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Estimation of extreme rainfall over north India

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ABSTRACT. Hershfield (1961) using statistical techniques worked out PMP estimates for USA which have been found to be comparable with the results obtained by the conventional storm analysis methods. This technique has been utilised in this paper for the preparation of generalised charts of PMP for the plain areas of different States in north India. A table showing PMP values for individual stations in the Himalayan region has also been prepared. In addition to the above, an attempt has also been made to draw an envelope frequency factor curve based upon the rainfall data of 760 long-period stations in north India. This curve has been compared with the similar curve prepared by Hershfield on the basis of world record rainfall data.

1. Introduction

A knowledge of extreme rainfall over a basin is essential for the planning and design of hydraulic structures. In situations where no risks can be undertaken due to failure of such structures, the design is invariably based upon an estimated extreme rainfall of the basin. This estimate of extreme rainfall has in recent years come to be known as probable maximum precipitation and hereafter referred to as PMP. Extreme rainfall or PMP has been defined as the greatest depth of rainfall for a given duration that is physically possible over a given basin during a given duration. In other words, it is that magnitude of storm rainfall for a given duration which should not be exceeded over a problem basin over a long period of years, say thousands of years.

In day-to-day practice, PMP is derived over a flat terrain by the analysis of a large number of major recorded rain storms in and near the problem basin, transposing the outstanding storm patterns over the given basin in a critical manner so as to obtain maximum rain depths for different durations. The transposed rain depths thus obtained are then maximized for moisture charge, wind etc and finally the maximized envelope rain depths are picked up for various durations as the 'design storm' depths. On the basis of analysis of a large number of recorded rain storms in USA, generalised PMP charts have been prepared by US Weather Bureau (1956, 1960) for different areas and durations.

2. PMP determination by Hershfield method

In recent years Hershfield (1961) prepared estimates of PMP point rainfall for USA using statistical techniques. Preliminary appraisal of this method in USA (Myers 1967) and Canada (Bruce and Clark 1966) has shown that the estimates obtained by this method are fairly comparable with the results obtained by the conventional storm analysis method. WMO *Guide to Hydrometeorological Practices* (1965) and WMO Technical Note on *Estimation of Maximum Flood* (1969) have recommended this method for preparing estimates of extreme rainfall for small basins where daily rainfall data at individual stations are available for a long period of time but data for storm maximization are lacking. Wiesner (1970) feels that this method has the advantage of taking account of the actual data, expressing it in terms of statistical parameters and is easy to use.

An attempt has been made in this paper to utilise the Hershfield (1961) technique for deriving extreme one-day point rainfall magnitudes for the five contiguous north Indian States of the Punjab, Haryana, Uttar Pradesh, Bihar and West Bengal (Fig. 1). The total area comprised by these five States excluding their respective Himalayan areas, is about 2,40,800 sq. miles. In this area only those rainfall stations have been selected for this study whose daily data are continuously available for the last 60 to 70 years from 1891. The total number of such rainfall stations in this area is of the order of 470. Table 1 gives the Statewise distribution of plain-area stations together with their respective periods of continuous rainfall data.

3. Hershfield technique

The Hershfield's (1961) statistical model for obtaining PMP estimates for point rainfall were used by Dhar and Kamte (1969) employing the equation —

$$X_m = \overline{X} + \sigma K_m$$

where, X_m is estimated 24-hr PMP,

$\overline{X}$ and σ are respectively the mean and standard deviation of the annual series of maximum 24- hour rainfall and K_m is the frequency factor defined by Hershfield as the ratio of difference between the highest observed and mean of the annual rainfall series to the standard deviation of the annual maximum series.

In recent years Wilson (1963), Mazumdar and Rangarajan (1966), Lockwood (1969) questioned the universal applicability of $K_m=15$ given by Hershfield. Dhar and Kamte using $K_m \doteq 12$ indicated that the rainfall values so obtained for individual stations in Uttar Pradesh were of the order of 10^6 years manifesting rare probability of their occurrence.

4. Application of Hershfield technique to north India

The following statistics were worked out for each of the 468 stations mentioned in Table 1, using their respective one-day annual maximum rainfall data of the last 60 to 70 years from 1891—

$\overline{X}_N$=the mean of the annual maximum series using all the N-year values in the series,

$\overline{X}_{N-1}$=the mean of the annual maximum series with the largest value (*i.e.*, X_1) omitted from the series,

σ_N=Standard deviation of the annual maximum series using all the N-year values in the series,

σ_{N-1}=Standard deviation of the annual maximum series with the largest value (*i.e.*, X_1) omitted from the series, and

C_v=Coefficient of variation using all the N-year maximum values in the series.

