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Estimation of maximum one-day rainfall for different return periods in Uttar Pradesh

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ABSTRACT. The absence of generalized charts of maximum rainfall for different durations and return periods required for the design of small hydraulic structures is greatly felt by the design engineers in this country. The present study is one such attempt in that direction. In this study simple spatial relationships for one-day rainfall have been developed for the plains of Uttar Pradesh with the help of which point rainfall magnitudes for different return periods can be determined using the 2-year return period values. For the hilly regions of west Uttar Pradesh the magnitudes of one-day rainfall for different return periods have been worked out in respect of only those stations whose rainfall data are continuously available for 60 to 70 years from 1891. It was observed that average ratios of partial-duration series to annual series are almost identical with those obtained in USA.

1. Introduction

Intense rainstorm data is the principal factor required in the design of small hydraulic structures such as culverts, highway bridges, urban drainage works etc. In order to provide adequate waterways for such type of structures, the design engineer estimates the design flood of a specific return period from the severe rainstorm data. Comprehensive studies of frequency and duration of severe rainstorms are, therefore, an essential pre-requisite for the design of small hydraulic structures.

In India Iyer and Zafar (1938) were the first to study in a systematic manner the distribution of heavy rainfall. They prepared generalized charts showing the distribution of observational day (hereafter referred to as one-day) rainfall above certain magnitudes based upon the data of the period 1891 to 1920. In recent years Rao (1959) and Parthasarathy (1959) studied the frequency distribution of one-day rainfall of 10 inches and above. Krishnan *et al.* (1959) using the daily data of 150 observatory stations throughout the country studied maximum one-day rainfall for various return periods using Jenkinson's (1955) probability method. Parthasarathy and Singh (1961) while examining the short duration rainfall intensity-frequency regime of the country prepared a 2-year one-day rainfall map of India based upon the data of about 40 recorder stations.

In the present study an attempt has been made to study the maximum one-day rainfall for different return periods from 2 to 100 years for the Uttar Pradesh region (hereafter referred to as U.P.) using 60 to 70 years' daily rainfall data of about 250 stations. Suitable spatial relationships have been developed for the plain areas of U.P. , with the help of which maximum one-day rain amounts can be estimated for the standard return periods of 5, 10, 25, 50 and 100 years. For the hill areas of west U.P. due to high variability of rainfall and lack of dense network of rainfall stations, it has not been considered proper to develop spatial relationships. However, maximum one-day rain amounts for different return periods have been worked out for individual stations in this region which have a continuous rainfall record of 60 to 70 years from 1891.

2. Network of rainfall stations

In order to maintain homogenity in the basic data, 70-year period from 1891 to 1960 was selected for this study. Out of the total existing network of about 320 rainfall stations (total area of U.P.= 1,13,600 sq. miles) only those stations were considered whose daily rainfall data are continuously available for a period of 60 to 70 years from 1891. The number of such stations was found to be about 250 (Table 1).

The relationships worked out in this paper are based upon the observational-day rainfall data (*i.e.*, from 0830 IST of date to 0830 IST of next day). If, however, maximum 24-hour rainfall amounts for different return periods are desired, the same can be obtained by multiplying the magnitudes obtained in this study by a suitable conversion factor. Hershfield and Wilson (1957) have worked out an average factor of 1·13 on the basis of US data. No such average factor

TABLE 1

Number of rainfall stations in U.P. with periods of data from 1891 to 1960

Period of record (years)	No. of stations in U.P. plains (Area 94,000 sq. miles)	No. of station in West U.P. hills (Area 19,600 sq. miles)	Total	Remarks
70	202	1	203	At present there are about 323 rainfall stations in the whole of U.P. whose total area is about 1,13,600 sq. miles
69	6	9	15	
68	3	1	4	
67	4	8	12	
66	2	1	3	
63	2	3	5	
61	0	1	1	
60	7	0	7	
Total	226	24	250	

has so far been worked out on the basis of Indian data. Recently while studying the short duration rainfall data of Calcutta, Dhar and Ramachandran (1969) have found this factor to be of the order of 1·11 for that station. However, similar studies have to be carried out for a large number of rainfall recording stations in the country for obtaining an average conversion factor.

