International Journal of Science and Research (IJSR)
ISSN (Online): 2319-7064
Index Copernicus Value (2013): 6.14 | Impact Factor (2013): 4.438

Extreme Rainfall Events over the Uttarakhand State (1901-2013)

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Abstract: ***The occurrences of exceptionally heavy rainfall and associated flash floods during 16-18 June 2013 over Uttarakhand and neighbouring states resulted in severe floods, landslides, large scale loss of lives, properties and damages. The event was mostly linked with the occurrence of extreme event due to climate change. In view of this, an attempt has been made in this paper to analyze the extreme rainfall events for 1-day duration occurred over the Uttarakhand using 1901-2013 daily rainfall data for more than 100 stations located in and around the state. The study revealed that during 113 years period, highest numbers of extreme events are recorded during 1961-1970 decade and to some extent in 1981-1990 decade***

Keywords: Extreme Rainfall, Uttarakhand, Rainfall characteristics

1. Introduction

It is well known that India is a land of many rivers and mountains. The rivers and mountains not only have a greater cultural and religious significance, but they play important role in distribution of rainfall in space and time – and hence are the major sources for irrigation, drinking water, transport, generation of electricity and the livelihoods for a large number of people. Therefore, in recent years, the study of rainfall characteristics has attracted everybody's attention, especially because extreme weather conditions and possible climatic changes have been observed. A noteworthy examples of the consecutive flash floods over three major metro cities in the same year, i.e., Mumbai in July 2005, Chennai in October and December 2005 and Bangalore in October 2005 caused heavy damages to economy, loss of life, etc. (Guhatakurta et al, 2011). In June 15-18, 2013 Uttarakhand region experienced catastrophic heavy rainfall. It has washed away the region nearby the Kedarnath Temple killing hundreds of pilgrims.

In view of the above, in the present study, analysis of extreme rainfall events over the Uttarakhand region is made in order to know the spatial variations within the state for the period of 1901-2013 and frequency occurrence of extreme rainfall of 1-day durations on monthly, seasonal, annual and decadal basis. Uttarakhand (formerly known as Uttaranchal) is located at the foothills of the Himalayan mountain ranges, it is mostly a hilly State, having international boundaries with Tibet in the north and Nepal in the east. To its northwest lies Himachal Pradesh, while to the south is Uttar Pradesh. Uttarakhand being situated on the southern slope of mighty Himalayas (see Fig.1). The total geographical area of the state is 51125sq.km and of this, 93% is mountainous, and 65% is covered by forest. Glaciers are located at the highest elevations. The climate of Uttarakhand is predominantly distinguished in to two diverse divisions: the major hilly terrain and the smaller lower plains. The winter season of the state generally extends from October to February. July to September is the monsoon season over the Uttarakhand receiving about 90% of its annual rainfall during this season.

Figure 1: Map of Uttarakhand showing 2 sub-divisions, rivers and rainfall stations with altitude (m)

2. Materials and Methods

Daily rainfall data for all the available stations (about 100) (Fig.1) in and around the Uttarakhand region has been procured from the National Data Centre (NDC), India Met. Dept. (IMD), Pune, for the period of 1901-2013. Past extreme rainfall events were collected from Climate of Uttar Pradesh and Himachal Pradesh, Books published by IMD.

After the collection of data from different sources for more than 100 stations, all the data were arranged stationwise / statewise. Stations having less than 10 years data were not considered for the analysis. From the daily rainfall data for each month and for each year one highest value was evaluated for each station. Any outlier was not considered. From this data annual and seasonal highest rainfall was obtained for all the stations.

3. Results and Discussions

Analysis of rainfall data revealed that one-day extreme rainfall (of ≥100 mm) events occurred in all the months of the year. The maximum frequencies of extreme one-day rainfall was recorded in the month of October (75) and lowest frequency in the month of November (2) (see Fig.2). However, during different seasons, occurrence of extreme one-day rainfall was found to be more or less same (Table 1).

Table 1: Frequency of extreme 1-day rainfall during different seasons in and around the Uttarakhand

Season	*Jan - Feb*	*Mar - May*	*Jun - Sept*	*Oct - Dec*
Frequency of extreme 1-day rainfall	98	98	99	96