The value of the frequency factor K_m for each of the 468 stations was worked out by using the following equation (Hershfield 1961)—

$$K_m=(X_1-\overline{X}_{N-1})/\sigma_{N-1} \quad (2)$$

where X_1 is the largest value of the annual maximum series for each station. The K_m values thus obtained for different stations in each of the five States were then plotted on large scale base maps of these States and it was seen that they were randomly distributed and did not show any relationship with the geography of any particular area. Considering each State as a separate meteorological division, envelope values of K_m for each State were then determined and the same are shown in Table 2.

TABLE 1

Distribution of stations with long periods of daily rainfall data from 1891 in the plain areas of different States in north India

Length of records (years)	Number of plain area stations in each State with long periods of rainfall data				
	Punjab and Haryana (37,100 sq. miles*)	Uttar Pradesh (1,06,500 sq. miles*)	Bihar (67,200 sq. miles*)	West Bengal (30,000* sq. miles)	Total No. of stations
70	60	202	53	9	324
69	4	9	10	7	30
68	1	4	5	8	18
67	2	8	9	12	31
66	2	3	5	6	16
65	1	0	2	2	5
64	0	0	3	4	7
63	1	4	5	2	12
62	0	0	1	1	2
61	0	0	3	3	6
60	0	8	6	3	17
Total	71	238	102	57	468

*These areas do not include the Himalayan areas of these States

TABLE 2

The highest value of the frequency factor K_m for different States in north India*

State	Enveloping K_m values for one-day rainfall	No. of long-period stations used
Punjab and Haryana	14·5	71
Uttar Pradesh	12	238
Bihar	11	102
West Bengal	11	57
Total		468

*NOTE—A similar study has also been carried out recently in respect of Rajasthan and other central Indian States of Orissa, Madhya Pradesh and Gujarat. The envelope K_m values obtained for each of these States are given below by way of comparison —

State	Enveloping K_m values for one-day rainfall	No. of long-period stations used
Rajasthan	11	91
Gujarat	9	74
Madhya Praddesh	9	77
Orissa	10	26
Total		268

Generalised PMP charts for Orissa and Gujarat have been prepared and are being published elsewhere

From Table 2 it is seen that the highest value of K_m is of the order of 14·5 in the whole north Indian region. Since each State is assumed to be a separate meteorological division with its own distinct rainfall regime, it is felt that using one single highest value of K_m for the whole north Indian region may not give representative estimates of PMP for stations in different States. In view of this, envelope K_m values given in Table 2 have been used for determining PMP estimates for each of these States separately.

5. Generalised charts of extreme one-day rainfall for plain areas in north India

Using the envelope K_m values given in Table 2, PMP values were calculated for different stations in each State using the equation (1). Before these values were plotted on large scale base maps of the respective States for the preparation of generalised one-day PMP charts, coefficient of variation (C_v) values, obtained earlier for each station, were first plotted on large scale base maps of these States to smooth out the inherently large errors associated with standard deviations. According to Hershfield (1961, 1965 and 1970) this step is extremely important for the preparation of smooth generalised PMP charts by this technique. The C_v values of nearby stations were compared with one another and wherever necessary adjusted by suitably changing the value of standard deviation. The revised standard deviation values were then used to recalculate the PMP values of those stations whose C_v values were adjusted.

The generalised one-day PMP charts for the plain areas of the five north Indian States are shown at Figs. 2 to 4. In preparing these smooth generalised charts, the C_v, K_m and PMP values of the neighbouring stations in the adjacent States of Rajasthan, Madhya Pradesh and Orissa were also taken into consideration. From a careful study of these charts, it is seen that the highest values of PMP are obtained in northwestern areas of Punjab plains. Similar high PMP values are also obtained in the sub-mountain tracks of northeast U. P., adjoining north Bihar and in northern portions of West Bengal. In these areas the one-day PMP values are of the order of 35 to 40 inches. The other prominent areas in these States where high values of PMP (*i.e.*, 30 to 35 inches in one-day) obtained are the coastal areas of West Bengal and the elongated area between Faizabad and Sitapur slightly south of Bahraich in east U.P. The lowest value of one-day PMP in this whole region is of the order of 18 to 20 inches and such areas are located in southwest Haryana, southwest U.P. and southern tracts of Bihar plateau.

