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Analysis of the trend of heavy rainfall over Uttarakhand, India

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सार – उत्तराखंड राज्य में कुल वार्षिक वर्षा का लगभग 79% दक्षिण-पश्चिम मानसून मौसम यानी जून से सितंबर के दौरान प्राप्त होता है। इस अध्ययन में, भारी (Heavy), बहुत भारी (Very Heavy) और अत्यधिक भारी (Extremely Heavy) वर्षा की आवृत्ति की प्रवृत्ति का विश्लेषण करने के लिए उत्तराखंड में भारत मौसम विज्ञान विभाग (IMD) की चार विभागीय वेधशालाओं के मानसून सीजन के 1983 से 2023 तक के वर्षण डेटा का उपयोग किया गया है। टिहरी और मुक्तेश्वर वेधशालाएं उत्तराखंड के पहाड़ी क्षेत्र का प्रतिनिधित्व करती हैं, जबकि देहरादून और पंतनगर वेधशालाएं उत्तराखंड के मैदानी इलाकों का प्रतिनिधित्व करती हैं। भारी वर्षा जलवायु विज्ञान (Climatology) से पता चलता है कि उत्तराखंड के मैदानी इलाकों में पहाड़ी स्टेशनों की तुलना में भारी वर्षा वाले दिनों की आवृत्ति अधिक होती है। राज्य में अगस्त और जुलाई के महीनों के दौरान भारी वर्षा वाले दिनों की आवृत्ति अधिक और परिवर्तनशीलता कम होती है, जिसके बाद सितंबर और जून का स्थान आता है। एकदिशीय प्रवृत्तियों (Monotonic trends) की उपस्थिति का मूल्यांकन करने के लिए मान-कैंडल गैर-प्राचलिक प्रवृत्ति परीक्षण (Mann-Kendall non-parametric trend test) का उपयोग किया गया है। जिसका परिणाम देहरादून स्टेशन में भारी और अधिक वर्षा वाले दिनों की संख्या में एक कमजोर, सांख्यिकीय रूप से महत्वहीन बढ़ती प्रवृत्ति को दर्शाते हैं, जबकि अन्य स्टेशनों में कोई प्रवृत्ति नहीं देखी गई है। मात्रात्मक रूप से, देहरादून, पंतनगर और मुक्तेश्वर स्टेशनों पर कुल मानसून वर्षा में अत्यधिक वर्षा के प्रतिशत में एक महत्वहीन वृद्धि देखी गई है, जबकि टिहरी अत्यधिक वर्षा की मात्रा में एक महत्वहीन गिरावट प्रदर्शित करता है। IMD के मानदंडों के अनुसार, 24 घंटे की संचित वर्षा को बहुत हल्की, हल्की, मध्यम, भारी, बहुत भारी और अत्यधिक भारी श्रेणियों में वर्गीकृत किया गया है। वर्षा की अलग - अलग श्रेणियों के प्रवृत्ति विश्लेषण से तीन स्टेशनों (देहरादून, मुक्तेश्वर और पंतनगर) पर बहुत हल्की वर्षा वाले दिनों में एक महत्वपूर्ण बढ़ती प्रवृत्ति और तीन स्टेशनों (देहरादून, मुक्तेश्वर और टिहरी) पर शुष्क दिनों (Dry days) की एक महत्वहीन घटती प्रवृत्ति का पता चलता है। अन्य वर्षा श्रेणियां कोई प्रवृत्ति प्रदर्शित नहीं करती हैं।

ABSTRACT. Uttarakhand state receives around 79% of the total annual rainfall during the southwest monsoon season, i.e. from June to September. In this study, precipitation data of the monsoon season from 1983 to 2023 of four departmental observatories of the India Meteorological Department (IMD) in Uttarakhand have been used to analyse the trend of frequency of Heavy, Very Heavy and Extremely Heavy rainfall. Tehri & Mukteshwar observatories represent the hilly region of Uttarakhand, while Dehradun & Pantnagar observatories represent the plains of Uttarakhand. Heavy rainfall climatology reveals that the plains of Uttarakhand receive a higher frequency of heavy rainfall days than the hilly stations. The state experiences higher frequency and lower variability of heavy rainfall days during August & July months, followed by September & June. Mann-Kendall non-parametric trend test has been used to evaluate the existence of monotonic trends. The results show a weak, statistically insignificant increasing tendency in the number of heavy and more rainfall days in Dehradun station, while no trend is observed in other stations. Quantitatively, a non-significant rise in the percentage of extreme rainfall to the total monsoon rainfall is observed over Dehradun, Pantnagar & Mukteshwar stations, while Tehri exhibits a non-significant fall in the extreme rainfall quantity. As per the IMD criteria, the 24-hour accumulated rainfall is categorized into Very Light, Light, Moderate, Heavy, Very Heavy & Extremely Heavy. The trend analysis of individual categories of rainfall shows a significant increasing trend in very light rainfall days over three stations (Dehradun, Mukteshwar & Pantnagar) and a non-significant decreasing trend of dry days over three stations (Dehradun, Mukteshwar & Tehri). The other rainfall categories show no trend.

Key words – Heavy rainfall trend, Heavy rainfall pattern, monsoon rainfall variability, Uttarakhand, rainy days.

1. Introduction

Climate change has affected the intensity and frequency of precipitation over many parts of the world, particularly the increase in heavy rainfall (Easterling *et al*., 2017; Rajeevan *et al*., 2008; Goswami *et al*., 2006; Shahid, 2011; Wang & Zhou, 2005; Osborn & Hulme, 2002; Wan Zin *et al*., 2010 and Suppiah & Hennessy, 1998). At the same time, some places have shown no or decreasing trend of heavy precipitation as well (Hountondji *et al*., 2011; Saidi *et al*., 2015; Easterling *et al*., 2017; Suppiah & Hennessy, 1998). Climate

simulations indicate that a warmer climate could increase the intensity or frequency of extreme precipitation (Kharin *et al*., 2013; Fischer *et al*., 2016; Myhre *et al*., 2019).

Guhathakurta & Rajeevan (2008) studied meteorological subdivision-wise rainfall trends, and found three subdivisions Jharkhand, Chattisgarh, Kerala showed a significant decreasing trend, and eight subdivisions Gangetic WB, West UP, Jammu and Kashmir, Konkan and Goa, Madhya Maharashtra subdivision, Rayalseema, Coastal AP and North Interior Karnataka showed significant increasing trends during the south-west monsoon season. Later, much research on different subdivisions/states and regions of India were carried out by many to study the rainfall trend (Krishnakumar *et al*., 2009; Jain *et al*. 2013; Gajbhiye *et al*., 2016). Guhathakurta *et al*. (2020) examined the rainfall variability over Uttarakhand. They found that districts of Uttarakhand showed significant increase, significant decrease and non-significant changes in precipitation based on 30 years of rainfall data (1989 -2018). While the Uttarakhand state as a whole showed a non-significant increasing trend for monsoon seasonal and annual rainfall.