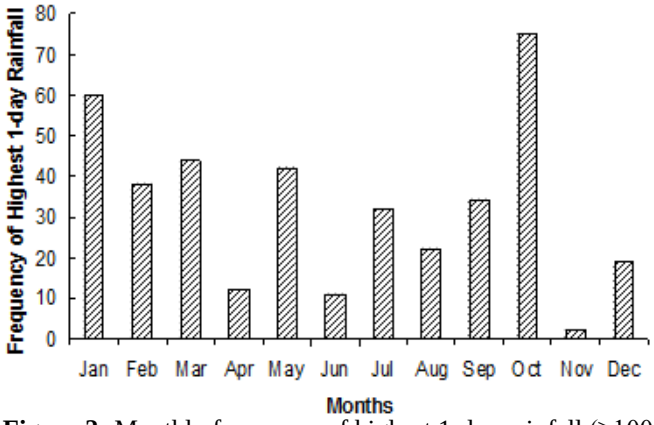

Figure 2: Monthly frequency of highest 1-day rainfall (≥100 mm)

Most of the stations have recorded one-day extreme rainfall during May to October in the range of 100 to 300 mm, except Khadrla station (Dist. Mahasu) which has recorded one-day extreme rainfall >700 mm in January. 40 stations recorded their annual highest one-day extreme rainfall in the range of 200-300 mm.

Inside the Uttarakhand, 12 stations recorded more than 400 mm of rainfall in 1-day (Table 2). Of these, Garbyang and Nainital stations recorded more than 500 mm of highest 1-day rainfall. Except Garbyang (in January) and Bazpur (in October), rest of the stations recorded their highest one-day rainfall in July, August and September monsoon months. However, prior to 1901, Hardwar and Mussoorie stations have recorded 1-day extreme rainfall of 495.3 mm and 439.4 mm respectively in Sept. 1880 and Aug. 1890.

Monthwise highest 1-day extreme rainfall recorded at different stations in and around the Uttarakhand (Table 3) shows that at higher altitude, Khadrala station (Himachal Pradesh) just northwest of Uttarakhand, has recorded highest 1-day extreme rainfall in January, February and November months, whereas in the plain areas, Dhampur station (Uttar Pradesh) located to south of Uttarakhand (Fig.3) recorded highest 1-day extreme rainfall in June, August and September months. Simla (O) recorded highest 1-day extreme rainfall of 800 mm in the October month. Besides, 16 stations nearby the Uttarakhand region recorded highest one-day rainfall in the range of 400 mm to 800 mm.

Table 2: Highest 1-day rainfall (>400 mm) recording stations inside the Uttarakhand (1901-2013)

No.	District	Station	Altitude (m)	Highest 1-day Rainfall (mm)	Date of Occurrence
1	Dehradun	Dehradun (O)	682	487.0	25/07/1966
2	Dehradun	Rajpur	975	440.4	25/08/1954
3	Uttar-Kashi	Kharsali (O)	2591	400.8	15/09/1963
4	Tehri-Garhwal	Mukhim	1981	450.0	05/09/1995
5	Pithoragarh	Askote	1372	450.0	05/09/1982
6	Pithoragarh	Berinag	1676	475.0	06/09/1965
7	Pithoragarh	Garbyang	3400	576.0	30/01/1968
8	Udham Singh Nagar	Bazpur	215	406.4	03/10/1934
9	Udham Singh Nagar	Khatima	203	405.6	13/09/1972
10	Nainital	Haldwani	348	413.0	11/07/1970
11	Nainital	kaladhungi	393	413.0	10/07/1970
12	Nainital	Nainital	2020	509.3	22/09/1958

Table 3: Monthwise statistics of highest 1-day rainfall and their date of occurrence around the Uttarakhand

Month	*Station*	*Altitude (m)*	*Highest 1-day Rainfall (mm)*	*Date of Occurrence*
January	Khadrala	2957	762.0	28/01/1968
February	Khadrala	2957	482.6	16/02/1963
March	Chini (Kalpa)	2781	479.0	03/03/2002
April	Garbyang	3400	279.8	04/04/1969
May	Chini (Kalpa)	2781	378.0	04/05/1971 & 02/05/1989
June	Dhampur	235	400.0	25/06/1989
July	Dehradun (O)	682	487.0	25/07/1966
August	Dhampur	235	600.0	30/08/1991
	Thakurdwara	244	600.0	11/08/1991
September	Dhampur	235	772.2	18/09/1880
October	Simla (O)	2202	800.0	19/10/1899
November	Khadrala	2957	279.4	21/11/1967

December	Kilba	2180	609.6	27/12/1958

It is seen from Fig.3 (from right to left) that stations lying to the leeside of the mountain ranges, especially located in the central part of the state, although are located at higher altitude have recorded less rainfall. Whereas station falling to the windward side viz. in the path of monsoon disturbances either located at high altitude or in the plain have recorded highest rainfall.