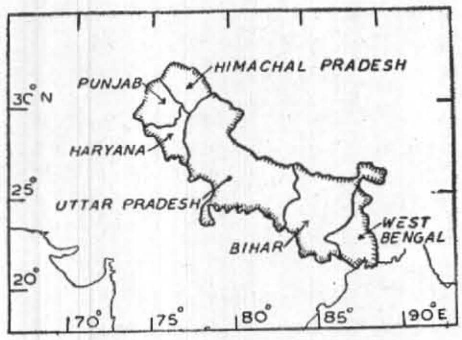

Fig. 1

TABLE 3

One-day PMP estimates for hill stations in north India

Station	Highest observed one-day rainfall (inches)	One-day PMP (inches)
Uttar Pradesh		
Almora	9	21
Berinag	8	22
Bironkhal	10	24
Champavat	15	31
Chaukuri	11	27
Joshimath	17	28
Landsdowne	13	34
Nainital	16	44
Okhimath	10	23
Pauri	10	18
Pithoragarh	8	20
Ranikhet	7	22
Punjab and Himachal Pradesh		
Barauli	17	25
Dharamsala	15	39
Kasauli	12	29
Kulu	5	14
Nagar	7	17
Palampur	13	37
Simla	11	23
Kilba	10	17
Kotkhai	7	17
Kotgarh	7	18
West Bengal		
Darjeeling	19	37
Kurseong	20	39
Mongpoo	21	43