3. Frequency analysis of rainfall data

U.S. Weather Bureau (Hershfield and Kohler 1960) after testing various methods of frequency analysis, have found Gumbel's (1941) extreme value method quite satisfactory for predicting the probability of occurrence of extreme values of rainfall. This has also been the experience of Reich (1963) while studying the rainfall intensity-frequency regime of South Africa.

In this study, Gumbel's (1941) extreme value distribution as adopted by Chow (1953, 1964) has been used in the analysis of daily rainfall data. For this distribution (Chow 1951) —

$$Y_T = \overline{Y} + K_T\,\sigma \qquad (1)$$

where,

Y = any variable subject to frequency analysis

Y_T = magnitude of Y for the return period of T years,

$\overline{Y}$ = mean value of Y,

σ = standard deviation of Y, and

$$K_T = -[1\cdot100 + 1\cdot795 \log_{10} \log_{10} (T/T-1)] \qquad (2)$$

For each observed extreme annual value of rainfall the corresponding value of K_M was determined using the formula $T=(N+1)/m$, where N is the total number of years of record and m is the rank number when N values are arranged in a descending order of magnitude. A theoretical straight line was then fitted to the data by the method of least squares.

The above procedure was followed in respect of each of the 250 stations and maximum one-day rainfall statistics for the return periods of 2, 5, 10, 25, 50 and 100 years were then obtained for each station.

4. Relation between annual and partial duration series

Langbein (1949) has shown that by using annual series data smaller values are obtained for return periods up to 10 years. It has, therefore, been the practice to use partial-duration values only up to 10-year return period as beyond this period both series are supposed to give almost identical values.

Since processing the partial-duration data is enormously laborious when compared to processing the annual series data, Hershfield and Wilson (1957) have derived average conversion factors on the basis of a selected sample of about 50 rainfall stations spread all over U.S.A. This procedure has been followed in the present study as conversion factors based on the Indian rainfall data are not available.

Out of 203 rainfall stations in U.P. for which 70 years' data are available, 48 stations (roughly one station for each district of U.P.) were selected for this purpose and their partial-duration data was compiled by going through the daily rainfall records. Using Chow's (1953) technique, partial duration values were then worked out for the return periods of 2, 5 and 10 years for each of the selected 48 stations. Ratios of partial duration to annual series were then worked out for each of these stations for return periods of 2, 5 and 10 years. Table 2 gives the average ratios for different return periods in the U.P. region along with similar ratios worked out in U.S.A. etc. It is evident from this table that ratios for one-day rainfall for U.P. region are almost identical with those found empirically in U.S.A. Huff and Neill (1959) have, however, observed that these ratios decrease slightly with increasing duration of storm rainfall.

TABLE 2

Average ratios of partial-duration to annual series

Return periods (Years)	Ratios obtained for U.P. region	U.S. Weather Bureau ratios (Hershfield & Wilson 1957)	Ratios for Illinois (Huff & Neill 1959)	Theoretical ratios (Chow 1953)
2-yr	1·13	1·13	1·13	1·21
5-yr	1·04	1·04	1·05	1·10
10-yr	1·02	1·01	1·01	1·05

The empirical ratios obtained in Table 2 for the U.P. region were then utilised to convert the annual series values (obtained earlier for 250 stations) into partial duration values in order to obtain more appropriate rainfall magnitudes. All the rainfall values mentioned hereafter for the lower return periods of 2, 5 and 10 years pertain to partial-duration series.

5. Maximum one-day rainfall estimates for different return periods for the plain areas of U.P.

The maximum one-day rainfall statistics was worked out by the Gumbel's method described earlier for 226 stations located in the U.P. plains for return periods of 2, 5, 10, 25, 50 and 100 years. This data was then utilised for the preparation of the following spatial relationships with a view to obtain maximum one-day rain intensity frequency regime for the U.P. plains.

Generalized chart of 2-year one-day rainfall — The 2-year values of maximum one-day rainfall (after conversion into partial-duration series) were plotted on a base map of the area and smooth isopleths of rainfall were drawn (Fig. 1). While drawing the isopleths more reliance was put on stations with 70-year data than on stations with data of less number of years.

