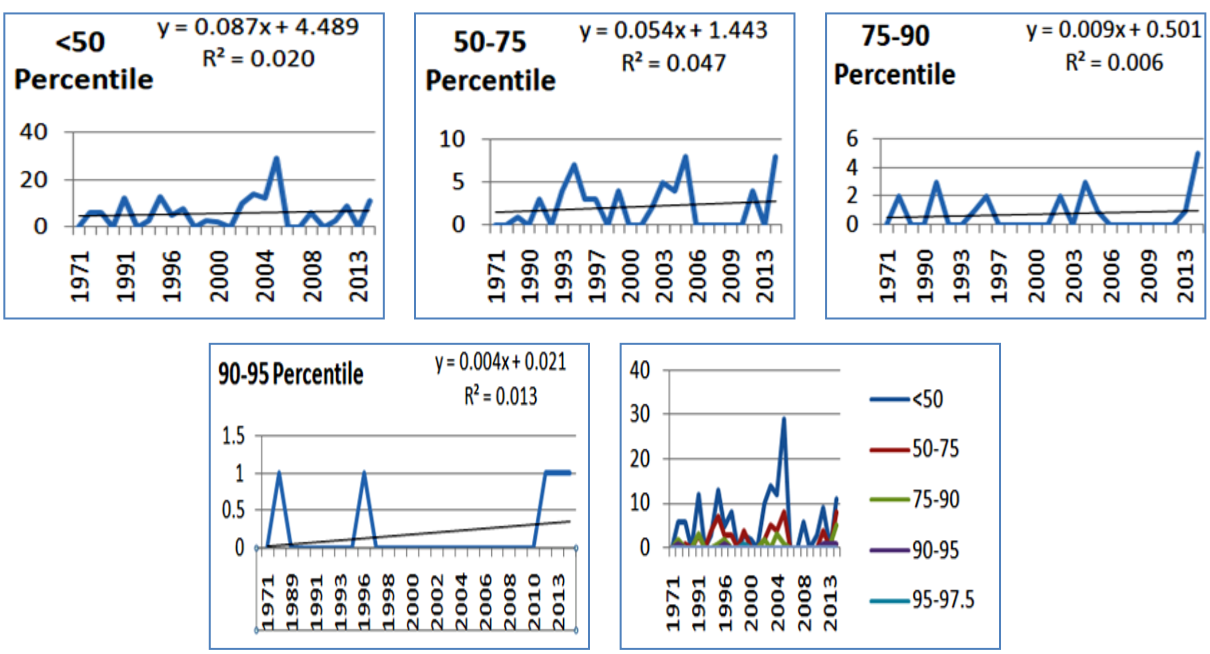

Fig. 4. Monsoon analysis 42479

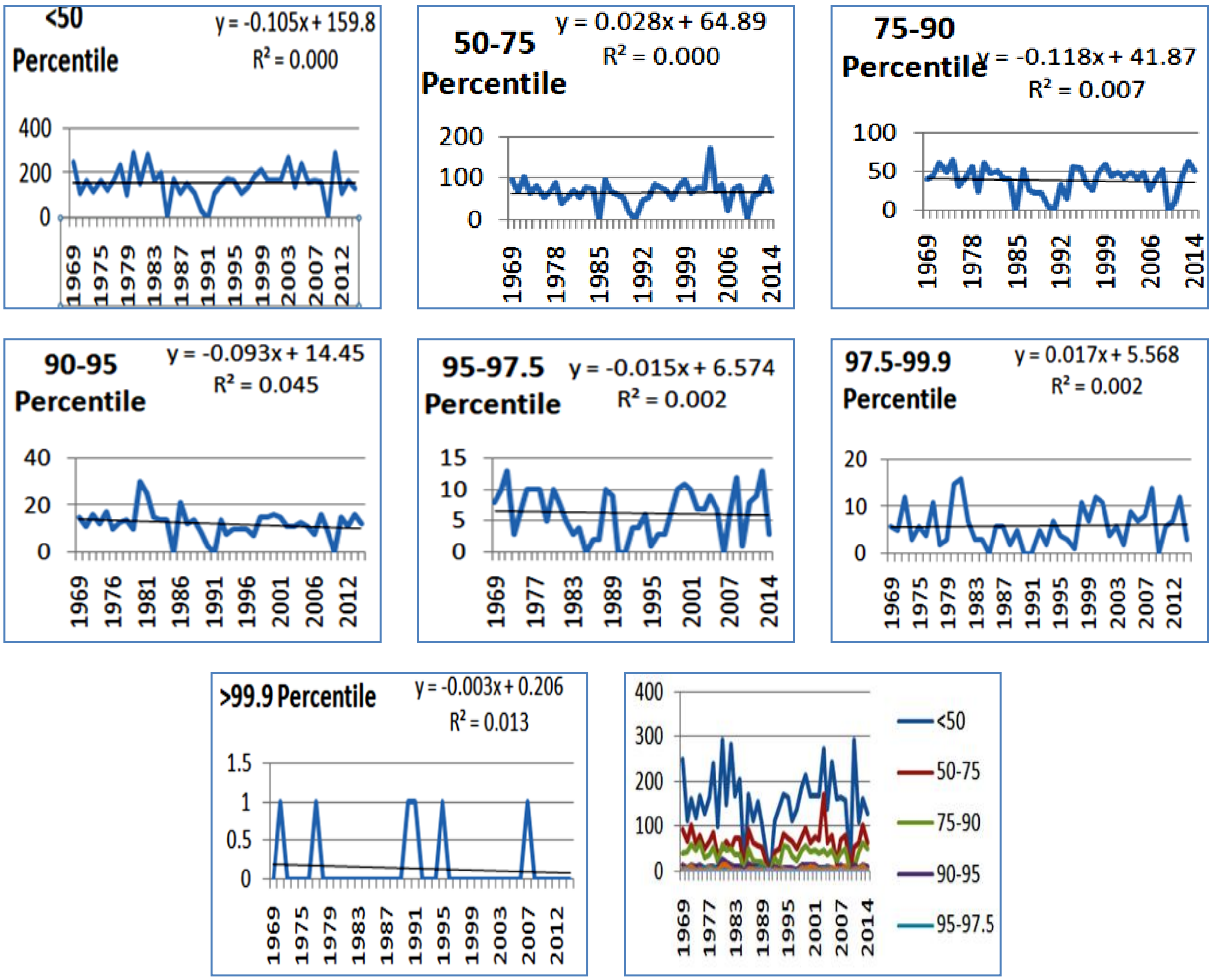

Fig. 5. Yearly analysis 42475

Second Quartile = Fifth Decile = 50th Percentile = Median

Based on the working formula for the median, formula for percentile may be written as:

$$P_i = l + \frac{h}{f}\left(\frac{iN}{100} - c\right); i = 1, 2, 3, \dots 99. \quad (1)$$

where,

l = lower boundary of Percentile group,

h = width of Percentile group,

f = frequency Percentile group,

N = total number of observations, *i.e.*, sum of frequencies,

c = cumulative frequency preceding Percentile group.

There are many definitions for Percentiles and used in literature as per the size, shape and structure of data. Three definitions are listed out here for ready reference.

Definition 1 **:** The n^{th} Percentile is the lowest score that is greater than a certain percentage (n) of the scores.

Definition 2 : The n^{th} Percentile is the smallest score that is greater than or equal to a certain percentage of the scores.

Definition 3 : A weighted mean of the percentiles from the first two definitions.

There are many practical working methods for the calculation of Percentiles, e.g., the nearest rank method. In nearest rank method ordinals ranks are used to calculate the Percentiles. As a matter of fact in Eq. (1), the term within bracket that is $\frac{iN}{100}$ is called ordinal