NOTE—Stations above 3,500 ft a.s.l. have been considered as hill stations

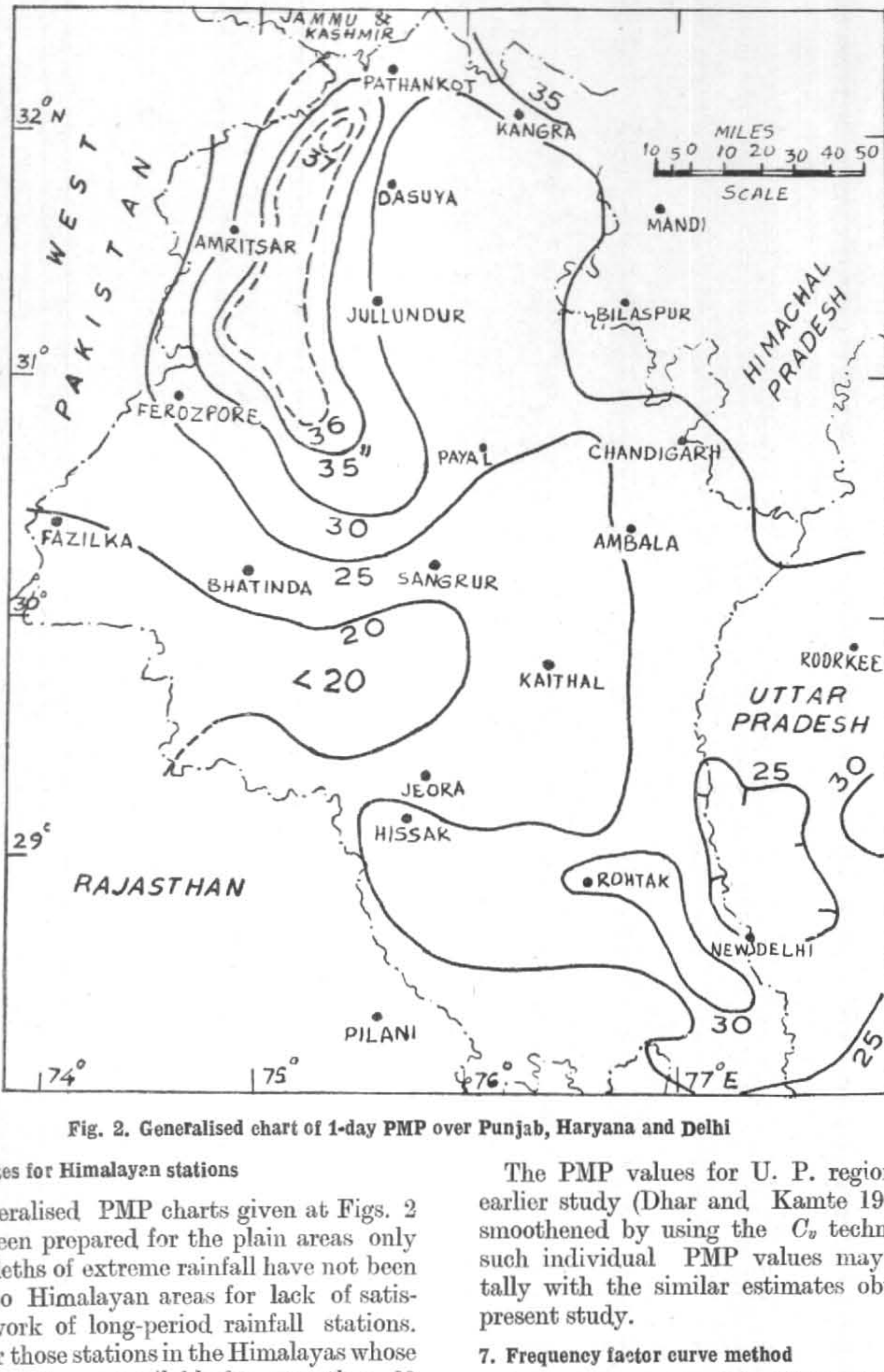

Fig. 2. Generalised chart of 1-day PMP over Punjab, Haryana and Delhi

6. PMP estimates for Himalayan stations

The generalised PMP charts given at Figs. 2 to 4, have been prepared for the plain areas only and the isopleths of extreme rainfall have not been extended into Himalayan areas for lack of satisfactory network of long-period rainfall stations. However, for those stations in the Himalayas whose daily rainfall data are available for more than 60 years or so, PMP values have been worked out by the above technique and the same are shown in Table 3. It is felt that these PMP estimates may serve as a rough guide to the design engineers for the preparation of preliminary project reports in these areas. Among the hill stations the highest values of one-day PMP (*i.e.*, above 40 inches have been obtained in respect of Nainital (U.P.) and Mangpoo (West Bengal) stations in the Himalayas.

The PMP values for U. P. region given in an earlier study (Dhar and Kamte 1969) were not smoothened by using the C_v technique and as such individual PMP values may not exactly tally with the similar estimates obtained in the present study.

7. Frequency factor curve method

In a recent study, Hershfield (1965) has also used the frequency factor curve method for the estimation of PMP. He has found that K_m is a function of duration of storm rainfall and the magnitude of mean annual maximum rainfall ($\overline{X}_N$). He has observed that K_m has a tendency to decrease with the increase of $\overline{X}_N$, for different durations. Plotting K_m against $\overline{X}_N$, he obtained a set of envolope curves of K_m for durations of 5 min., 1-hr, 6-hr and 24-hr. These envelope curves were

