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Influence of certain factors on rainfall frequency values

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ABSTRACT. Based on 84-year data of Calcutta, Delhi, Bombay and Madras, it has been found that to estimate the maximum one-day point rainfall for long return periods, more reliance is to be placed on stations with the longest records. For the error to be within ±25 per cent in about 80 per cent of cases, in the estimation of return period values, extrapolation may be made to five times the period of record and to ten times the period of record if the outliers are excluded from the series. Criteria to find the outliers have been suggested. Some evidence has been found to show that the return period values of rainfall of a station increase with increase in air pollution at that station.

1. Introduction

Precipitation-frequency estimates are often required for a variety of design purposes. There are a number of methods to find these estimates and to extrapolate heavy rainfall data beyond the range of observation, but perhaps most widely used is the Gumbel's (1954) extreme value technique using the method of least squares. The method is generally applied to the annual maximum series and the rainfall values so obtained are converted to the more realistic partial duration series by using suitable ratios.

The engineers often require to know the extent which extrapolation can be made in the Gumbel's method. Benson's (1960) analysis of an artificial series obeying Gumbel's rule supports the opinion of some engineers who believe that the experimental frequency curve must not be extrapolated beyond a return period greater than twice the duration of the observation period. Wolf (1965) pointed out that most hydrologists are prepared to permit extrapolation to perhaps four times the period of record. Murray(1969) stated that to estimate 50-year flood with sufficient accuracy, flood data for a continuous period of at least 20 years are to be taken.

It has been noticed by many workers that an outlier, an off shoot value, in an individual station record distorts the frequency analysis at that station. Miller (1965) has pointed out that in any record, even one as short as 10 years there is some possibility that the maximum event would have a return period of several hundred years. Rodda (1967) found fatuous results in cases in which the greatest fall was far in excess of the remainder of the annual maxima in the series. Dhar and Kulkarni (1971) also experienced similar difficulty while studying maximum one-day rainfall of stations in north India.

It is now well recognised that the heavy concentrations of air pollution found in towns and industrial areas have an effect on the local weather and climate. It is, therefore, possible that the return period values of rainfall of city areas may also be affected by urbanization, industrialization and traffic.

In the present paper an attempt has been made to study the influence of the above factors on the return period values of rainfall of a few stations in India.

2. Data

Four stations, Calcutta, Delhi, Bombay and Madras, have been selected for the present study because of the length and very high quality of their records. These are also the four international airports in India and are situated in areas where there is a concentration of the activities of the jet aircraft which are one of the possible sources of air pollution.

Daily rainfall data and annual rainfall of the above stations from 1891 are readily available in *Monthly Weather Reviews* and *Daily Weather Reports*. From these publications the maximum rainfall amounts on an observational-day for each year of record and annual rainfall for the above four stations from 1891 to 1974 (84 years) were extracted.

TABLE 1(a)

One-day maximum rainfall (mm) for different return periods for different periods of record (Figures in brackets below the rainfall values are percentage errors)

