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A Pilot study for the estimation of probable maximum precipitation using Hershfield Technique

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ABSTRACT. Statistical technique developed by Hershfield has been used in this note to determine one-day PMP estimates for the plain areas of Uttar Pradesh. Extreme annual one-day rainfall data was collected for 230 stations in this region from the scrutiny of daily rainfall data of 60 to 70 years from 1891 to 1960. The enveloping value for the frequency factor *Km* in the modified Chow's general formula was found to be 12 for this region. This value was utilized in obtaining PMP values for 230 stations in this region. On the basis of this data a generalized chart of PMP was prepared for the plain areas of Uttar Pradesh for one-day duration. It has been seen that on an average in this region one-day PMP values obtained by this technique are 2·4 times the highest observed one-day rainfall during the past 60 to 70 years.

1. Introduction

U. S. Weather Bureau have developed, since 1947, procedures for the estimation of probable maximum precipitation (hereafter referred as PMP). PMP has been defined as the greatest depth of precipitation for a given duration that is physically possible over a particular drainage area.

In this note an attempt has been made to utilize the Hershfield (1961) technique in order to derive one-day PMP values. Plain areas of Uttar Pradesh (U.P.) have been selected for ths pilot study as long-term rainfall data from 1891 are available for a large number of stations distributed uniformly over this region.

2. Hershfield technique

By this technique PMP for a station is derived by the statistical analysis of rainfall data. This approach is based on the assumption that the information regarding the extreme value of rainfall at a station is contained in the long rainfall records of that station. It is claimed that this method eliminates subjectivity, which is associated to some extent with the conventional method. The technique is briefly summarized here.

Hershfield used Chow's (1951) general formula for frequency analysis in develop;ng his technique. In Chow's general formula—

$$X_T = \overline{X} + \sigma K_T \qquad (1)$$

the extreme phenomenon, X_T corresponding to a return period of T years is a function of the mean $(\overline{X})$ of the observed extreme of N years, its standard deviation, σ and the ferquency factor K. The frequency factor K depends upon the return period T and its value for the extreme value distribution has been given by Chow (1953) as—

$$K_T = -1{\cdot}100 - 1{\cdot}795 \log_{10} \log_{10} (T/T-1) \qquad (2)$$

Hershfield used Chow's Eq. (1) in the form—

$$X_m = \overline{X} + \sigma K_m \qquad (3)$$

where X_m is the estimate of one-day PMP for a station, $\overline{X}$ is the mean of an array of extreme annual one-day rain amounts at that station and σ is the standard deviation of the series. In equation (3) K_m is determined in the following empirical manner :

The mean $(\overline{X})$ and the standard deviation (σ) of the series of annual extreme values for a station are first worked out neglecting the highest value of the series. Then the highest value of the series is substituted for X_m in Eq. (3) to obtain the value of K_m. In other words, the purpose is to obtain some future highest value of rainfall based upon all the present available values which obviously do not include the highest value. Hershfield calculated in this way K_m values for about 2650 stations (10 per cent of stations were from various parts of the world and 90 per cent from USA) whose data were available for a period ranging from 10 to 70 years (with about half exceeding 30 years). He obtained 15 (actual value 14·5) as the enveloping value for K_m and assumed the following formula for estimating PMP for one-day point rainfall—

$$X_{PMP} = \overline{X} + 15\,\sigma \qquad (4)$$

where X_{PMP} is the PMP point rainfall and $\overline{X}$ and σ are the mean and the standard deviation of the series of extreme annual rainfall values of a station for one-day duration.

3. Application of Hershfield technique

The plain areas of Uttar Pradesh (excluding the hilly areas of Dehra Dun, Nainital, Almorah, Garhwal, Tehri-Garhwal districts) whose total area is about 94000 sq. miles, was selected for this

TABLE 1

Number of stations with period of record from 1891 to 1960

Length of record available (years)	No. of Stations
70	202
69	9
68	3
67	3
66	2
64	1
63	2
62	1
60	7
Total	230

TABLE 2

Distribution of frequency factor K_m from records of one-day maximum point rainfall for 230 stations in the plain areas of U.P.

Range of K_m	Frequency
1·01 — 2·00	0
2·01 — 3·00	31
3·01 — 4·00	103
4·01 — 5·00	58
5·01 — 6·00	25
6·01 — 7·00	8
7·01 — 8·00	1
8·01 — 9·00	1
9·01 —10·00	1
10·01 —11·00	1
11·01 —12·00	1
Highest value of K_m	12·0

TABLE 3

Stations whose one-day PMP values were found to be 35 inches and more

Station	Highest one-day rainfall since 1891 (inch)	One-day PMP using K_m=12 (inch)
Maharajgang	17·31	36·14
Tarabganj	16·85	38·43
Hardoi	14·55	38·66
Pawayan	17·66	37·06
Nagina	19·25	37·08
Hardwar	14·00	37·42
Kathgodam	12·00	36·00

pilot study. Only those rainfall stations were considered whose daily data were available for a period of 60 to 70 years from 1891 to 1960. The number of such stations was found to be 230 and their period of availability of data is given in Table 1.