The magnitudes of extreme one-day rainfall in all the months and during seasonal, annual are given in Table 4. It is seen that magnitude of extreme one-day rainfall is higher in the monsoon months in both the inside as well as nearby stations of the Uttarakhand state. There is noteworthy decrease in the magnitude during March to May

Table 4: Magnitude of extreme one-day rainfall (mm) for stations in and around the Uttarakhand

Months / Seasons	Extreme one-day rainfall (mm) for stations			
	Inside Uttarakhand		Around Uttarakhand	
	Lowest	Highest	Lowest	Highest
Jan	18.0	576.0	24.4	762.0
Feb	17.8	381.8	12.7	482.6
Mar	0.8	288.0	15.3	254.0
Apr	3.0	279.8	17.8	200.0
May	5.0	370.0	7.6	378.0
Jun	1.6	362.0	52.0	400.0
Jul	48.3	487.0	38.9	470.0
Aug	41.2	398.8	51.1	600.0
Sep	40.2	475.0	78.7	400.6
Oct	27.9	307.3	23.1	241.2
Nov	0.4	134.0	6.3	279.4
Dec	3.2	288.0	19.0	609.6
Annual	81.3	576.0	134.6	762.0
Jan-Feb	25.0	576.0	36.0	762.0
Mar-may	16.4	370.0	17.8	378.0
Jun-Sep	53.3	487.0	88.1	600.0
Oct-Dec	27.9	307.3	30.0	609.6

The spatial distribution of highest one-day rainfall in and around the Uttarakhand state (Fig.3) shows that magnitude of highest one-day rainfall is less than 300 mm in the most of the central parts of the Uttarakhand state. This is mostly due to the orographic influence over the rainfall distribution as there are 86 high altitude peaks (>6000 m) located in this region. Stations which fall to the windward side recorded heavy rainfall (> 300 mm) and those which lie to the leeside recorded less rainfall (< 300 mm). Stations near the foot hills of Himalayas recorded comparatively heavy rainfall ranging between 400 to more than 800 mm. Broadly, stations in the central part of the state recorded less magnitude of extreme 1-day rainfall than stations in the eastern or western part of the state.

The decadal variation (see Fig.4) showed that prior to 1950, the number of one-day extreme rainfall recorded were very few. This may be because of less number of raingauge stations in those days. After the independence of India in 1947, in collaboration with US Geological Survey, Dr.Dhar (Hon. Emeritus Scientist, IITM, Pune) and his team installed more number of raingauges in the entire Indian and Nepal Himalayas. Therefore, of the 1951 to 2013 period, large numbers of extreme events (34) have been recorded in the 1961-1970 decade. Thereafter, there is noteworthy decrease in extreme rainfall events.