As per the India Meteorological Department (IMD) (ADGM (R), 2015), Heavy rainfall is defined as 24-hour accumulated rainfall between 64.5 mm & 115.5 mm, Very Heavy as rainfall between 115.6 mm & 204.4 mm, and Extremely Heavy as rainfall greater or equal to 204.5 mm. These quantities of 24-hour accumulated rainfall are considered unusually higher than the mean value, and their occurrences are above the 95 percentile. In this paper, "extreme rainfall" represents Heavy, Very Heavy, and Extremely Heavy rainfall categories.

The southwest monsoon is the principal rainy season for Uttarakhand as the state receives around 79% (1162.7 mm) of the total annual rainfall (1477.6 mm) during four months of southwest monsoon season, i.e. from June to September. Category of heavy or more rainfall is mainly observed during monsoon season. Due to the disproportionately large rain during monsoon season, the state incurs the loss of thousands of crore of rupees every year (USDMA). Any shift or increase in monsoon precipitation can significantly expand the state's vulnerability to natural hazards. Therefore, the trend analysis of Heavy, Very Heavy, and Extremely Heavy rainfall over Uttarakhand is helpful to plan adaptation and mitigation strategies in an informed manner.

2. Data and methodology

IMD has been continuously strengthening its surface observational network by increasing the number of surface observatories across India. Since 1992, IMD has introduced a District-wise Rainfall Monitoring Scheme (DRMS) under which some selected observatories record and transmit rainfall information on a real-time basis for better rainfall representation. Besides DRMS stations, rainfall data are received from other observatories for archival and climatology preparation. Before 2011, there were 2821 stations under DRMS across India; the number of DRMS stations increased to 3955 in 2014, 5211 in 2022, and 5896 in 2023. Similarly, there were 37 DRMS stations in Uttarakhand before 2012. The number of DRMS stations has now increased to 71 in 2023.

The first attempt at automatic recording and transmission of meteorological data was carried out by IMD in the 1980s. Under this initiative, 100 satellite-based Data Collection Platforms (now known as Automatic Weather Station (AWS)) were installed all over India by IMD (Srivastav, 1995). Under the modernization plan of IMD in 2006-07, KALPANA-1/ INSAT-3A satellite-based 125 AWSs were installed across India. After that, the AWS network was further strengthened by installing 550 AWS during 2008-2012 and 1350 Automatic Rain Gauge (ARG) during 2009-2016 (Ranalkar *et al*., 2012, 2014). In 2020-2022, 200 Agro AWS were installed across the country. Under the modernization scheme, 08 AWSs were installed in Uttarakhand during 2006-07. The network of automatic stations in Uttarakhand increased to 21 AWS and 21 ARG in 2012. In 2019, 107 AWSs and 28 ARGs were installed in Uttarakhand by the State Government under the technical guidance of IMD. In 2024, the network of automatic stations in Uttarakhand has now increased to 135 AWS and 49 ARGs.

The number of observatories in Uttarakhand (and India) are continuously varying and increasing over the years. With denser observational and monitoring networks, detecting extreme rainfall events occurring at lesser spatial scales has become possible. The increased detection efficiency of extreme rainfall events due to the strengthening of the observational network often gives an impression of an increasing trend in extreme rainfall events over Uttarakhand in recent decades. A trend in extreme rainfall over Uttarakhand should be visible in the long-period rainfall data of stations in Uttarakhand. Therefore, in this study, the daily rainfall data for 41 years (1983-2023) from four departmental observatories of IMD in Uttarakhand have been analyzed to determine the trend of extreme precipitation and other precipitation categories. The data of departmental observatories are of the highest standards and quality as these observatories are manned by IMD staff and upkeep & maintenance of observatories are regularly carried out. The two departmental observatories, *viz*. Tehri (elevation- 1931 m) & Mukteshwar (elevation- 2311 m) are over mountains and

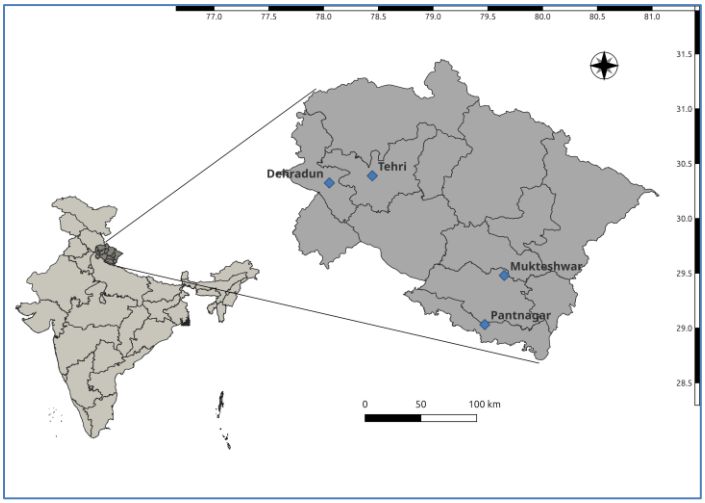


Fig. 1. Location of departmental stations of IMD whose data is used for this study

represent the hilly region of Uttarakhand. Pantnagar (elevation- 233 m) observatory is over plains along the foothills and Dehradun (elevation- 620 m) observatory is in a valley between Shivaliks and Himalayas. Thus, two stations represent the mountainous region and other two stations the plains of Uttarakhand. Geographically, culturally and administratively Uttarakhand is divided into two divisions, the western 7 districts come under the Garhwal division and the eastern 6 districts come under the Kumaun division. The Dehradun & Tehri stations represent Garhwal, while the Pantnagar & Mukteshwar stations represent Kumaun divisions. The locations of observatories are shown in Fig. 1.

Depending on the number of synoptic observations and communication made daily and the type of meteorological instruments available, the surface observatories are classified into six classes, from Class I to Class VI. Class I are principal climatological stations operated by departmental staff. Class II are ordinary climatological stations at which observations are made at fixed times, including readings of extreme temperature and precipitation. Dehradun and Mukteshwar are Class I, Pantnagar is a Class IIb, and Tehri is a Class IIa observatory.

The daily rainfall data of Dehradun and Mukteshwar observatories are available for the entire study period, while four years of rainfall data of Pantnagar observatory is missing. Only 21 years (2003-2023) of rainfall data of Tehri observatory is available.

