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A STUDY OF EXTREME POINT RAINFALL OVER FLASH FLOOD PRONE REGIONS OF THE HIMALAYAN FOOTHILLS OF NORTH INDIA

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Abstract. In north India flash floods normally occur in the foothill and sub-montane regions of the Himalayas during the monsoon months due to incidence of heavy falls of rain. An attempt has been made in this study to estimate extreme rainfalls (also called probable maximum precipitation) for stations in and near the Himalayan foothills and sub-montane regions from longitude 75° E to 90°E. Only those stations in the foothill regions with unbroken records of daily rainfall for 60 to 70 years have been selected. Hershfield's latest statistical technique has been used while values of the frequency factor in the extreme rainfall equation for individual stations have been obtained from the north Indian data.

Etude des pluies ponctuelles extrêmes dans les régions collinaires montagneuses du pied de l'Himalaya, en Inde du nord

Résumé. En Inde du Nord, des crues brutales se produisent normalement dans les montagnes et les collines du pied de l'Himalaya, durant les mois de mousson ; elles sont dues à d'importantes chutes de pluie. Dans la présente étude, on s'est efforcé d'estimer la précipitation extrême (appelée également précipitation maximale probable) pour des stations situées à l'intérieur ou à proximité de cette région, entre les longitudes 75° à 90° Est. On s'est limité aux stations pour lesquelles on dispose d'observations continues de pluies journalières pour des périodes de 60 à 70 ans. La technique statistique la plus récente de Herschfield a été utilisée dans ce but, mais les valeurs du facteur de fréquence dans l'équation de la pluie extrême pour des stations individuelles sont tirées uniquement des données recueillies en Inde du Nord.

INTRODUCTION

In north India numerous streams and rivulets rise in the Himalayan foothills and submontane regions from Kashmir in the west to Assam in the east. These streams are subject to flash floods due to the incidence of heavy rainfall in their respective catchment areas during the monsoon months. Rain occurs from orographic lifting of moisture laden winds along the steep slopes of the foothills. The intense rainfall over the steep terrain causes sharp rises in the mountain streams resulting in flash floods in the sub-montane regions downstream.

There have been numerous instances in the past when flash floods in the mountain streams of the Himalayas have been responsible for causing landslips and have washed away entire villages, bridges, roads ; disrupting communications for days. In September 1880, due to intense falls of rain in the Garhwal-Kumaon hills, more than 150 persons were killed in Nainital Town alone due to landslips and flash floods. In June 1950, due to unprecedented rains in Darjeeling and Jalpaiguri districts, flash floods and landslips destroyed numerous villages and killed hundreds of people, besides disrupting communications for days. In recent times such tragedies have been occurring in different regions of the Himalayas. In July 1963, a portion of Phalgam Town, a hill resort in the Kashmir Valley, was washed away by the sudden, swift rising wall of water from a nearby rivulet. In July 1970 a major tragedy took place in the Alaknanda Valley in the Garhwal Himalayas leaving behind a trail of misery in the wake of widespread destruction of life, property and agricultural lands. It has been reported that during the night of 20 July a caravan of 30 vehicles was washed away by the surging waters of the Alaknanda River at a place called Belakuchi Bazar in the Chamoli district.

As intense rainfall in a short duration is the main cause of flash floods in the hilly areas, an attempt has been made in this paper to estimate extreme point rainfall, also called Probable Maximum Precipitation (PMP), that can occur over the foothill regions of the Himalayas from Punjab in the west to north Bengal in the east. Such estimates of extreme rainfall, besides helping design engineers in planning roads and bridges in these hilly regions, will also be useful to flash flood forecasters in issuing timely warnings of floods to downstream towns and villages.

This study has been made on the basis of long-period rainfall data of stations located in and near the foothill and sub-montane regions of the Himalayas. For this study, only those rainfall stations have been considered whose daily rainfall data are available for the last 60 to 70 years. Most of these stations are not equipped with self-recording raingauges, as a result, estimates of extreme rainfall could not be worked out for durations of less than a day. The available rainfall data have been analysed by the latest statistical technique which has also been recommended by the World Meteorological Organization (WMO, 1973) for the estimation of extreme point rainfall.