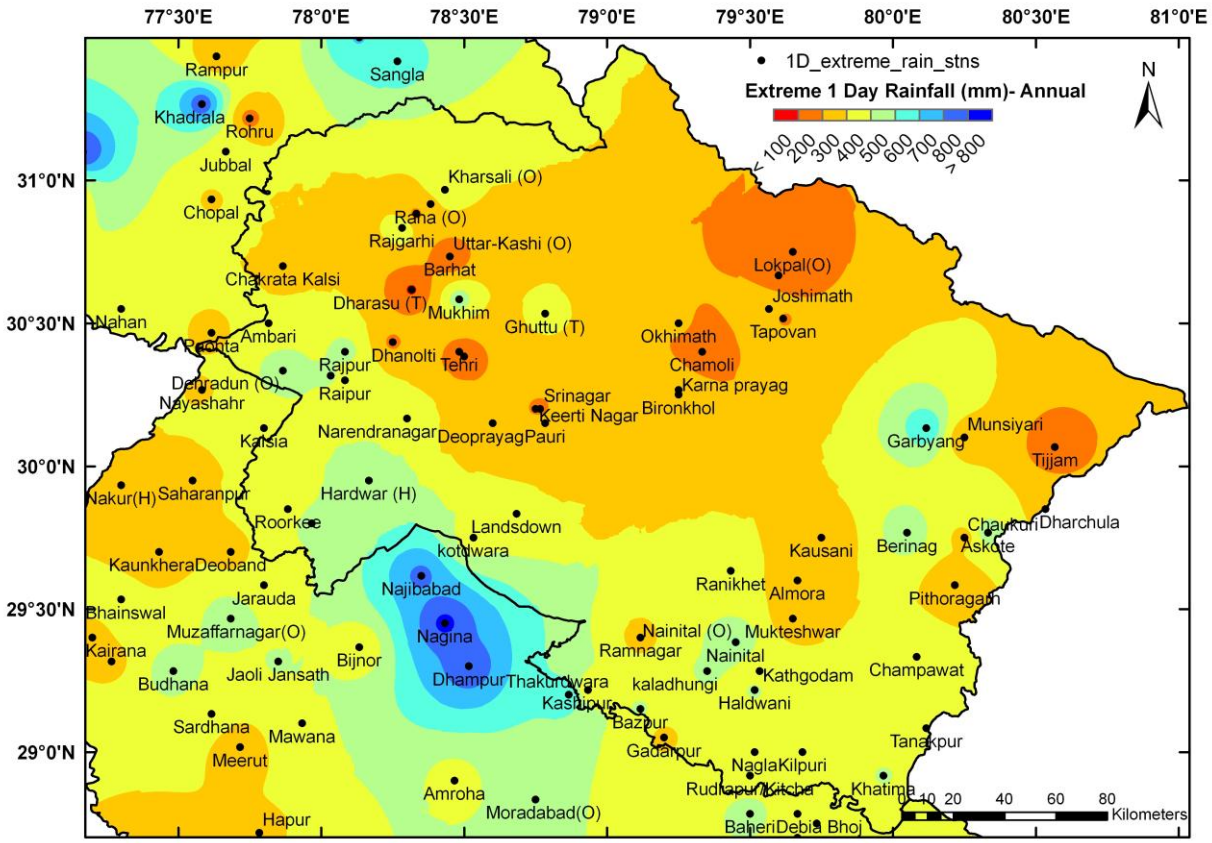

Figure 3: Spatial distribution of extreme 1-day rainfall in and around Uttarakhand

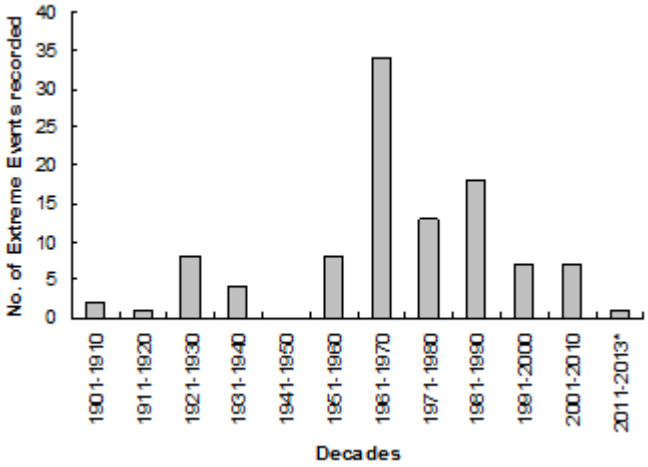

Figure 4: Decadal frequency of 1-day extreme rainfall events

Note: 2011-2013 is not a full decade, but no. of extreme events in these three years has been shown just by way of comparison.

The extreme rainfall events recorded by individual stations also support the fact that there is decrease in extreme rainfall events during seasonal as well as annual basis. More than 40% of the stations have shown decreasing trend and very few (about 10-12) stations have shown increasing trend in extreme rainfall events inside the Uttarakhand state.

Analysis of June 2013 rainfall showed that stations nearby the Kedarnath experienced heavy rainfall of 100 to 200 mm. Although nearby Stations viz. Dehra Dun, Mukteshwar recorded > 200 mm of rainfall during the heavy spell, these stations have recorded more than 450 mm of rainfall in the past. Just to the south of Landsdown, Nagina (Dist. Bijnor, Uttar Pradesh) recorded 823 mm of rainfall in one-day during 17-18 Sept. 1880 rainstorm with the spread over more than 100000 sq.km area (Dhar et al, 1975).

4. Conclusions

While studying the impact of climate change on global scale, lots of studies has come forth showing that there is an increasing trend of extreme precipitation events. The torrential rainfall episode during 15-18 June 2013 occurred over Uttarakhand and neighbouring states invited research on extreme rainfall events over this region.

In the present study, analysis of extreme rainfall events during 1901 to 2013 of about 100 stations in and around the Uttarakhand state showed that more than 40% of the stations showed decreasing trend in extreme rainfall events. Most of the extreme events have occurred in the months of July, August and September.

Although heavy rainfall of 2013 occurred for the first time in June, was mostly because of cloud burst. The heavy rainfall became severe due to rapidly melting of glacier in the upper reaches of Chorabari Lake releasing large amount of accumulated water from the lake as there was no outlet in the lake. In addition to this, man made interventions and poor planned development in this region is also responsible for such evidences (Dobhal et al, 2013).

5. Acknowledgement

Authors are thankful to Director, IITM, Pune for his keen interest and encouragement for carrying out this study. Authors express their sincere thanks to all the Himalayan Project Authorities, Forest Departments, and India Met. Dept. IMD, Pune for supplying the relevant rainfall data.

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