Mann-Kendall (Mann 1945; Kendall 1975) non-parametric trend test has been used to evaluate the existence of monotonic trends in meteorological data. This test is simple and robust and can be applied if the data series has missing values and data don't conform to any statistical distribution. The temporal/serial independence of the data was checked using the autocorrelation function (ACF).

For independent rainfall time series, the Mann-Kendall statistic S is computed as:

$$S=\sum_{i=1}^{n-1}\sum_{j=i+1}^{n} sgn(x_j-x_i) \quad (1)$$

where, x_i and x_j are sequential data for the ith and jth terms; n is the sample size; and

$$sgn(x_j-x_i)=\begin{cases}+1; if\ (x_j-x_i)>1\\ 0; if\ (x_j-x_i)=0\\ -1; if\ (x_j-x_i)<1\end{cases} \quad (2)$$

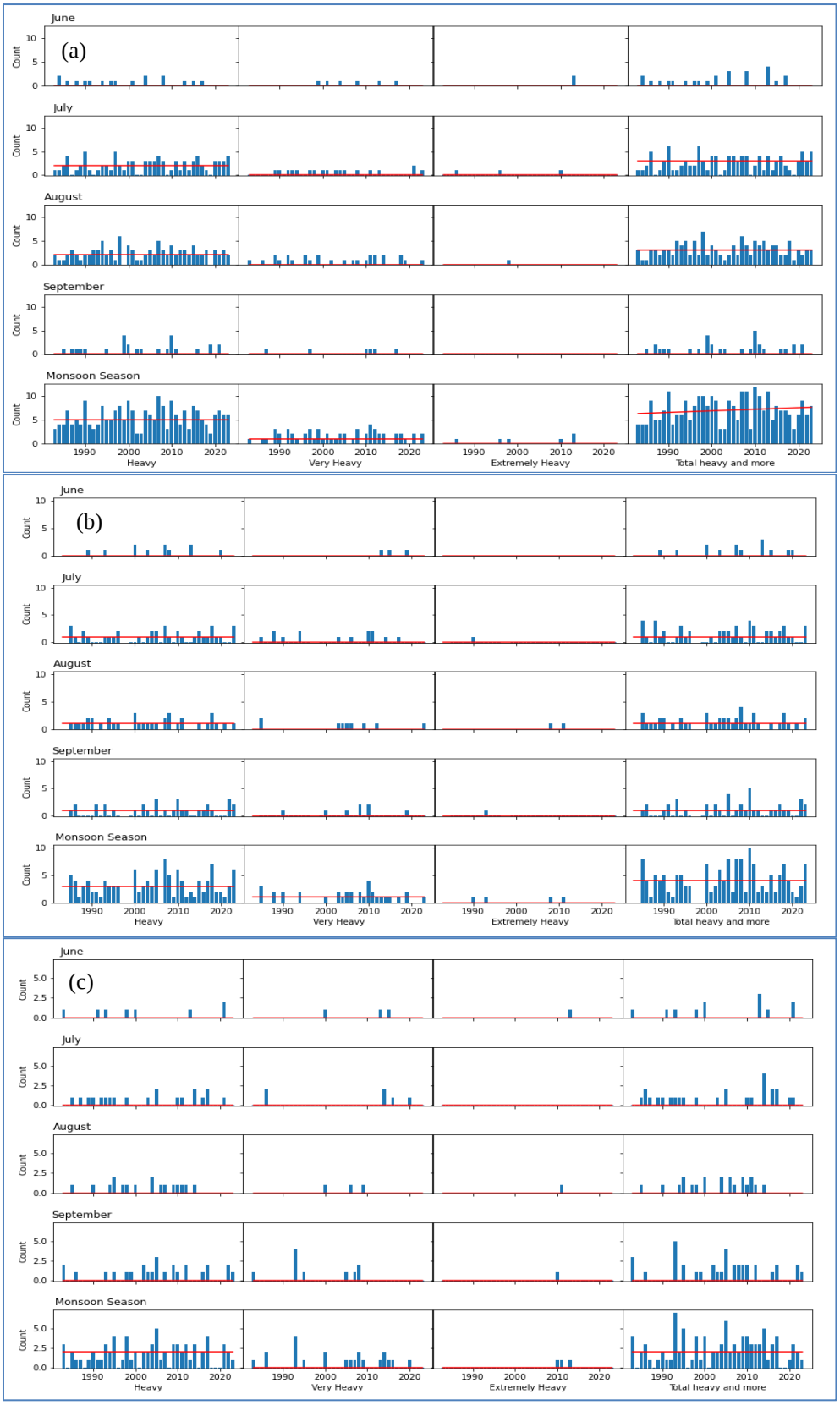
For n ≥ 10, the statistic S is approximately normally distributed with the mean E(S) = 0 and

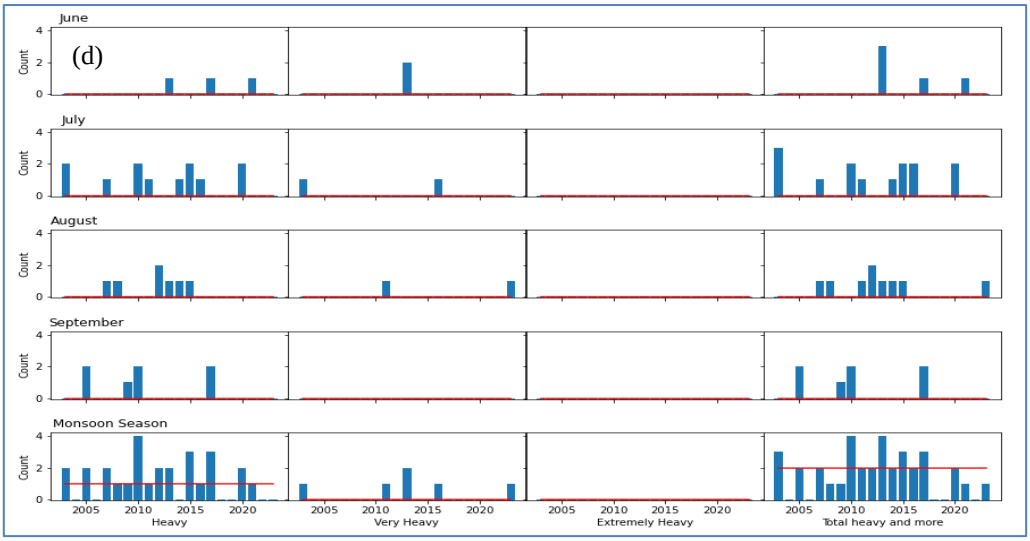
$$Var(S)=\frac{n(n-1)(2n+5)-\sum_{p=1}^{q} t_p(t_p-1)(2t_p+5)}{18} \quad (3)$$

The variable q and t_p are number of tied group's and number of data values in the pth group, respectively. The standardized test statistic (Z) is given as follows:

$$Z=\begin{cases}\frac{S-1}{\sqrt{Var(S)}}, if\ S>0\\ 0, if\ S=0\\ \frac{S+1}{\sqrt{Var(S)}}, if\ S<0\end{cases} \quad (4)$$

A positive value of Z indicates an increasing trend, while a negative value of Z indicates a decreasing trend.