STATISTICAL TECHNIQUE USED

In this paper, the statistical technique developed by Hershfield (1961) has been employed for estimating extreme rainfalls for about 80 stations located in and near the Himalayan foothills from longitude 75°E to 90°E.

The statistical method used for estimating extreme rainfall for these stations is based upon the assumption that information regarding extreme rainfall of a station is contained in the long rainfall records of that station. This technique has an advantage of providing quick estimates of extreme rainfall and to a large extent is free from subjectivity.

The statistical technique used here has been tried in different parts of the world such as the USA (Hershfield, 1961, 1965 ; Myers, 1967), Canada (Bruce and Clark, 1966) and Australia (Wiesner, 1970) and results obtained there have been found to be quite comparable with the results obtained by the conventional hydrometeorological methods.

In India, Dhar and Kamte (1969, 1971 and 1973) have used this method for obtaining estimates of extreme point rainfall for different parts of north Indian plains north of latitude 20°N. The only drawback with this method is that it gives extreme rainfall estimates for point stations or small basins whose areas are of the order of 1000 km² or so (WMO, 1973). However, according to Wiesner (1970), the advantage in using this method is that it takes into account actual rainfall data and expresses the record in terms of statistical parameters and is easy to use.

The procedure used for obtaining extreme rainfall by the above technique has been described in detail in the latest WMO manual for estimation of probable maximum precipitation (WMO, 1973), consequently the procedure used is only briefly touched upon here.

ESTIMATION OF EXTREME RAINFALL IN THE FOOTHILL AREAS OF THE HIMALAYAS

From an examination of stations in and near the foothills of the Himalayas from longitude 75°E to 90°E, it was found that there are about 80 rainfall stations with data available for the last 60 to 70 years. A list of these stations together with their latitudes and longitudes is given in Table 1. This Table also shows the highest 1-day rainfall experienced by these stations during the last 60 to 70 years. For each of these stations, annual maximum rainfall series were determined and from these series, the mean of the annual maximum series (X_n) and the standard deviation (S_n) were worked out. According to Hershfield (1961, 1965) the PMP for a station can be obtained from the following equation :

$$X_{PMP} = X_n + K S_n \qquad (1)$$

where

X_{PMP}	=	the extreme rainfall for a station,
X_n	=	mean of the annual maximum series,
S_n	=	standard deviation of the annual maximum series, and
K	=	frequency factor which depends upon the statistical distribution, the number of years used and the return period.

In his earlier study, Hershfield (1961) obtained the value of the frequency factor K by using the equation

$$K = \frac{X_1 - X_{n-1}}{S_{n-1}} \qquad (2)$$

where

X_1	=	largest value of the annual maximum series,
X_{n-1}	=	mean of the annual maximum series omitting the largest value from the series, and
S_{n-1}	=	standard deviation of the annual maximum series omitting the largest value from the series.

TABLE 1

Extreme point rainfall estimates for stations in the foothill regions of the Himalayas from longitude 75°E to 90°E