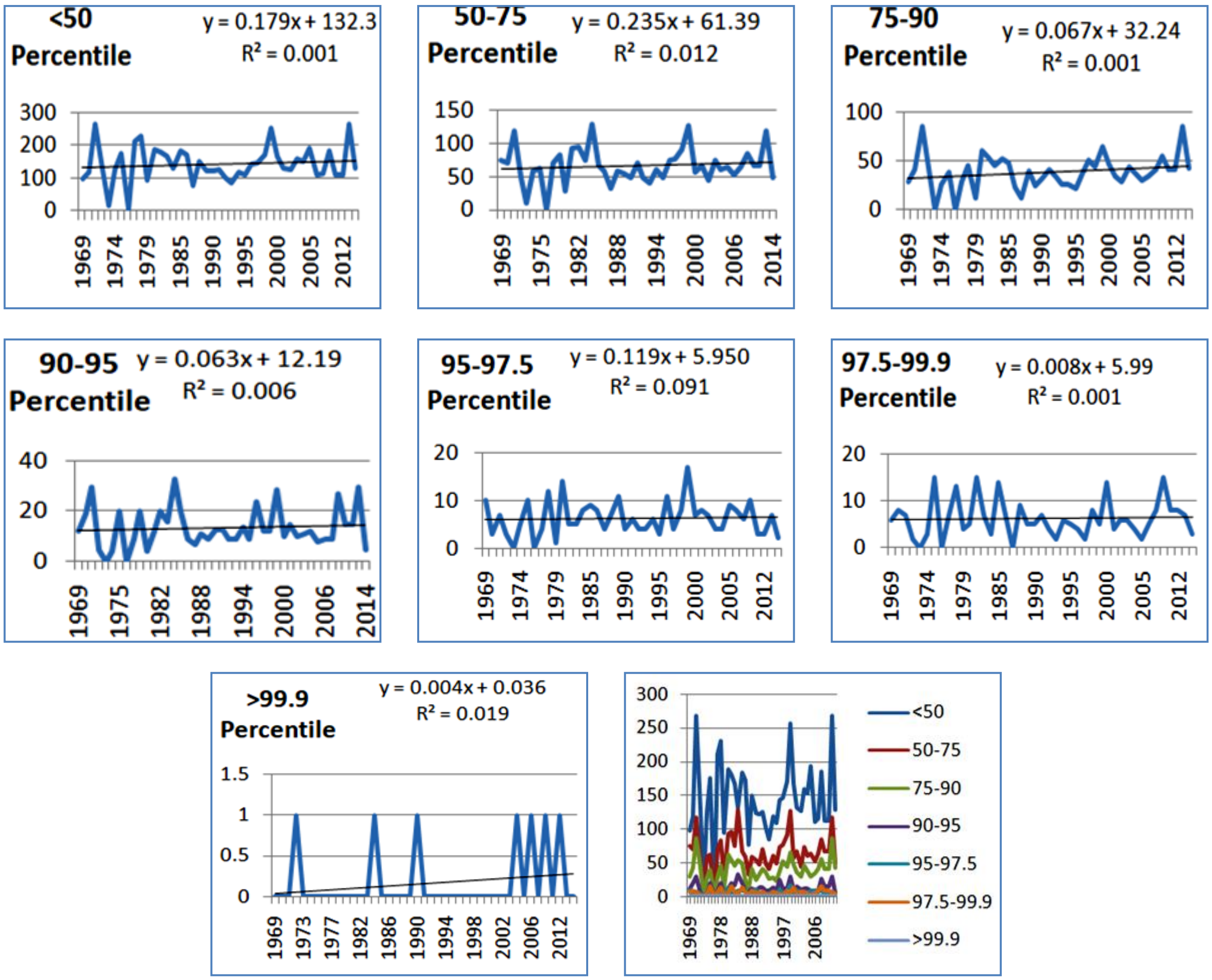

Fig. 6. Monsoon analysis 42475

rank. Many computational tools, *viz.*, MS Excel,SPSS are also where the calculation of percentile is simple. In this study, we calculate the Percentiles with the help of MS Excel. Based on the Percentile, we classified the intensity of rainfall in different categories (Table 3).

Based on these percentile criteria we prepare station-wise yearly, monthly and Monsoon frequency distribution for each station.

Student's t-statistic is given by:

$$t = \frac{\bar{x}-\mu}{s/\sqrt{n}} \qquad (2)$$

where, $\bar{x}$ is sample mean and $s/\sqrt{n}$ is standard error. Now, we take the null hypothesis