(a)
June
July
August
September
Monsoon Season
Count
Heavy
Very Heavy
Extremely Heavy
Total heavy and more
(b)
June
July
August
September
Monsoon Season
Count
Heavy
Very Heavy
Extremely Heavy
Total heavy and more
(c)
June
July
August
September
Monsoon Season
Count
Heavy
Very Heavy
Extremely Heavy
Total heavy and more



Figs. 2(a-d). Month-wise and seasonal frequency and trend (in red color) of extreme precipitation categories of (a) Dehradun, (b) Pantnagar, (c) Mukteshwar, and (d) Tehri stations

TABLE 1

(a) Station-wise and (b) month & season-wise Mann-Kendal's statistics for extreme precipitation

(a)

Station	Trend	Tau	S	Z	P	Slope
Dehradun	no trend	0.11	88	0.98	0.32	0.03
Mukteshwar	no trend	0.07	60	0.67	0.50	0
Pantnagar	no trend	0.00	2	0.01	0.98	0
Tehri	no trend	-0.11	-24	-0.71	0.47	0

(b)

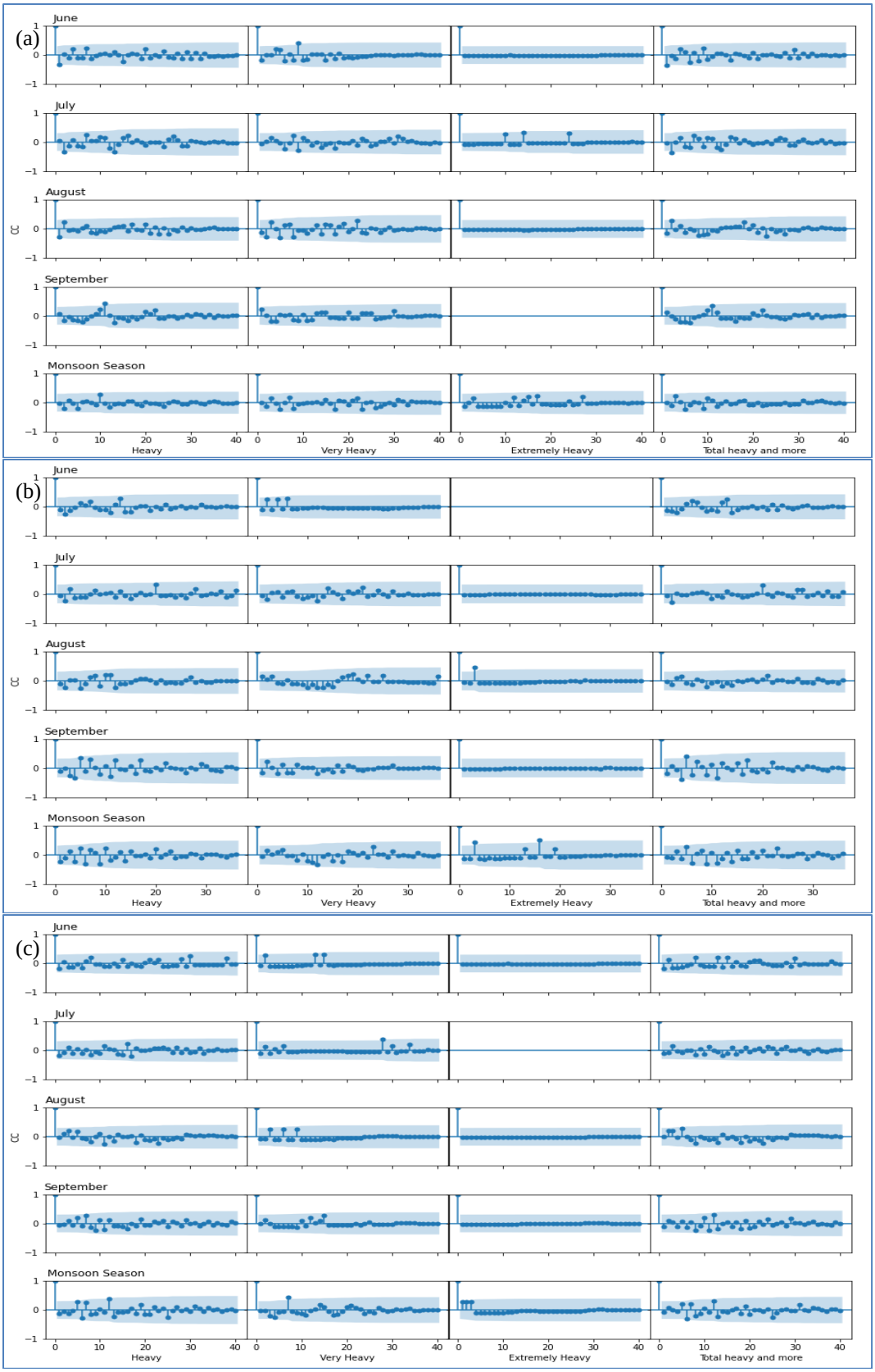
Month/Season	Trend	Tau	S	Z	p	Slope
June	no trend	-0.09	-78	-0.89	0.36	0
July	no trend	-0.01	-11	-0.11	0.91	0
August	no trend	-0.11	-88	-0.98	0.32	-0.01
September	no trend	0.02	20	0.21	0.82	0
Monsoon season	no trend	-0.06	-47	-0.51	0.60	-0.01

3. Results and discussion

3.1. *Trend in frequency of extreme precipitation*

The number of extreme precipitation events *i.e.*, Heavy, Very Heavy and Extremely Heavy rainfall from 1983 to 2023 have been plotted month-wise for all the stations in Fig. 2. To test the serial independence of the data, the autocorrelation function is plotted in Fig. 3. Modified Mann–Kendall test is required for cases where serial correlation is present. However, no significant lag-1 correlation was detected for all the stations, thus the series may be considered temporally independent and the standard Mann-Kendall trend test may be employed. The linear trend line in Fig. 2 is drawn using Sen's slope estimator. Sen (1968) developed the non-parametric procedure for estimating the trend slope in the sample of n pairs of data. Table 1 shows the presence of trend, Kendall Tau, Mann-Kendal's score (S) and Sen's slope for monsoon season extreme rainfall at all stations of Uttarakhand. The Dehradun station shows a slight non-significant increase in the frequency of extreme rainfall during monsoon season, while the rest of the stations show no trend (Fig. 2 & Table 1).