Sr. No.	Name of the station	Latitude (° ′)	Longitude (° ′)	Highest observed 1-day rainfall (mm)	Extreme 1-day rainfall (mm)
1.	Jagadhri	30-10	77-18	287	559
2.	Naraingarh	30-28	77-08	235	546
3.	Kharar	30-45	76-39	224	513
4.	Dadupur	30-15	77-25	445	785
5.	Nawashahr	31-07	76-07	240	584
6.	Samrala	30-50	76-11	263	597
7.	Dasuya	31-48	75-38	279	625
8.	Una	31-28	76-17	276	569
9.	Garhshankar	31-13	76-07	255	534
10.	Hoshiarpur	31-32	75-55	290	579
11.	Tibri	32-06	75-35	386	742
12.	Gurdaspur	32-02	75-24	370	754
13.	Pathankot	32-17	75-39	294	599
14.	Madhopur	32-22	75-37	351	602
15.	Hamirpur	31-42	76-32	248	552
16.	Palampur	32-07	76-32	344	561
17.	Kangra	32-06	76-15	306	508
18.	Dharamsala(L)	32-13	76-19	387	559
19.	Nurpur	32-18	75-55	293	571
20.	Kulu	31-57	77-07	127	340
21.	Simla	31-06	77-10	271	538
22.	Kasauli	30-53	76-58	298	564
23.	Barauli	30-55	77-00	419	564
24.	Almora	29-36	79-40	222	566
25.	Berinag	29-46	80-03	205	549
26.	Champawat	29-20	80-05	390	693
27.	Pithoragarh	29-35	80-13	201	566
28.	Ranikhet	29-38	79-26	191	541
29.	Chaukuri	29-45	80-15	274	640
30.	Lansdowne	29-50	78-41	323	714
31.	Pauri	30-09	78-47	261	536
32.	Bironkhal	30-15	79-15	255	632
33.	Srinagar	30-12	78-46	172	455
34.	Karnaprayag	30-16	79-15	198	582
35.	Kotdwara	29-45	78-32	349	681
36.	Ambari	30-30	77-49	318	610
37.	Bhogpur	30-20	78-15	343	612
38.	Raipur	30-18	78-05	292	678

Sr. No.	Name of the station	Latitude (° ′)	Longitude (° ′)	Highest observed 1-day rainfall (mm)	Extreme 1-day rainfall (mm)
39.	Dehradun	30-19	78-00	332	546
40.	Rajpur	30-24	78-05	440	632
41.	Chakrata	30-42	77-52	229	578
42.	Nainital	29-23	79-27	399	648
43.	Haldwani	29-13	79-31	307	554
44.	Ramnagar	29-24	79-07	267	673
45.	Kathgodam	29-17	79-32	307	724
46.	Nagla	29-37	80-15	326	851
47.	Puranpur	28-31	80-09	290	627
48.	Saharanpur	29-57	77-33	267	640
49.	Roorkee	29-51	77-53	258	564
50.	Hardwar	29-57	78-10	356	785
51.	Salimpur	29-58	78-03	285	655
52.	Kalsia	30-08	77-48	324	645
53.	Najibabad	29-37	78-21	230	503
54.	Nagina	29-27	78-26	489	747
55.	Nighasan	28-14	80-52	298	620
56.	Bahraich	27-34	81-36	326	602
57.	Nanpara	27-52	81-30	280	577
58.	Atraula	27-19	82-25	200	526
59.	Domeriaganj	27-13	82-40	231	561
60.	Bansi	27-10	82-56	241	533
61.	Maharajganj	27-09	83-34	440	740
62.	Bagha	27-06	84-06	439	688
63.	Burharwa	27-14	84-38	235	584
64.	Sitamarhi	26-35	85-29	321	642
65.	Sheohar	26-32	85-17	395	726
66.	Madhubani	26-21	86-05	397	653
67.	Supaul	26-07	86-37	282	533
68.	Araria	26-08	87-23	276	561
69.	Forbesganj	26-18	87-16	343	681
70.	Kishanganj	26-07	87-56	370	683
71.	Siliguri	26-43	88-26	323	510
72.	Darjeeling	27-03	88-16	493	719
73.	Mongpoo	26-55	88-30	546	691
74.	Kurseong	26-53	88-17	502	617
75.	Jalpaiguri	26-32	88-43	403	531
76.	Alipurduar	26-28	89-33	378	516
77.	Falakata	26-31	89-12	271	493
78.	Buxa	26-46	89-35	538	592
79.	Kalchini	26-42	89-27	455	554

Using the above empirical approach, the highest value of K on the basis of data of about 2 600 stations was found to be of the order of 15 (Hershfield, 1961). Thus, Hershfield's original equation of obtaining extreme rainfall for a point station took the form

$$x_{PMP} = X_n + 15\,S_n \qquad (3)$$

In equation (3), Hershfield thought that the frequency factor K was independent of rainfall magnitude. It was later found (Hershfield, 1965) that the frequency factor varies inversely with rainfall magnitude. In other words, the value of 15 was found to be high for areas of generally heavy rainfall and low for arid areas (WMO, 1973). Using the latest approach on data from 1 030 long-period stations in north India which included both plain and hilly stations: Dhar and Kamte (1973), obtained a relationship between the frequency factor K and mean annual maximum rainfall (X_n) for a 1-day period duration. This relationship is shown in Fig. 1. In this figure, Hershfield's relationship based on world record rainfall data (Hershfield, 1965) is also shown as curve no. II by way of comparison. It is seen from Fig. 1 that the frequency factor K has a tendency to decrease with increasing value of X_n. It is also evident from this figure that the relationship based on north Indian data has a steeper slope when compared to Hershfield's curve for 1-day rainfalls. In other words, Fig. 1