From the daily rainfall records, the highest one-day (24 hours ending at 0300 GMT) rain amount in each year for each station was picked up and in this way for each station an array of extreme annual values of rainfall was obtained. The mean and the standard deviation of each of these series were worked out, first with the largest rainfall omitted from the series and then with all the values in the series.

The values of mean (*i.e.*, $\overline{X}_{N-1}$) and standard deviation (*i.e.*, σ_{N-1}) with the largest value (say X_1) omitted from the series were then substituted in the equation (5)—

$$K_m = (X_1 - \overline{X}_{N-1})/\sigma_{N-1} \qquad (5)$$

to obtain the value of K_m. In this way 230 values of K_m were obtained for a network of 230 stations spread all over Uttar Pradesh (excluding hilly areas). Table 2 gives the frequency distribution of K_m values for 230 stations in U.P. The K_m value thus obtained were plotted on a map of U.P. region and it was seen that they were randomly distributed and did not show any relationship with the geography of any particular area in this region.

It is seen from Table 2 that the enveloping value of K_m for this region is 12 and not 15 as obtained by Hershfield on the basis of his study of USA and other world rainfall data. In a similar study for Puerto Rico (US Weath. Bur. 1961) the highest value of K_m was found to be less than 9 on the basis of rainfall data of 89 stations. Mazumdar and Rangarajan (1966) from their study have found that Hershfield's enveloping value for K_m (*i.e.*, 15·0) gives too high a value of PMP. They have, therefore, suggested that PMP values for any area should be based upon the regional envelope value of K_m instead of the world envelope value. Wilson (1963) has also expressed doubts about the universal transpossibility of the K_m factor 15. In view of this, the regional envelope value of K_m (*i.e.*, 12·0) obtained in this study has been used for determining PMP values of individual stations. It has, however, been found that for a data of 70-year period, K_m =12·0 corresponds to a return period of about 10^6 years while the Hershfield's envelope value of K_m =15 corresponds to about 10^7 years (Hershfield 1961).