$$H_0: \mu \leq 0 \qquad (3)$$

To test that the trend is statistically significant, we test the null hypothesis as given in Eq. (3). By the methods of statistical hypothesis testing, we know that null hypothesis will not be rejected if $t_{calculated}$ ($t_{observed}$) $\leq$ $t_{critical}$ (t_{table}) and will be rejected if $t_{calculated}$ ($t_{observed}$) $\geq$ $t_{critical}$ (t_{table}). As a matter of fact, the trend will be statistical significant if $t_{calculated}$ ($t_{observed}$) $\geq$ $t_{critical}$ (t_{table}) and will not be statistically significant if $t_{calculated}$ ($t_{observed}$) $\leq$ $t_{critical}$ (t_{table}). It is also noted that t-tests are of two types (in general) one-tailed and two-tailed. To test the statistical significance, we have an alternative procedure that is the method of p value. In this method, we need to calculate the p - value and it is compared with the value of α. the trend will be statistical significant if p value is less than the value of α and will not be statistically significant if p value is greater than the value of α. For example if we take $\alpha = 0.05$ and the calculated value of p is .50, then the trend will not be considered as statistically significant. Increasing or decreasing trend may be seeing by calculating the slope of

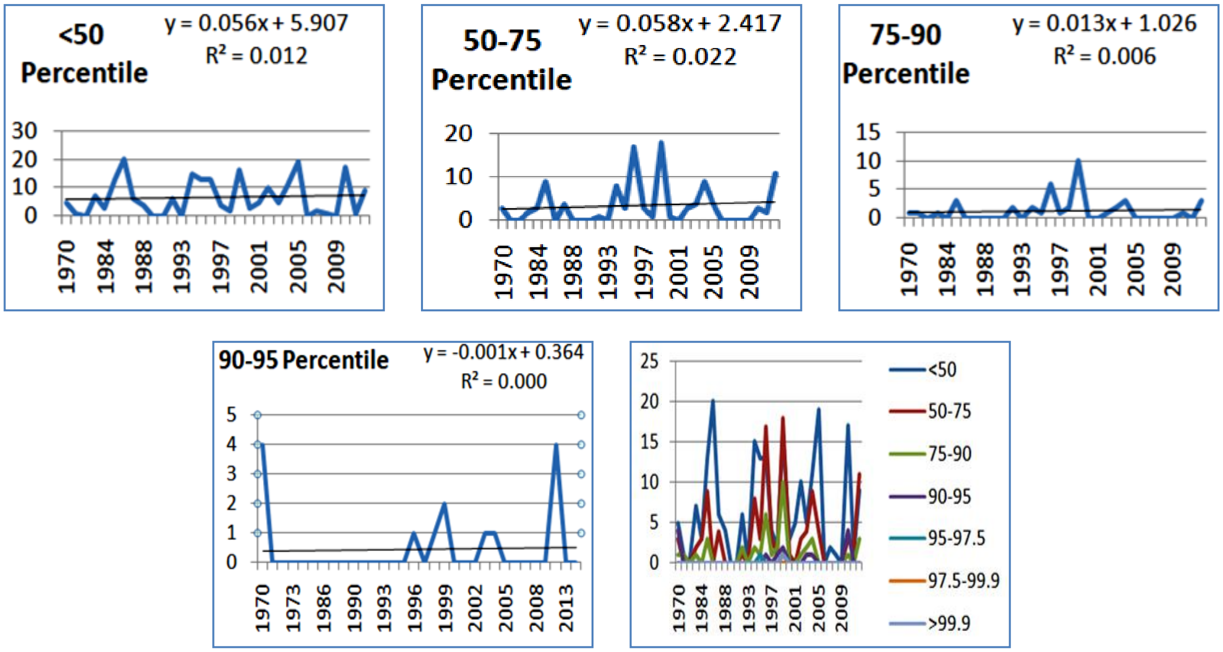

Fig. 7. Yearly analysis 42369

the curve R^2 values of the corresponding data series (corresponding frequency curve). We shall use both the approaches, *viz*., *t*-test (single tailed) at 95% confidence level ($\alpha = 0.05$) and method of p values for analyzing the trend of the frequency distributions of monthly and yearly trend series. We shall also calculate the corresponding slopes and R^2 values. Trend analysis will give us an idea about the pattern in the variability of the rainfall for long time. The main motto in this study to find out that the trend is statistically significant or not.

3. Results and discussion

3.1. *Intensity classification*

Since rainfall having different patterns for different regions, therefore use of a single value will not hold good. To consider this aspect, in this study we have opted the percentile method for the classification of rainfall intensity. Station-wise percentile values are calculated and given in the Table 4. Therefore, we approximated and generalized the results of Table 4 and have the following classification for the stations (Table 5).