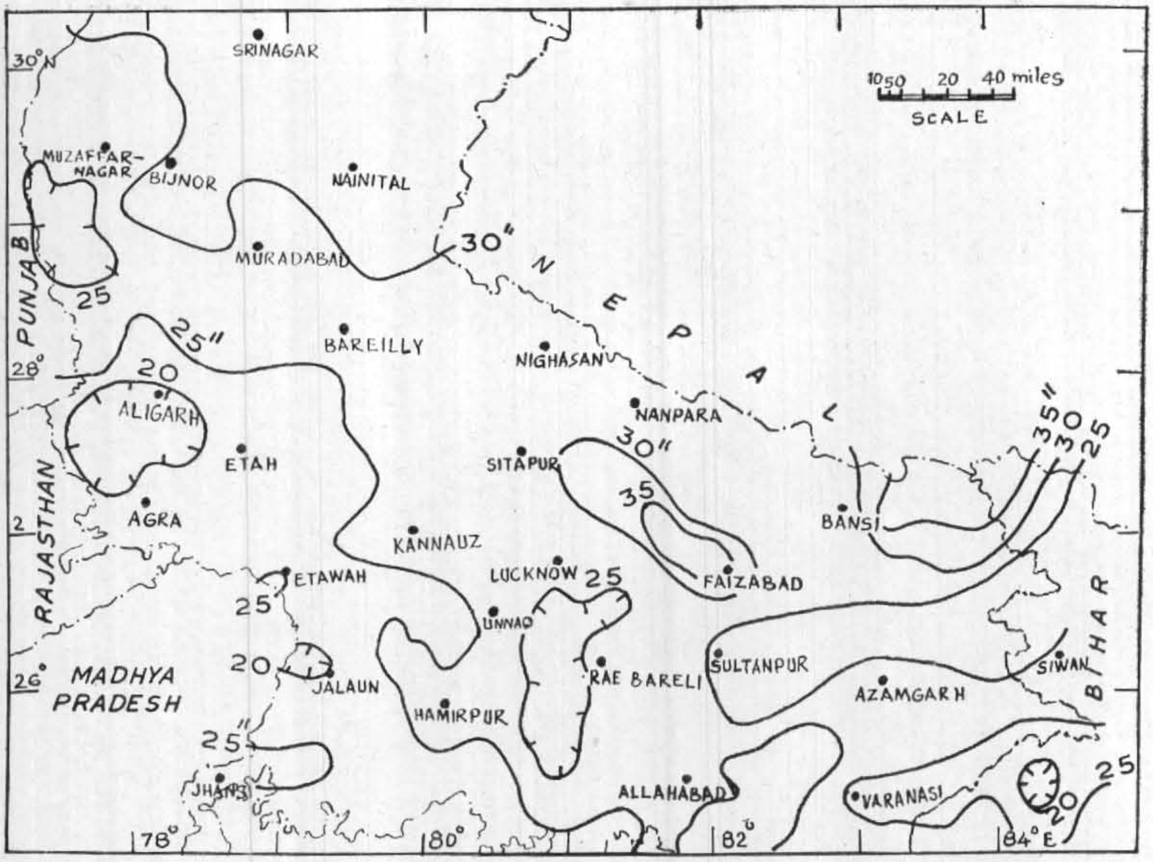

Fig. 3. Generalised chart of 1-day PMP over Uttar Pradesh

drawn on the assumption that at a particular value of $\overline{X}_N$, the maximum value of K_m will be reached. The maximum values of K_m for different durations were fixed up with the help of Jenning's (1950) world enveloping rainfall relationship. Gupta *et al.* (1968) has used K_m values from these curves in order to work out PMP values for different durations for a station in west U.P. (*viz.*, Dehra Dun). His one-day estimate of PMP for this station more or less tallies with the estimate given in the generalized charts.

An attempt has also been made to prepare separate envelope frequency factor curves for one-day rainfall for each of the five States based upon the annual miximum rainfall data of each of the States. It has, however, been found that the present network of long period rainfall stations (*i.e.*, stations having 60 to 70-year data) is not adequate enough to draw the area envelope K_m curves with confidence for any of the five States. However, a regional envelope K_m curve based upon the data of about 760 long-period rainfall stations in north India (roughly north of Lat. 21°N outside Assam and Kashmir States) has been prepared and is shown in Fig. 5 as curve No. I. By way of comparison, Hershfield's (1965) envelope K_m curve based upon the world record rainfall data has been shown as curve No. II in Fig. 5. It is seen from this figure that the slope of curve No. I is very steep when compared to the Hershfield's curve (*i.e.*, curve No. II). This is mainly due to the fact that K_m values decrease very rapidly as $\overline{X}_N$ values increase. In other words, it means that the dispersion of annual maximum rainfall is quite high for stations receiving heavy falls of rain when compared with stations which receive comparatively low rainfall. However, using envelope K_m values from curve No. I of Fig. 5, PMP charts were recently prepared for West Bengal (Dhar, Kamte and Kulkarni