Return period (years)	Period of Record									
	84 years	42 years		28 years			21 years			
	(1891-1974)	(1891-1932)	(1933-1974)	(1891-1918)	(1919-1946)	(1947)-1974)	(1891-1911)	(1912-1932)	(1933-1953)	(1954) 1974)
CALCUTTA										
2	112·5	118·3 (+5)	108·1 (—4)	116·6 (+4)	118·7 (+5)	105·1 (—7)	119·5 (+6)	119·1 (+6)	111·4 (—1)	105·5 (—6)
5	160·7	182·1 (+13)	139·4 (—13)	189·5 (+18)	158·7 (—1)	138·4 (—14)	206·0 (+28)	161·6 (+1)	142·6 (—11)	139·3 (—13)
10	192·6	224·4 (+17)	160·1 (—17)	237·8 (+23)	185·3 (—4)	160·5 (—17)	263·3 (+37)	189·7 (—1)	163·2 (—15)	161·7 (—16)
25	233·0	277·7 (+19)	186·2 (—20)	298·8 (+28)	218·8 (—6)	188·4 (—19)	335·7 (+44)	225·3 (—3)	189·2 (—19)	189·9 (—19)
50	262·9	317·3 (+21)	205·6 (—22)	344·1 (+31)	243·6 (—7)	209·1 (—21)	389·4 (+48)	251·6 (—4)	208·6 (—21)	210·9 (—20)
100	292·5	356·7 (+22)	224·9 (—23)	389·0 (+33)	268·3 (—8)	229·6 (—21)	442·7 (+51)	277·8 (—5)	227·8 (—22)	231·7 (—21)
Average annual rainfall (cm)	160·2	159·8	160·5	159·8	160·7	160·0	155·2	164·4	160·6	160·4
NEW DELHI										
2	94·5	89·3 (—5)	100·3 (+6)	88·0 (—7)	92·7 (—2)	104·4 (+11)	85·8 (—9)	93·5 (—1)	94·2 (—0)	107·5 (+14)
5	139·5	131·8 (—5)	150·2 (+8)	132·5 (—5)	141·1 (+1)	154·4 (+11)	133·2 (—5)	136·4 (—2)	144·0 (+3)	162·7 (+17)
10	169·3	159·9 (—6)	183·2 (+8)	162·0 (—4)	173·1 (+2)	187·4 (+11)	164·6 (—3)	164·8 (—3)	176·9 (+5)	199·2 (+18)
25	207·0	195·4 (—6)	224·9 (+9)	199·3 (—4)	213·6 (+3)	229·2 (+11)	204·3 (—1)	200·6 (—3)	218·6 (+6)	245·3 (+19)
50	234·9	221·8 (—6)	255·8 (+9)	226·9 (—3)	243·6 (+4)	260·2 (+11)	233·7 (—1)	227·2 (—3)	249·5 (+6)	279·5 (+19)
100	262·7	247·9 (—6)	286·5 (+9)	254·3 (—3)	273·4 (+4)	290·9 (+11)	263·0 (+0)	253·6 (—3)	280·1 (+7)	313·5 (+19)
Average annual rainfalll (cm)	69·7	64·8	74·7	68·0	64·8	76·3	68·7	60·8	70·1	79·2
BOMBAY										
2	175·4	166·9 (—5)	185·1 (+5)	148·2 (—15)	184·5 (+5)	198·5 (+13)	140·9 (—20)	196·6 (+12)	173·2 (—1)	199·1 (+13)
5	252·3	241·1 (—4)	268·4 (+6)	196·9 (—22)	266·4 (+6)	297·1 (+18)	191·5 (—24)	286·0 (+13)	243·0 (—4)	300·6 (+19)
10	303·1	290·2 (—4)	323·6 (+7)	229·2 (—24)	320·6 (+6)	362·4 (+19)	225·1 (—26)	345·1 (+14)	289·2 (—5)	367·8 (+21)
25	367·5	352·3 (—4)	393·3 (+7)	269·9 (—27)	389·1 (+6)	444·9 (+21)	267·4 (—27)	419·9 (+14)	347·6 (—5)	452·7 (+23)
50	415·1	398·3 (—4)	445·0 (+7)	300·2 (—28)	439·9 (+6)	506·1 (+22)	298·8 (—28)	475·3 (+15)	390·9 (—6)	515·7 (+24)
100	462·5	444·1 (—4)	496·3 (+7)	330·2 (—29)	490·4 (+6)	566·8 (+23)	330·0 (—29)	530·3 (+15)	433·9 (—6)	578·2 (+25)
Average annual rainfall (cm)	189·5	177·1	202·0	174·9	179·9	213·9	172·0	182·1	184·9	219·1
MADRAS										
2	125·8	128·3 (+2)	123·8 (—2)	129·6 (+3)	126·3 (+0)	122·8 (—2)	121·1 (—3)	136·5 (+9)	121·0 (—4)	127·3 (+1)
5	169·4	175·7 (+4)	167·0 (—1)	180·7 (+7)	172·3 (+2)	166·2 (—2)	173·3 (+2)	183·5 (+8)	168·4 (—1)	171·8 (+1)
10	198·2	207·1 (+5)	195·5 (—1)	214·5 (+8)	202·8 (+2)	195·0 (—2)	207·9 (+5)	214·7 (+8)	199·8 (+1)	201·2 (+1)
25	234·7	246·8 (+5)	231·7 (—1)	257·3 (+10)	241·3 (+3)	231·3 (—1)	251·6 (+7)	254·1 (+8)	239·4 (+2)	238·4 (+2)
50	261·7	276·2 (+5)	258·4 (—1)	289·0 (+10)	269·9 (+3)	258·2 (—1)	284·0 (+9)	283·3 (+8)	268·9 (+3)	265·9 (+2)
100	288·6	305·4 (+6)	285·0 (—1)	320·5 (+11)	298·3 (+3)	284·9 (—1)	316·2 (+10)	312·3 (+8)	298·1 (+3)	293·3 (+2)
Average annual rainfall (cm)	125·9	128·8	123·0	126·3	131·9	119·4	111·9	137·5	117·7	128·4