Ratio of 100 to 2-year rainfall — Ratios of 100 to 2-year one-day rainfall were worked out for all the 226 stations in the U.P. plains. These ratios were then plotted on a base map of the area and it was noticed that they were randomly distributed and did not exhibit any marked zonal effect. Considering a district as the smallest unit of area which is meteorologically homogeneous, average ratios were then worked out for all the 45 districts in the U.P. plains. These ratios are given district-wise in Table 3. Taking plain areas of U.P. as a whole, average ratio was also calculated

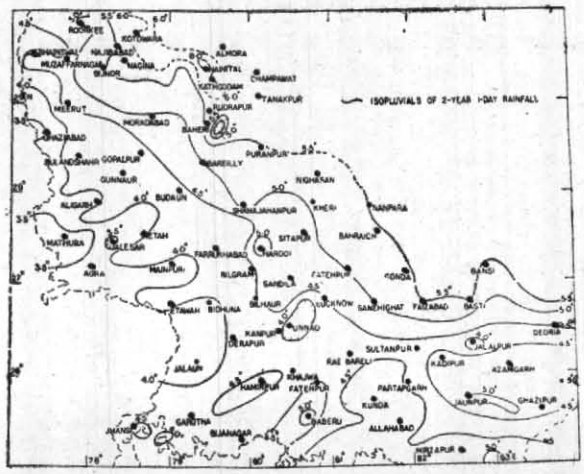

Fig. 1. Generalised Chart of Max. 2-year, 1-day rainfall for U.P. Plains

which is given below along with the highest and lowest values.

Type of ratio	*Ratio of 100 to 2-year max. one-day rainfall*
Average	2·27
Highest	2·45
Lowest	2·00

Hershfield and Wilson (1957) have worked out the average ratio for U.S.A. and has found it to be of the order of 2·2 while in the *Guide for Hydrometeorological Practices* (WMO 1965), 2·5 has been suggested as the optimum value for obtaining 100-year estimate from 2-year value. Mazumdar and Rangarajan (1966) have worked out similar ratios for areal rainfall in east U.P. and have found that these ratios do not significantly change with increase in areas.

Another simple method of deriving 100-year rainfall (X_{100}) from the mean ($\bar{X}$) and standard deviation (σ) of annual series has been given by Hershfield (1961) by using the relationship,

$$X_{100} = \bar{X} + 3 \cdot 5 \, \sigma \tag{3}$$

The above relationship was tested with the data obtained by Gumbel method for U.P. stations and it was found that this formula gives better estimates of 100-year rainfall if the factor 3·35 is used in place of 3·50 in Eq. (3).

Frequency interpolation nomogram — The technique given in U.S. weather Bureau *Technical Papers* (1959, 1961) was followed in constructing a