The trend in the frequency of extreme rainfall for Uttarakhand state as a whole by taking the average of four stations is shown in Fig. 4 and Mann-Kendal's statistics are shown in Table 1(b). No trend is observed in the frequency of extreme rainfall during June, July, and September months, while a slight non-significant decreasing trend is observed during August and thus, for monsoon season. The decreasing trend in the monsoon season may be due to the inclusion of Tehri station that has a lower frequency of extreme rainfall, and the station's data is available from 2003 onwards.


(a)
June
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Monsoon Season
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Heavy
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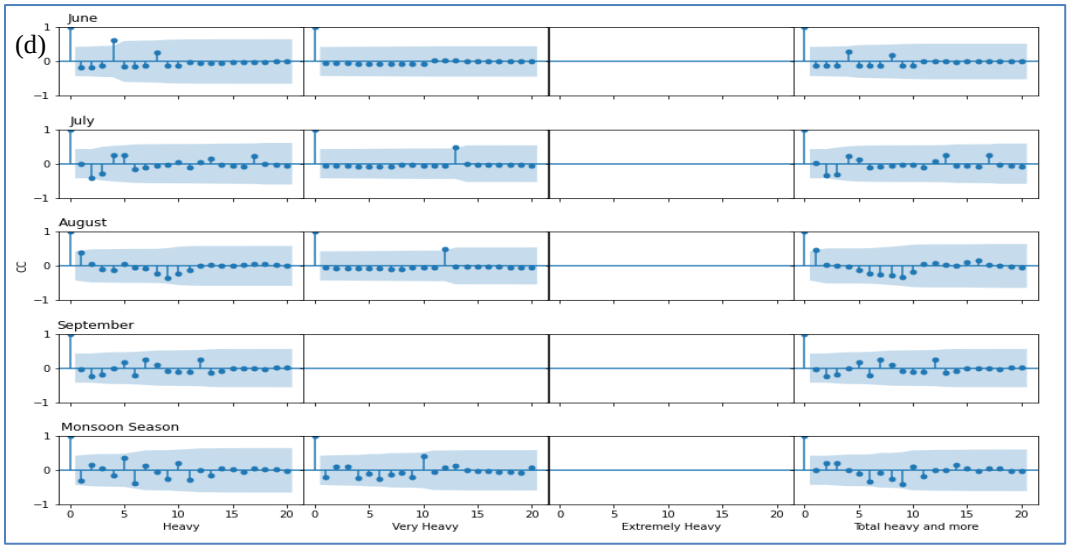


Fig. 3(a-d). Autocorrelation function of the frequency of extreme precipitation categories of (a) Dehradun, (b) Pantnagar, (c) Mukteshwar, and (d) Tehri stations.

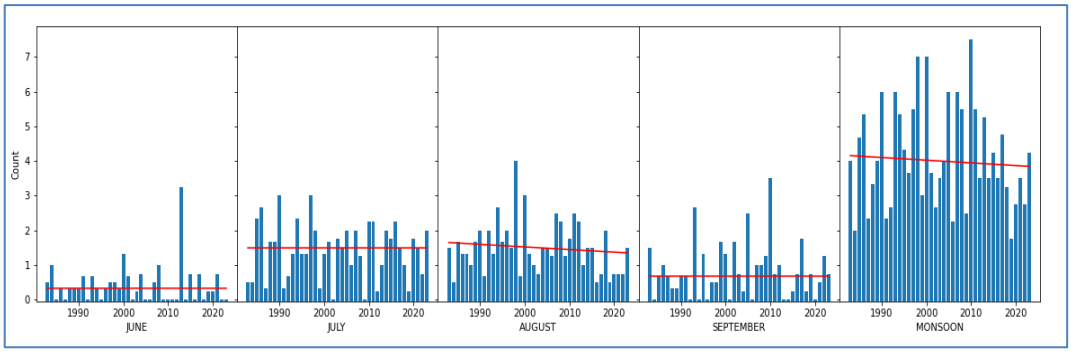


Fig. 4. Month and season-wise frequency and trend (in red) of extreme precipitation in Uttarakhand

TABLE 2

Mann-Kendal's statistics for extreme rainfall's contribution to the total monsoon rainfall

Station	Trend	Tau	S	Z	p	Slope
Dehradun	no trend	0.06	53	0.58	0.5	0.09
Mukteshwar	no trend	0.12	104	1.15	0.2	0.23
Pantnagar	no trend	0.01	9	0.10	0.9	0.03
Tehri	no trend	-0.08	-18	-0.51	0.6	-0.24

3.2. *Trend in the quantity of precipitation*

Monsoon is the principal rainy season for Uttarakhand, and the state experiences many disasters due to higher rainfall like, flash floods, landslides, inundations, etc. Most of the geo- & hydrological disasters are triggered by heavy rainfall (Kim *et al*., 2012; Vadivel *et al*., 2019; Thapliyal & Singh, 2023). The quantitative contribution of extreme rainfall, i.e. Heavy, Very Heavy, and Extremely Heavy rainfall to the total monsoon rainfall is studied in this section. On average, 37% of monsoon rainfall occurs in the heavy or higher rainfall category in Dehradun station, 33% in Pantnagar, 24% in Mukteshwar, and 19% in Tehri station. Thus, the contribution of extreme precipitation in total monsoon precipitation over plains stations is higher than the hilly stations. Fig. 5 illustrates the box-whisker plot of month-wise & seasonal contribution of extreme rainfall in the total monsoon rainfall experienced over different stations. In the Garhwal region, the proportion of extreme rainfall in total rainfall is higher during July and August. In the Kumaun region, the proportion of extreme rainfall is highest in September followed by July and August.