It is found that for lower intensity (50 percentile), there is no significant variation over four different locations of UP. For example, it is 1.0 approximately for all the stations. However, in higher intensities, there are differences in the percentile values over four stations. For example, the station Bareilly (North), the 95 percentile value is 15.7 mm and much higher than the other three stations. The same is valid for 75, 90 and 99.9 also. Frequency distributions and monthly frequencies of all stations for yearly and monsoon season are calculated however, they are not given because it is voluminous

3.2. *Year wise analysis*

In this subsection year wise and station wise analysis is done. From Fig. 1, it is observed that yearly trends of Bareilly (42189) for all the classes of intensities are slightly decreasing. However, these trends are not statistically significant. From Fig. 7, it is observed that yearly trends of Lucknow (42369) for lower classes of intensities upto 95-97.5 are slightly increasing. For higher intensities *viz*., 97.5-99.9 and >99.9 trends are slightly decreasing. However, these trends are not statistically significant. From Fig. 3, it is observed that the trends are of mixed type. Trends for all the intensity classes are slight decreasing except for two classes *viz*., 50-75 and 97.5-99.9. For two classes' *viz*., 50-75 & 97.5-99.9 trends are slight increasing. But the trends as mentioned are not statistically significant. From Figs. 3&5, it is observed that the trends are of mixed type. Trends for all the intensity classes are slight decreasing except for two classes, *viz*., 50-75 and 97.5-99.9. For two classes' *viz*., 50-75 and 97.5-99.9 trends are slight increasing. But the trends as mentioned are not statistically significant. It is important to note that yearly trends for Allahabad and Varanasi are same.