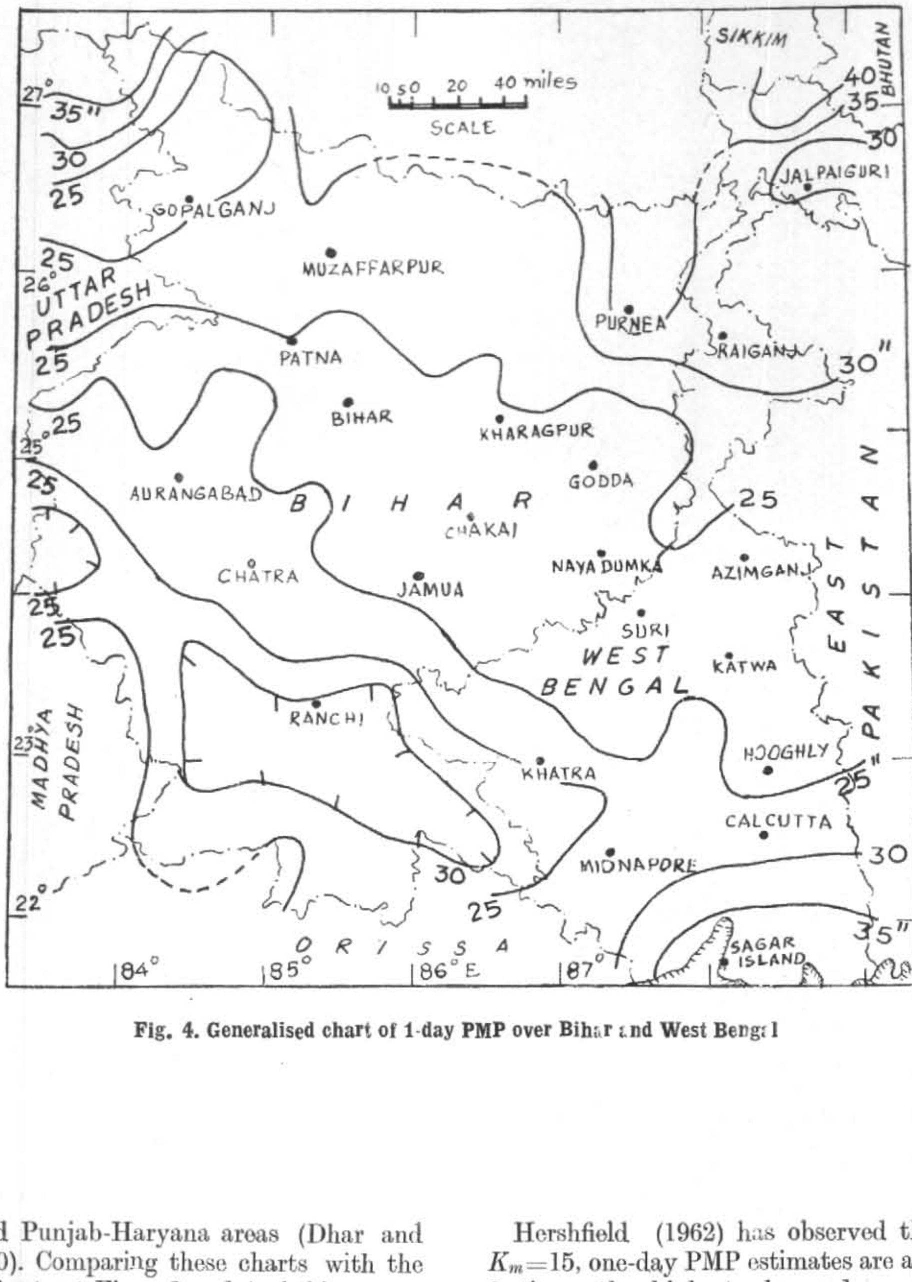

Fig. 4. Generalised chart of 1-day PMP over Bihar and West Bengal

see Ref.) and Punjab-Haryana areas (Dhar and Kulkarni 1970). Comparing these charts with the generalised charts at Figs. 2 and 4 of this paper, it is seen that the PMP estimates are quite comparable for most of the stations.

Using Hershfield's curve No. II in Fig. 5 PMP estimates have been worked out for some 20 plain-area representative stations located in the different parts of north India and these estimates have been compared with the similar estimates obtained by using the area envelope K_m values given in Table 2. The results are compared in Table 4. It is seen from a study of this Table that estimates based upon Hershfield's K_m curve are generally much in excess for most of the stations.

Hershfield (1962) has observed that by using $K_m = 15$, one-day PMP estimates are approximately 3 times the highest observed one-day rainfall recorded over a long-period of years. Ratios of PMP, based upon K_m factors given in Table 2, to the highest observed rainfall for individual stations have been worked out for all the 468 stations and the average values for different States are given in Table 5.

It is seen from Table 5 that the average ratio in the case of Punjab-Haryana area is very close to the ratio obtained by Hershfield. This is due to the fact that in the case of Punjab and Haryana areas the envelope K_m value used is almost equal to the one used by Hershfield.