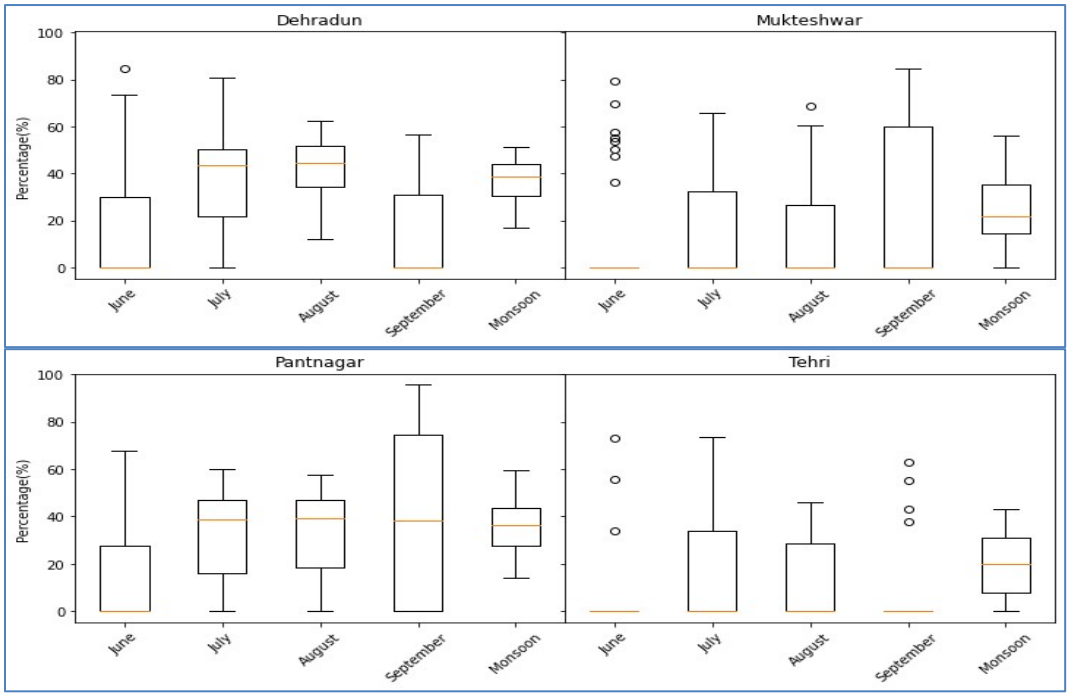


Fig. 5. Box-whisker plot of month-wise & seasonal percentage of total monsoon rainfall as extreme rainfall experienced over different stations

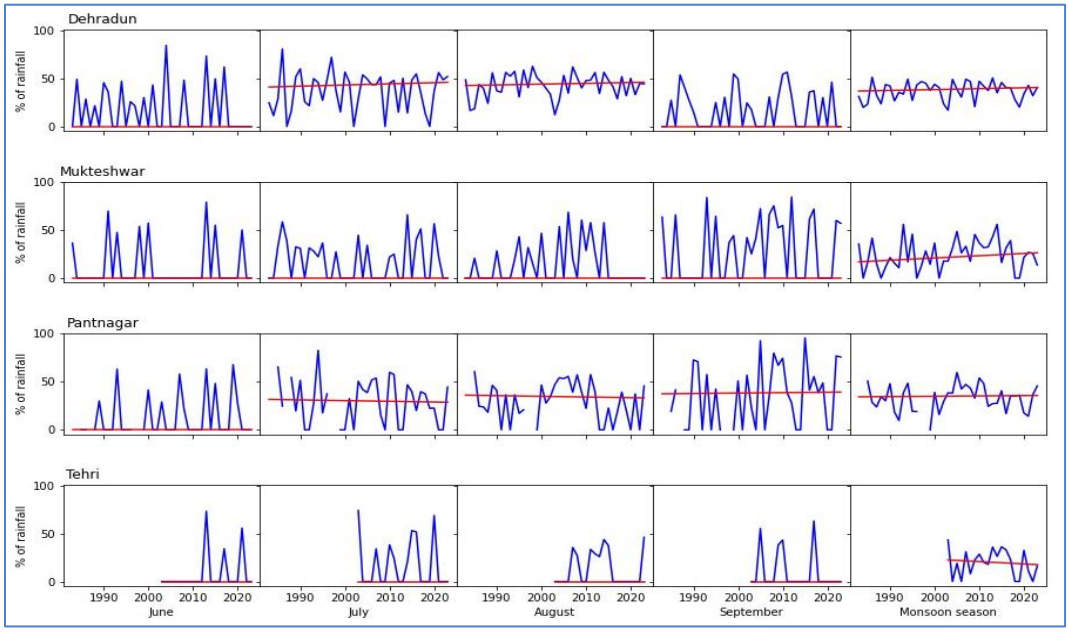


Fig. 6. Month-wise and seasonal trend (in red) and percentage of total monsoon rainfall as extreme rainfall experienced over Dehradun, Pantnagar, Mukteshwar and Tehri stations

The analysis of the frequency of extreme rainfall revealed no significant trend. This led us to investigate changes in the contribution of extreme rainfall to the total monsoon rainfall. Fig. 6 shows the percentage of monsoon rainfall experienced as extreme rainfall over different stations. The Mann-Kendal's statistics for the series are shown in table 2. The proportion of extreme rainfall in total monthly rainfall in some years has reached more than 80% in Dehradun, Mukteshwar & Pantnagar stations and up to 74% in Tehri station. The Dehradun, Pantnagar & Mukteshwar stations show a non-significant rise in the extreme rainfall quantity. At the same time Tehri exhibits a non-significant fall in the extreme rainfall as a percentage of total monsoon rainfall.