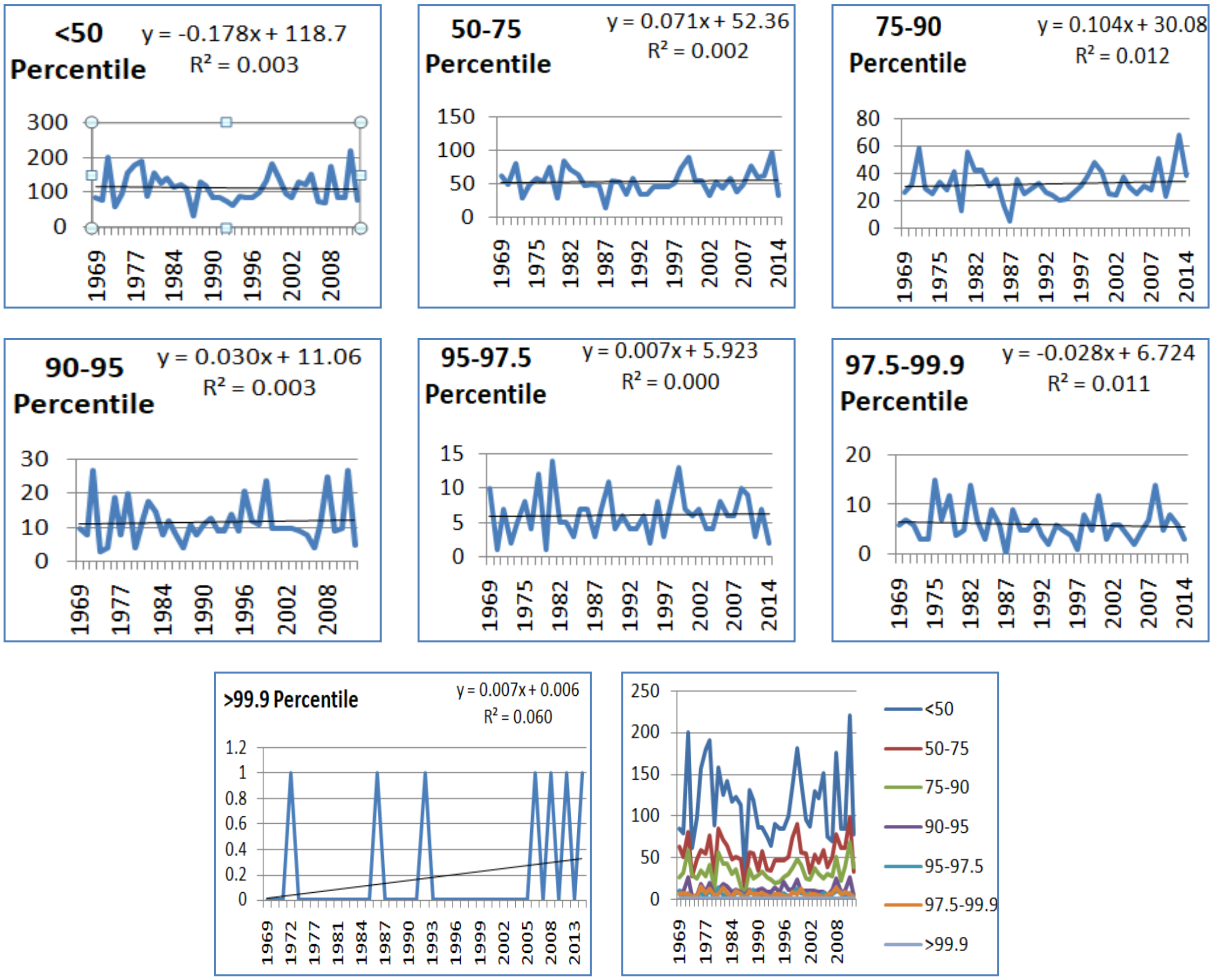

Fig. 8. Monsoon analysis 42369

3.3. *Analysis for monsoon season*

This subsection is dedicated to monsoon season. The statistical parameters are summarized in the Fig. 2 (42189), 4(42479), 6(42475), 8(42369) for the stations. From Fig. 2, we found that trend is not uniform. Trends for low and the highest classes *viz*., <50, 50-75, 75-90 & >99.9 are slight decreasing. Trends for middle intensity classes *viz*., 90-95, 95-97.5&97.5-99.9 are slight increasing. As a matter of fact all these trends are not statistically significant. From Fig. 4, we see that trends are slight increasing for all intensity classes except two classes *viz*., <50 & 97.5-99.9. Trends are not significant. From Fig. 6, it is observed that the trend for the monsoon season for Allahabad is of mixed kind. There is no uniform trend among the different intensity classes. For three intensity classes *viz*., <50, 90-95 & >99.9 trends are slight decreasing. For remaining four intensity classes *viz*., 50-75, 75-90, 95-97.5 &97.5-99.9, the trends are slight increasing. But both these trends namely increasing and decreasing are not statistically significant. Fig. 8 gives the monsoon trend analysis for Lucknow, trends for higher intensity classes 95-97.5, 97.5-99.9 & >99.9 is slight decreasing. Trend for the intensity class 75-90 is also slight decreasing. For other remaining intensity classes *viz*., <50, 50-75 and 90-95 the trend is slight increasing. Although, all these trends are not statistically significant.

3.4. *Monthly analysis*

In this subsection, we will represent the monthly analysis. Firstly, we have performed the frequency check for all the intensity classes for all the months and for all the stations. It is observed that for all the stations and all the months trends are not statistically significant. There are either slight increasing or slight decreasing trends. Station wise brief monthly analysis is represented here :

Station Bareilly (42189) : It is observed that no rainfall reported in the highest intensity group *viz*., >99.9

for eight months except in May, June, July and August. It is also observed that trend of highest intensity group *viz*., >99.9 for these four months in which rainfall occurred in this group is slight increasing except in the month of August. In the month of August the trend is slight decreasing for the highest intensity class. For the lowest intensity class *viz*., < 50 trends are slight decreasing in all the months except in May. In the month of May it is slight increasing. The similar slight decreasing pattern holds good for the intensity class 50-75 for all the months except for May, September and November. For the intensity class 75-90 the pattern is of mixed kind. In the months April, May, September and December it is slight increasing. For remaining months it is slight decreasing pattern. For the percentile group 90-95 the trend is slight increasing for March, May, August, September, October and December. For remaining months it is slight decreasing. For the percentile group 95-97.5 trend is slight decreasing for all the months except April, May, October to December. For April, May and October it is slight increasing and no rainfall reported in November and December in this group. For the percentile group 97.5-99.9 it is observed that no rainfall reported in the months of March, November and December. For the months of January, April, June and August the trend is slight decreasing for percentile group 97.5-99.9. For remaining months the trend is slight increasing.