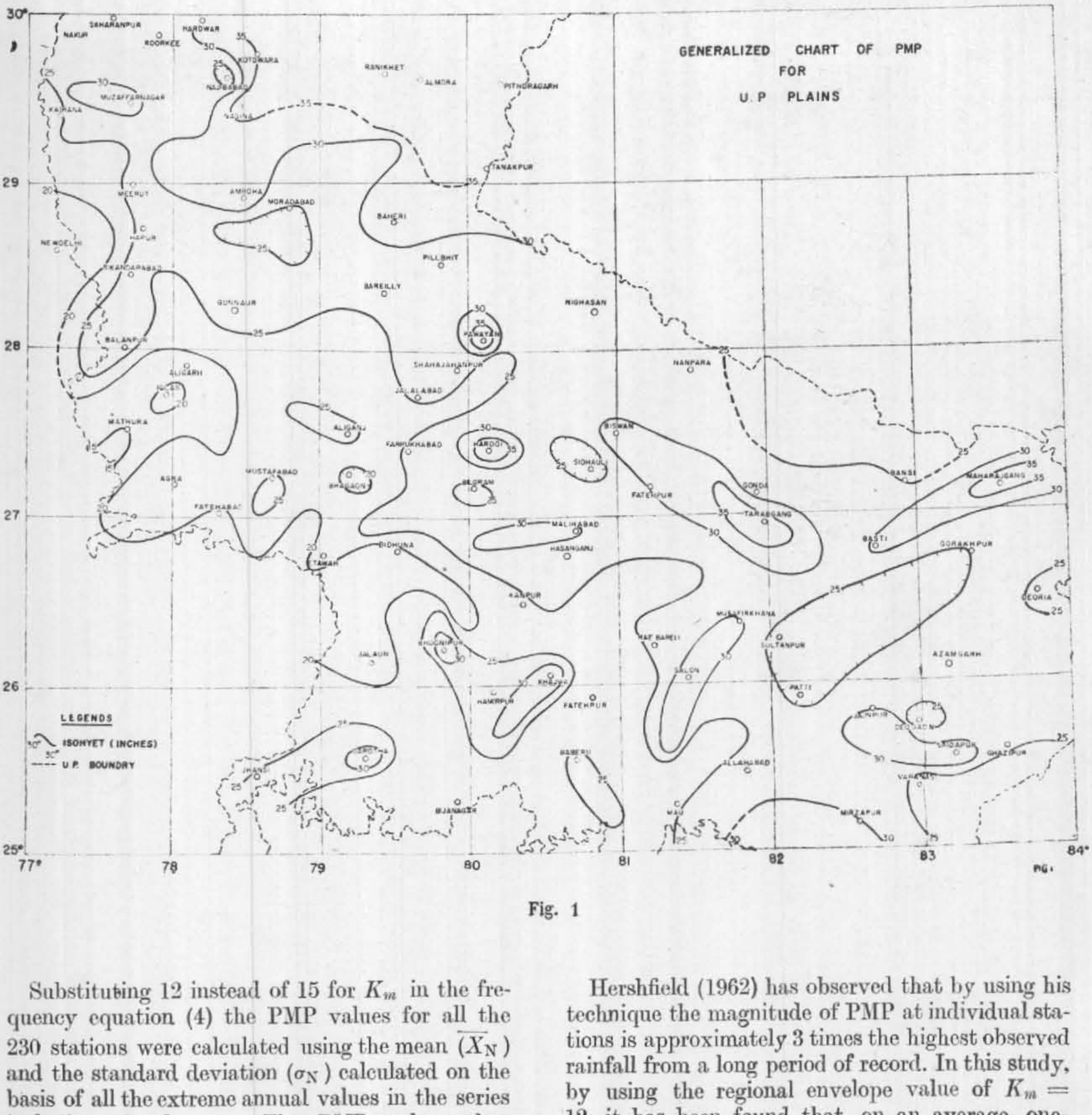

Fig. 1

Substituting 12 instead of 15 for K_m in the frequency equation (4) the PMP values for all the 230 stations were calculated using the mean $(\overline{X}_N)$ and the standard deviation (σ_N) calculated on the basis of all the extreme annual values in the series including the largest. The PMP values thus obtained for each station were then plotted on a base map of U.P. and the generalized chart of one-day PMP is prepared and shown in Fig. 1. It is seen from Fig. 1 that excepting some isolated areas in the southwest, extreme southeast and northern portions of Gonda and Basti districts the rest of U.P. is practically covered with PMP values of 25 inches and above. Further examination of this map shows that there are small areas in the eastern as well as in the northwestern U.P. close to the foot hills of the Himalayas which have PMP values greater than 30 inches. Stations whose one-day PMP values were found to be of the order of 35 inches and above are listed in Table 3.

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Hershfield (1962) has observed that by using his technique the magnitude of PMP at individual stations is approximately 3 times the highest observed rainfall from a long period of record. In this study, by using the regional envelope value of $K_m = 12$, it has been found that, on an average, one-day PMP is 2·4 times the highest one-day observed rainfall during 60 to 70-year period of record. At individual stations the ratios, however, vary from 1·7 to 3·4. The PMP values derived in this note will be useful in checking the values of PMP obtained by conventional methods in this region. They will also be helpful to the design engineer for making preliminary estimates of probable maximum flood, especially for those small-basins where point rainfall itself practically represents the basin average rainfall.

The PMP values derived are based upon observational-day rain amounts and conversion into 24-hour PMP rain depths may, however, be carried out by the use of empirical factors derived in USWB Technical Report (U.S. Weath. Bur. 1961) or by the procedures given by Wisler and Brater (1959). Similar studies regarding determination of regional enveloping values of K_m for other meteorologically homogenous divisions of this country for various durations, are in progress.

4. Conclusion

From the foreoging the following can be broadly concluded —

1. A regional enveloping values of K_m in the frequency formula $X_{PMP} = \overline{X} + K_m \sigma$ for the U.P. plains region was found to be equal to 12.
2. With the help of this value of K_m one-day PMP values were worked out for 230 stations whose rainfall data are available for the last 60 to 70 years. The generalised chart of one day PMP for U.P. plains (Fig. 1) may be used for preparing tentative estimates of PMP for small basins in this region.
3. The average ratio of one-day PMP to observed one-day highest rainfall for the region was found to be of the order of 2·4. This ratio varies in this region for individual stations from 1·7 to 3·5.
4. The highest estimate of one-day PMP at a station in this region was found to be of the order of 38·70 inches at Hardoi. The highest observed one-day rainfall of 20·30 inches was recorded at Khajwa (District Fatehpur) during the 66-year period from 1895 to 1960. The highest value of $K_m = 12$ was obtained for Hasanganj (Unnao District) which is located in the centre of the region. The PMP value for this station was, however, found to be of the order of 27 inches only.
5. Barring a few isolated areas in southwest, southeast and northeast, the rest of U.P. region is covered with PMP values of 25 inches and above.
6. It has been found that for a data of 70-year period, $K_m = 12$ corresponds to about 10^6-year return period.

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