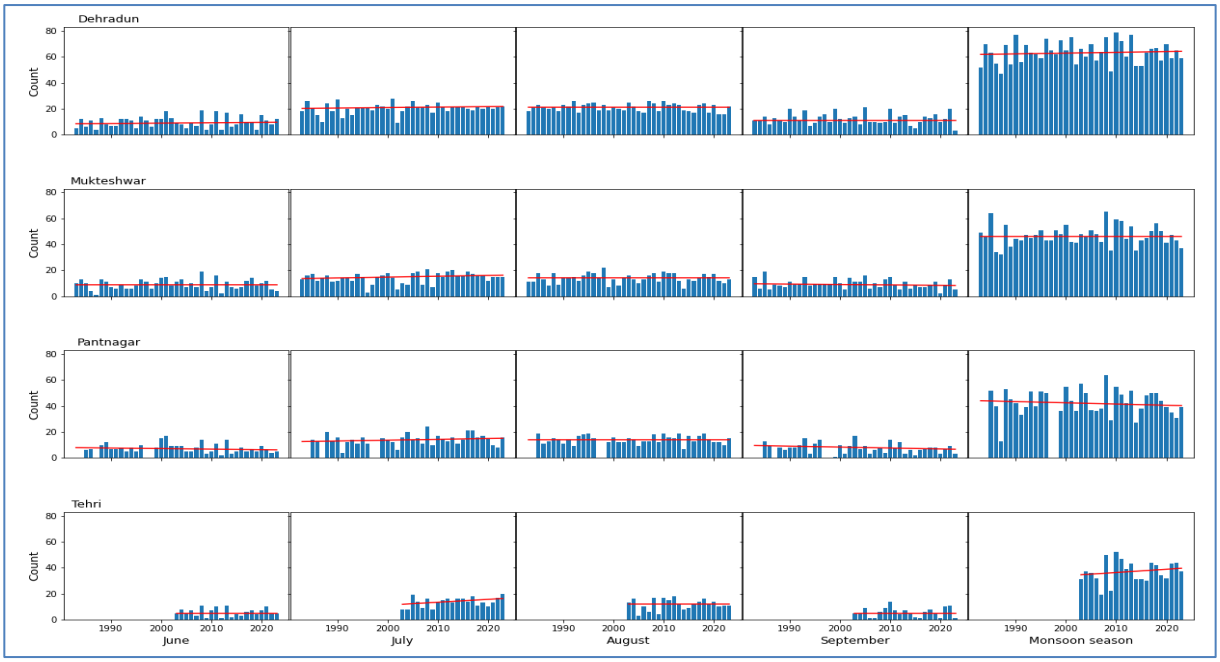


Fig. 7. Month-wise and seasonal frequency and trend of rainy days over different stations in Uttarakhand

TABLE 3

Mann-Kendal's statistics for very light & light rainfall categories over different stations

Station	Rainfall category	Trend	Tau	S	Z	p	Slope
Dehradun	Very light	increasing	0.33	275	3.08	0.002	0.23
Mukteshwar	Very light	increasing	0.31	259	2.90	0.003	0.25
Pantnagar	Very light	increasing	0.52	346	4.53	0.000	0.35
Tehri	Light	no trend	0.16	33	0.96	0.33	0.20

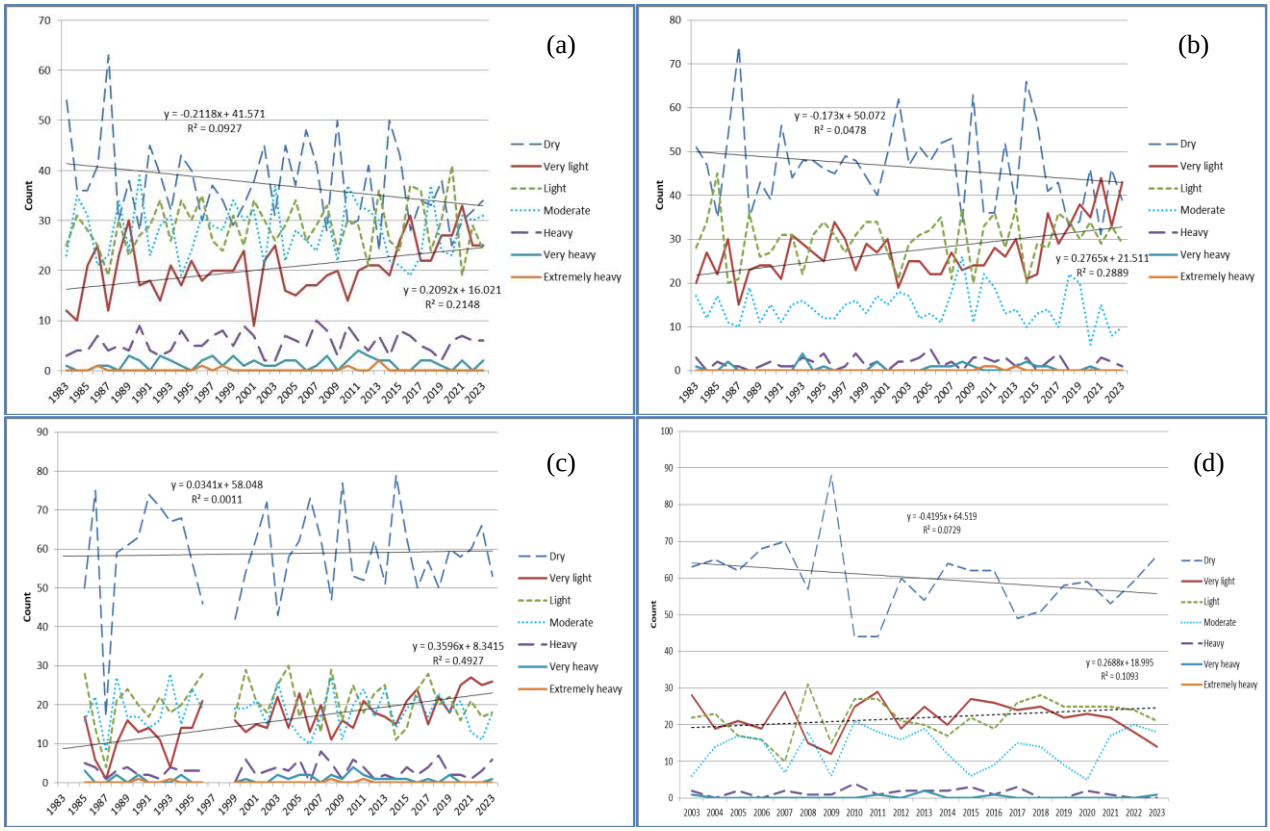
3.3. *Trend in different categories of precipitation*

According to IMD, a rainy day is defined as a day in which the 24-hour accumulated rainfall is 2.5mm or more. According to the trend analysis, all the stations of Uttarakhand show a non-significant increasing/decreasing trend in the number of rainy days during different monsoon season months. However, for the monsoon season as a whole, Dehradun, Pantnagar & Mukteshwar stations show no trend in the frequency of rainy days. Tehri station exhibits a non-significant rising trend in rainy days during the monsoon season (Fig. 7).

IMD has categorized the 24-hour accumulated rainfall into Very Light (Trace-2.4 mm), Light (2.5-15.5 mm), Moderate (15.6-64.4 mm), Heavy (64.5-115.5 mm), Very Heavy (115.6-204.4 mm) & Extremely Heavy (≥ 204.5 mm) categories based on the percentile of rainfall statistics of station rainfall data (ADGM(R), 2015). Changes in the frequency of less than heavy rainfall categories are analysed and the graphs are plotted in Fig. 8. The trend lines are shown as solid black lines for Dry and Very Light rainfall and dashed black lines for Light category of rainfall. The declining number of dry days is evident over Dehradun, Mukteshwar and Tehri stations. The number of days with very light rainfall is showing a significant increasing trend in Dehradun, Mukteshwar, and Pantnagar stations, while over Tehri station, the number of light rainfall days (dashed black line in Fig. 8(d)) are showing a non-significant increasing trend. Table 3 shows the Mann-Kendal's statistics for very light & light rainfall over different stations. The other categories of rainfall exhibit no trend. Thus, the decreasing frequency of dry days may be attributed to the increasing very light/light category rainfall over most stations of Uttarakhand.