Station Allahabad (42475) : It is observed that in the highest percentile group > 99.9 either no rain is reported or slight decreasing trend except in the months of January and August. The trend is slight increasing for the months of January, February, May, June, October and December in the lowest percentile group (<50). For remaining months in the same percentile group trend is slight decreasing. Similar pattern also followed for the percentile group 50-75 for all months except in the months of August and October. Trend followed in the percentile group 75-90 slight increasing in the pre-monsoon and winter months. The similar pattern also followed in the month of June also. For remaining months the pattern is slight decreasing. In the percentile group 90-95, the slight decreasing pattern followed in February, May and July to November. For remaining months the pattern is slight increasing. In the percentile group 95-97.5, the trend is slight decreasing for all months except January, April, June and July. In the percentile group 97.5-99.9, the trend is mixed either reported no rainfall or slight increasing and slight decreasing.

Station Lucknow (42369) : It is found that in the lowest percentile group (<50) the trend is slight decreasing for all the months except in January, February, June and July. Almost similar pattern is observed in the percentile groups 50-75 and 75-90 with an exception in few months. The pattern in percentile group 90-95 is slight decreasing in all months except in April to July and November. No rainfall reported in December. In the percentile group 95-97.5 no rainfall reported in months of February to April and November. For the months July to September and December the trend is slight decreasing. For remaining months the trend is slight increasing. Similar pattern followed in the percentile group 97.5-99.9 with an exception in the months of January to march. In the highest percentile group > 99.9 either no rainfall reported in the months of February to May and November or slight increasing in the months of January, June to August. For the remaining months the trend is slight decreasing.

Station Varanasi (42479) : It is found that in percentile group <50, the trend is slight decreasing for March, April, June, August, September, November and December. For remaining months it is slight increasing. Almost similar pattern is followed in the percentile group 50-75 with two exceptions June and December. In the percentile group 75-90 the pattern is quite different. It follows slight decreasing trend in March, May, June, September and November. For remaining months it is slight increasing. In the percentile group 90-95, the trend is slight increasing for all months except for February, September, November and December. In the percentile group 95-97.5 for three months *viz*., March, November and December no rainfall is reported. For remaining of the months it is slight decreasing except February, June and July. In the percentile group 97.5-99.9, for the three months *viz*., January, March and December no rainfall is reported. For February, August, September and November the trend is slight decreasing. For other months the trend is slight increasing. In the highest spell category, for Jan. to May and December months no rainfall is reported. For the months June to August the trend is slight decreasing. For remaining three months trend is slight increasing.

4. Conclusions

To find out the trend and intensity of rainfall based on hourly rainfall data, four stations *viz*., Bareilly, Lucknow, Allahabad and Bapatpur (Varanasi Airport) of Uttar Pradesh (UP), India have been selected. Firstly hourly rainfall data of all four stations ranging from 1969 to 2014 is examined. The percentile of hourly data is calculated to define various intensities of hourly rainfall of the stations. Based on different percentiles groups, intensity of the rainfall is classified into very light spell, light spell, moderate spell, intense spell, very intense spell, extremely intense spell , exceptionally intense spell. For each percentile group, yearly, monthly, JJAS (monsoon) frequency distribution is prepared. Frequency distribution trend is analyzed by means of *t*-test, *p*-value, slope and R square. Statistical significance of the trend is done by *t*-test. It is found that rainfall intensity of the yearly, monthly, JJAS (monsoon) for all the four stations is not statistically significant. Yearly and monsoon trends for the stations are either slight increasing or decreasing (not statistically significant) for different percentile groups. As far as limitations of this study are concerned, the data is missing for few years/months/hours. The quality of the analysis may be improved if the missing data could be found. It is important to note that yearly trends for Allahabad and Varanasi are same. To study the whole UP, the more representative stations may be included in the domain of the study. This is for the future scope.

Acknowledgment

The author is thankful to National Data Centre (NDC), India Meteorological Department, Pune for the data provided. Author is also grateful to Dr. P. Guhathakurta, Sc. 'F', IMD Pune for helping me during this work. Author is also thankful to Dr. S. C. Sahu, Sc. 'F' & Dr. S. Bandhopadhyay Sc. 'F', for kind support.

The contents & views expressed in this research paper/ article are the views of the author and do not necessarily reflect the views of the organizations they belong to.

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