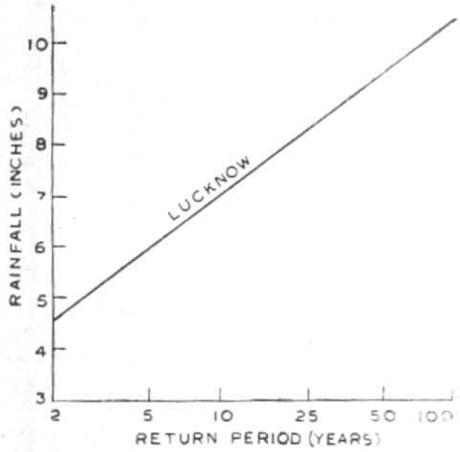

Fig. 2. Return-period interpolation diagram

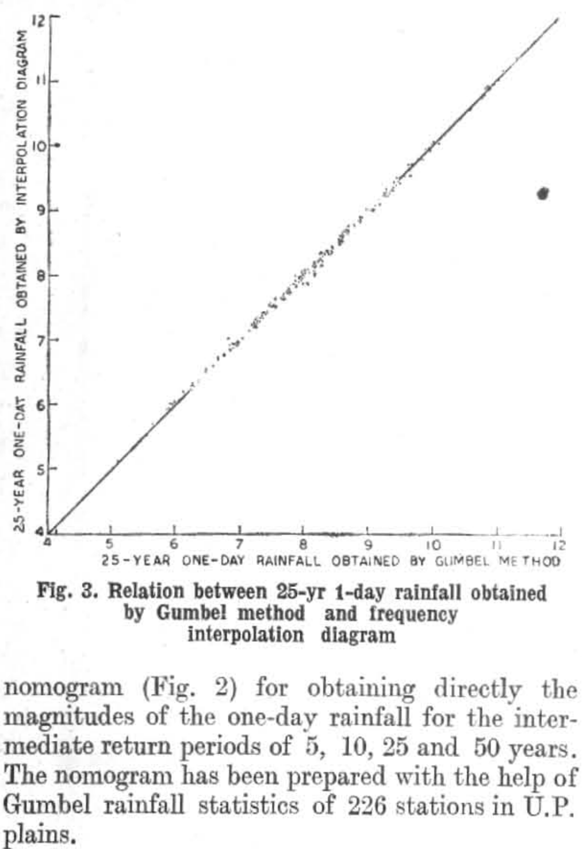

Fig. 3. Relation between 25-yr 1-day rainfall obtained by Gumbel method and frequency interpolation diagram

nomogram (Fig. 2) for obtaining directly the magnitudes of the one-day rainfall for the intermediate return periods of 5, 10, 25 and 50 years. The nomogram has been prepared with the help of Gumbel rainfall statistics of 226 stations in U.P. plains.

The magnitudes of 5, 10, 25 and 50-year rainfall for any station in U.P. plains can be determined by plotting the 2 and 100-year values (obtained by any of the methods mentioned earlier) on the corresponding 2 and 100-year vertical intercepts of the nomogram. The two points are then joined by a straight line and the points of intersection of the straight line with 5, 10, 25 and 50-year vertical intercepts give the magnitudes of one-day rainfall for these return periods.

In recent years U.S. Weather Bureau has adopted this approach for the preparation of generalised charts of maximum rainfall for different return periods and durations (USWB 1963, 1964, 1965). The use of the nomogram for the estimation of rainfall magnitudes for different return periods is described here.

An example of estimation of maximum one-day rainfall—Let us suppose that 50-year one-day rainfall is desired for designing a certain structure near Lucknow. To supply this information we require (*i*) 2-year one-day rainfall, (*ii*) 100-year one-day rainfall and (*iii*) frequency interpolation nomogram for this region.

Maximum 2-year one-day rainfall for Lucknow can be picked up by examining the generalised 2-year rainfall map of U.P. at Fig. 1. It is seen from this map that 2-year one-day value for this station is about 4·5 inches. The average ratio of 100 to 2-year rainfall for Lucknow district is 2·34 from Table 3. Multiplying the 2-year value with this ratio, we obtain 100-year value which is of the order of 10·50 inches. The 2 and 100-year values thus obtained are plotted on the corresponding vertical intercepts of the nomogram (Fig. 2) and a straight edge is laid across these values. The 50-year return period rainfall is then read off at the intersection of the straight-edge with the 50-year intercept and the value thus obtained is 9·50 inches. If the rainfall values of these three return periods (*i.e.*, 2, 50 and 100 years), after converting the 2-year value into annual series, are plotted on a Gumbel probability paper it will be noticed that all these points very nearly lie on a straight line, as it should be.

The rainfall values obtained by the above method for about 200 stations were compared with those obtained directly by the Gumbel method and it was observed that for most of the stations the values tallied within $\pm$ 3 per cent. This is easily verified in Fig. 3 which shows the relationship between the values obtained by the above two methods for a return period of 25 years.