TABLE 4

Comparison of PMP estimates for 20 plain-area stations in north India by using Hershfield and enveloping values of K_m

Station	Highest observed one-day rainfall (inches)	One-day PMP estimate (inches)	
		Using Hershfield curve No. II of Fig. 4	Using enveloping K_m values for different States (*vide* Table 2)
	Punjab		
Gurdaspur	15	38	37
Jullundur	11	31	30
	Haryana		
Rohtak	19	39	31
Hissar	12	29	26
Gurgaon	10	33	31
	Uttar Pradesh		
Saharanpur	11	32	27
Bareilly	11	30	26
Gorakhpur	11	29	25
Lucknow	12	32	27
Allahabad	13	34	29
Hamirpur	10	32	27
Agra	9	28	22
	Bihar		
Muzaffarpur	13	35	28
Hazaribagh	12	33	26
Chaibasa	9	26	20
Naya Dumka	11	27	20
	West Bengal		
Alipore (Calcutta)	15	36	29
Sagar Island	14	38	33
Jalpaiguri	16	32	29
Behrampore	11	31	24

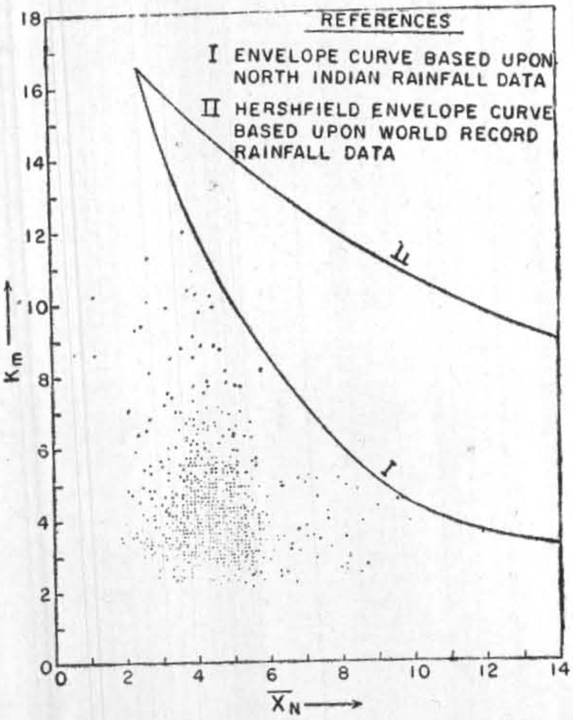

Fig. 5. Relationship between mean of annual max 24-hr rainfall $(\overline{X}_N)$ and frequency factor K_m

TABLE 5

Average ratios of one-day PMP to maximum observed one-day rainfall

State	K_m values used	Average ratio	No. of long period rainfall stations used
Punjab and Haryana	14·5	2·70	71
Uttar Pradesh	12	2·43	238
Bihar	11	2·18	102
West Bengal	11	2·16	57

8. Summary and conclusions

(*i*) Using 60 to 70 years' one-day rainfall data of 468 stations in north India, enveloping values of frequency factor K_m in the Hershfield equation $X_{PMP} = \overline{X} + \sigma\ K_m$ were determined for different States in north India for obtaining one-day PMP estimates. These point PMP estimates were utilised for preparing generalized PMP charts for one-day duration. These charts are given in Figs. 2 to 4.

(*ii*) Due to paucity of satisfactory network of long-period rainfall stations in the Himalayan regions, generalised PMP charts have not been extended to these areas. However, for the guidance of the design engineer PMP values have been worked out for those Himalayan stations whose data are available for the last 60 to 70 years and the same are shown in Table 3.

(*iii*) Based upon the long-period one-day rainfall data of about 760 stations in north India, an enveloping frequency factor curve has been prepared. This curve has been compared with the similar curve prepared by Hershfield on the basis of world record rainfall data. It has been observed that the slope of the north Indian curve is rather steep when compared to the Hershfield curve. As such, PMP estimates obtained with the help of the curve, for stations which generally receive heavy falls of rain are relatively low.

(*iv*) Using Hershfield's K_m curve based upon world record rainfall data (curve No. II of Fig. 4) one-day PMP values have been worked out for some 20 representative plain-area stations in north India and the same are shown in Table 4.

It is seen that PMP values based upon Hershfield curve, give quite high values of PMP for most of the stations when compared to the values obtained from the generalized charts at Figs. 2 to 4 of this paper.

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