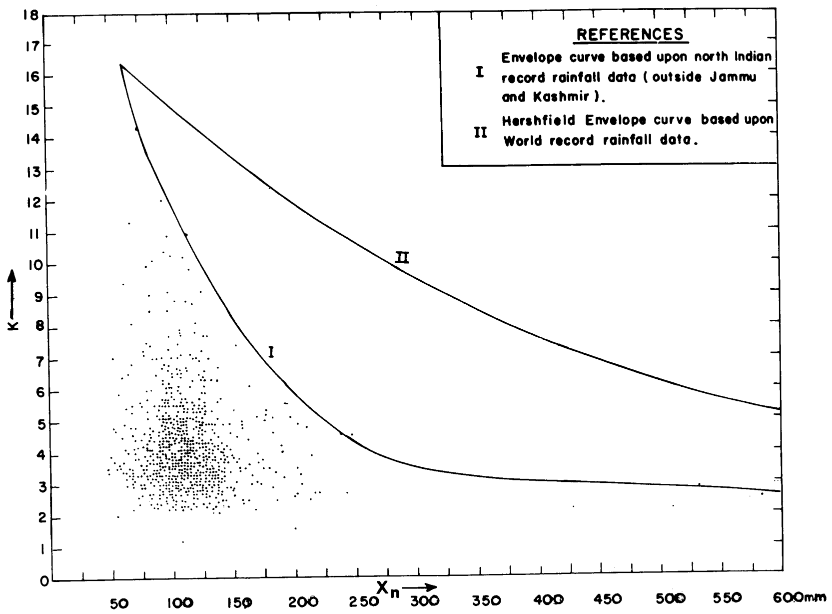

Fig. 1 – Relationship between frequency factor (K) and mean annual maximum rainfall (X_n) for a 1-day period.

clearly shows that high values of extreme rainfall for a north Indian station would be obtained if values of K are picked out from the Hershfield curve based upon world record data. Because of this, the extreme rainfall has been worked out in this paper for stations in Himalayan foothills on the basis of the relationship obtained for north Indian data (curve no. I of Fig. 1).

Corresponding to X_n values of individual stations in the Himalayan foothills, K values were picked out from curve no. I in Fig. 1. Using X_n, S_n and K for individual stations in equation (1) extreme values of rainfall were then worked out for each of the stations and the corresponding extreme rainfall estimates are given in Table 1. It is seen from this table that along the Himalayan foothill regions extreme 1-day rainfall varies from 850 to 340 mm. The highest 1-day extreme rainfall of 850 mm was obtained for the Nagla station in the Nainital district in the Kumaon Hills while the lowest value of 340 mm was obtained for the Kulu station in Kangra district in Himachal Pradesh. It is also observed that the extreme rainfall is quite high in the outer foothill regions of the Himalayas and decreases sharply as one moves into the interior of the Himalayas. For the Himalayan foothill region under study, the ratio of the extreme 1-day rainfall to the highest observed 1-day rainfall over a period of 60 to 70 years was found to be of the order of 2. Hershfield (1962) found this ratio to be of the order of 3 on the basis of USA and other world record data.

CONCLUSIONS

This study has shown that extreme rainfalls over the foothill regions of the Himalayas can vary from 850 to about 340 mm per day. Rainfall decreases considerably as one moves from the outer foothills to the inner ranges of the Himalayas. The average ratios of extreme 1-day rainfall to the highest 1-day observed rainfall over the last 60 to 70 year period was found to be of the order of 2 for this region while Hershfield has found this ratio to be of the order of 3.

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