6. Maximum one-day rainfall for west U.P. hill stations

From Table 1 it is seen that there are 24 stations in the hill areas of west U.P. for which long period rainfall data are available from 1891. The rainfall data of these 24 stations were analysed by the Gumbel frequency method as described earlier. The magnitudes of one-day rainfall thus obtained for return periods of 2, 5, 10, 25, 50 and 100 years are given in Table 4; the 2, 5 and 10-year values, however, refer to partial-duration series. Average

TABLE 3

Average ratios of 100 to 2-yr rainfall for districts in U.P. Plains

District	No. of stations n each district	Average ratios	District	No. of stations in each district	Average ratios
Agra	8	2·38	Hamirpur	8	2·22
Allahabad	8	2·36	Hardoi	4	2·26
Aligarh	7	2·21	Jalaun	4	2·15
Azamgarh	5	2·23	Jaunpur	4	2·45
Ballia	3	2·00	Jhansi	9	2·36
Bulandshahr	5	2·45	Kheri	3	2·11
Bijnor	4	2·13	Kanpur	6	2·38
Banda	8	2·15	Lucknow	3	2·34
Banaras	2	2·14	Mainpuri	7	2·25
Barabanki	4	2·21	Moradabad	6	2·21
Bahraich	3	2·19	Meerut	6	2·27
Bareilly	8	2·30	Mirzapur	3	2·25
Basti	5	2·09	Mathura	7	2·28
Budaun	5	2·36	Muzaffarnagar	6	2·43
Deoria	3	2·10	Pilibhit	4	2·13
Etah	4	2·29	Pratapgarh	3	2·21
Etawah	4	2·13	Rae-Bareli	4	2·40
Farrukhabad	5	2·38	Shahjahanpur	4	2·25
Fatehpur	3	2·30	Sultanpur	4	2·27
Faizabad	5	2·22	Saharanpur	10	2·38
Gonda	3	2·16	Sitapur	4	2·22
Gorakhpur	3	2·17	Unnao	4	2·40
Ghazipur	4	2·23			

ratios of n-year to 2-year rainfall for each hill district have also been calculated and same are shown in Table 5. These ratios, however, cannot fully represent each and every point in the hilly districts owing to highly rugged terrain of the region and therefore, have to be used with great caution.

The average ratios mentioned above can be helpful in obtaining preliminary estimates of maximum one-day rainfall for different return periods for any station in the four hill districts of west U.P. provided the 2-year one-day rainfall for that station is known. To illustrate this point let us suppose that one-day rainfall estimate for a 25-year return period is required for a station in Almora district whose rainfall data are available for the last 20 years or so. On the basis of its available data, 2-year value may be obtained by the annual series method. This value may be converted into a partial-duration series by using the conversion factor 1·13 (*vide* Table 2) or by using the partial duration series directly. The 2-year value thus obtained may be multiplied by the appropriate district average ratio from Table 5 (*i.e.*, by 1·77 in the present case) to obtain 25-year one-day rainfall for that station.

7. Observed highest one-day rainfall

Stations which received rain amounts of 15 inches or more in one-day during the period 1891 to 1960 have been shown in Table 6. It is seen that the highest one-day point rainfall has been of the order of 20 inches in this region. Return periods of the highest observed one-day rain amounts for each of these stations were also shown in the above table. It is seen that some of the stations have recorded heavy falls of rain in the past whose return periods have been found to be

TABLE 4

Magnitude of one-day rainfall for hill stations in West U.P.