3.4. *Heavy rainfall climatology*

The category & month-wise frequency and pattern of heavy rainfall in Uttarakhand are obtained from the long-period data of IMD departmental stations in Uttarakhand.



Figs. 8(a-d). Frequency of category-wise rainfall over (a) Dehradun, (b) Mukteshwar, (c) Pantnagar, and (d) Tehri stations of Uttarakhand and trend line shown in solid black & dashed black colors

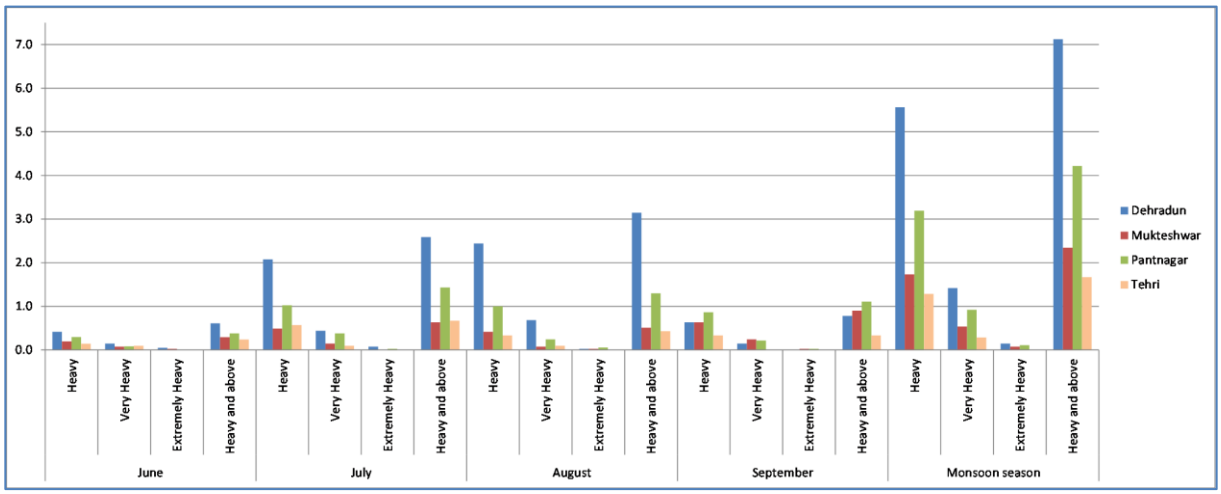


Fig. 9. Month-wise and seasonal frequency of Heavy, Very Heavy & Extremely Heavy rainfall over different stations of Uttarakhand

The average frequency of Heavy, Very Heavy and Extremely Heavy rain is higher over plains stations with Dehradun experiencing 7.1 days of heavy and more rainfall during the monsoon season followed by Pantnagar (4.2), Mukteshwar (2.3) & Tehri (1.7) as shown in Fig. 9. The average frequency of Heavy & Very Heavy rain is higher during July & August months. During September, which is the last month of the monsoon season, the average frequency of Heavy & Very Heavy rain significantly decreases in stations of the Garhwal region, while stations of the Kumaun region show a marginal decrease or increase in frequency. From Fig. 9, it can be

TABLE 4

Month and station-wise coefficient of variability (in %) of frequency of extreme rainfall

	June	July	August	September	Monsoon
Dehradun	163.5	65.3	45.8	141.8	36.8
Mukteshwar	232.3	135.5	145.6	135.3	73.7
Pantnagar	190.5	89.4	78.9	110.1	59.2
Tehri	294.1	144.9	139.4	219.1	76.7

seen that during monsoon season, 74% to 83% of the extreme precipitation occur as Heavy rainfall, 17% to 23% as Very Heavy rainfall, and up to 3% as Extremely Heavy rainfall.

Table 4 shows the coefficient of variability (CV in %) of frequency of extreme rainfall in different stations of Uttarakhand. The CV is highest during the advance phase of monsoon over Uttarakhand, i.e. in June followed by September when the withdrawal of monsoon takes place from Uttarakhand. July and August are principal rainy months for Uttarakhand as the state receives 417.8 mm and 385.7 mm of rainfall during July and August, respectively. The CV during these two months is lower for all the stations. The CV of frequency of extreme rainfall is lower in plain stations than in hilly stations.

4. Conclusions

(i) The monsoon season rainfall data of Class I & Class II departmental surface observatories in Uttarakhand state have been utilized for the trend analysis of the frequency of extreme precipitation, i.e. Heavy, Very Heavy and Extremely Heavy rainfall. The Mann-Kendall non-parametric trend test reveals no significant trend in the frequency of extreme rainfall over Uttarakhand. However, a non-significant slight increase in the frequency of extreme rainfall during monsoon season is observed over Dehradun station.

(ii) The change in the contribution of extreme rainfall in total monsoon rainfall amount is also analyzed. It is found that the Dehradun, Pantnagar & Mukteshwar stations show a non-significant rise in the extreme rainfall quantity. At the same time, Tehri exhibits a non-significant fall in the extreme rainfall quantity as a percentage of total monsoon rainfall. It is observed that the proportion of extreme precipitation in the total monsoon rainfall (CV of frequency of extreme rain) is higher (lower) over plains than the stations in the hills of Uttarakhand.

(iii) None of the stations show any significant trend in the number of rainy days. The trend analysis of individual categories of 24-hour accumulated rainfall shows a significant increasing trend in very light rainfall days over Dehradun, Mukteshwar & Pantnagar stations and a non-significant increasing trend in light rainfall days over Tehri station. The rising trend of Very Light/Light rainfall days steered to the decreasing trend of dry days over Dehradun, Mukteshwar & Tehri stations. The other rainfall categories show no trend.

(iv) Climatologically, the plains experience more extreme rainfall days as compared to hill stations with Dehradun experiencing an average of 7.1 days of extreme rainfall during the monsoon season followed by Pantnagar (4.2), Mukteshwar (2.3) & Tehri (1.7). Month-wise analysis shows that, climatologically, the average frequencies of extreme rainfall days significantly decrease in stations of the Garhwal region during September month while stations of the Kumaun region experience a marginal decrease (Pantnagar) or increase (Mukteshwar) in frequency during September month.

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