Station	District	Rainfall magnitudes (inches) for the return periods of					
		2-yr*	5-yr*	10-yr*	25-yr	50-yr	100-yr
Almora	Almora	3·58	4·72	5·56	6·60	7·46	8·30
Ambari	Dehra Dun	6·26	7·88	9·11	10·63	11·90	13·15
Berinag	Almora	4·47	5·35	6·05	6·92	7·65	8·38
Bhogpur	Dehra Dun	7·02	8·74	10·06	11·70	13·06	14·42
Bironkhal	Garhwal	3·87	5·68	6·95	8·51	9·77	11·03
Chakrata	Dehra Dun	4·56	5·78	6·69	7·83	8·78	9·71
Champawat	Almora	5·08	6·90	8·21	9·84	11·16	12·48
Chaukuri	Almora	4·71	6·16	7·23	8·56	9·65	10·74
Dehra Dun	Dehra Dun	6·16	7·59	8·86	10·53	11·92	13·31
Joshimath	Garhwal	2·59	3·58	4·29	5·17	5·89	6·60
Karnaprayag	Garhwal	3·81	4·91	5·72	6·74	7·58	8·41
Kashipur	Nainital	5·77	7·64	9·01	10·71	12·10	13·48
Kathgodam	Nainital	5·74	7·74	9·18	10·97	12·43	13·88
Lansdowne	Garhwal	5·47	7·76	9·38	11·39	13·02	14·64
Nagla	Nainital	5·00	7·33	8·96	10·97	12·60	14·21
Nainital	Nainital	8·59	10·89	12·61	14·76	16·54	18·30
Okhimath	Garhwal	4·09	5·25	6·11	7·19	8·07	8·95
Pauri	Garhwal	3·51	4·39	5·05	5·88	6·57	7·26
Pithoragarh	Almora	3·59	4·63	5·41	6·37	7·17	7·95
Raipur	Dehra Dun	5·80	7·51	8·77	10·35	11·64	12·93
Rajpur	Dehra Dun	8·17	10·09	11·57	13·41	14·95	16·49
Ranikhet	Almora	4·03	5·17	6·02	7·08	7·95	8·82
Rudrapur	Nainital	5·67	7·26	8·45	9·93	11·15	12·36
Srinanar	Garhwal	3·12	3·85	4·42	5·11	5·70	6·28

*Refers to partial-duration series

of the order of hundreds and even thousands of years. Lockwood (1967) has also experienced similar return periods for some of the stations in Malaya on the basis of 20-year data. Probable maximum precipitation (PMP) study for this region (Dhar and Kamte 1969) using Hershfield technique (1961), has shown that the highest one-day PMP can be of the order of 38 inches.

8. Summary

Simple relationships have been developed for the estimation of maximum one-day rainfall for different return periods in plain areas of Uttar Pradesh. Knowing 2-year rainfall for a station, which can be obtained from the generalised chart at Fig. 1 and knowing the district in which the station is located, estimates of maximum one-day

TABLE 5

Average ratios of n-year to 2-year rainfall for West U.P. hill districts

District	No. of stations considered	Average ratios of n-year to 2-year				
		5-yr	10-yr	25-yr	50-yr	100-yr
Almora	6	1·29	1·51	1·77	1·99	2·21
Dehra Dun	6	1·25	1·45	1·67	1·87	2·07
Garhwal	7	1·33	1·57	1·87	2·11	2·36
Nainital	5	1·45	1·58	1·92	2.17	2·43

TABLE 6

Stations in U.P. having one-day rainfall of 15 inches or more

Station	District	Highest one-day rainfall (inch)	Date	Return period of the highest observed rainfall (yr)
Basti	Basti	16·25	28 Sep 1930	1000
Bhognipur	Kanpur	17·99	31 Aug 1944	2000
Champawat	Almora	15·35	27 Sep 1897	590
Hasanganj	Unnao	16·24	1 Sep 1915	5000
Kaisarganj	Bahraich	16·85	25 Sep 1901	1110
Khajwa	Fatehpur	20·27	31 Aug 1915	5000
Lalitpur	Jhansi	15·12	10 Sep 1941	440
Maharajganj	Gorakhpur	17·31	28 Sep 1900	630
Meja	Allahabad	20·16	22 Jun 1916	5000
Muzaffarnagar	Muzaffarnagar	18·90	3 Jul 1956	3330
Nagina	Bijnor	19·25	10 Jul 1928	1430
Nainital	Nainital	15·70	24 Aug 1927	40
Pawayan	Shahjahanpur	17·66	1 Oct 1958	630
Saidpur	Ghazipur	16·89	29 Aug 1940	1110
Tarabganj	Gonda	16·85	25 Sep 1901	630

rainfall can be made for the return periods of 5 10, 25, 50, and 100 years with the help of Table 3 and frequency interpolation diagram at Fig. 2. For stations in hilly areas of west U.P., estimates of maximum rainfall for these return periods have also been worked out and are given in Table 4. Return periods of some outstanding rain amounts (15 inches and more in one-day) have also been presented in Table 6 in order to give an idea of frequency of such falls of rain at these stations.

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