3. Method and analysis

From the above data, annual maximum series for each station, for different periods of record, were obtained and treated by Gumbel's (1954) extreme value technique using the method of least squares and maximum rainfall estimates for different return periods were computed. The estimates based upon short periods of record were compared with those of 84 years record and percentage errors were calculated. The results are given in Table 1. Average annual rainfall for each period of record are also given in that table.

The annual maximum series were examined to see if there were any outliers in them. An outlier is the greatest value which is far in excess of the remaining values in the series. Its return period is much more than the period of record. Dhar and Kulkarni (1971) found that whenever the difference was of the order of 3 inches or more between the highest and next highest values in the annual series, fatuous results were obtained. In the present study, after a number of trial analysis, it was found that when the difference between the highest and next value was of the order of 18 per cent or more of the highest ever recorded value and when the return period of the highest value was of the order of 3 times or more of the period of record, the errors in frequency values exceeded ± 25 per cent in atleast about 20 per cent of cases of records of not less than 10 years. If the period of record is short, the highest ever recorded value of some nearby station with long period of record may be taken. The return period of the highest value is to be found after excluding it from the series. In some cases where the difference between the second and the third highest values in the series is large enough to satisfy the above conditions, both the first and second highest values may be taken to be the outliers. After omitting all such outliers, the series were again analysed and the results which have changed from those in Table 1, are given in Table 2.

The maximum percentage errors for different return periods and different lengths of record were found from Table 1 and Table 2 and are shown in Table 3. Percentage number of cases in which the errors are within ± 25 per cent were also found from Table 1 and Table 2 and are shown in Table. 4

4. Results

It is seen from Table 3 that the error increases as the length of record decreases. The error also increases as the return period increases. The standard error of rainfall estimated by Gumbel's method is approximately given by

$$\sigma_x = \frac{1}{a}\left(\frac{T_x}{n}\right)^{1/2} \qquad (1)$$

where T_x is the return period of rainfall of magnitude x within the probability range of 0·15 to 0·85, $\frac{1}{\alpha}$ is equal to 0·7797 times the standard deviation of the extremes x and n is the total years of record. This also shows that the error (σ_x) will be more if the length of record (n) is less and return period (T_x) is more.

From Table 3 it is also seen that the error becomes less, about half for higher return periods, if outliers are omitted from the analysis. Table 4 shows that for error to be within ± 25 per cent in about 80 per cent of cases, for say 100-year return period, the length of record necessary will be about 20 years with outliers included in analysis and only 10 years if the outliers are excluded from the analysis. The number of cases for each period of record, as seen from Table 4, is not sufficient to draw very reliable conclusions, but the results indicate that for the error to be within ± 25 per cent in about 80 per cent of cases, the extrapolation may be made to five times the period of record and even to ten times the period of record if the outliers are omitted from the analysis.

Increase in return period values from one period to the other in case of the two 42—year periods (1891-32 and 1933-74) and the three 28-year periods (1891-18, 1919-46 and 1947-74) for Delhi and Bombay could be seen from Table 1. Recent studies have shown that the air in these cities is seriously contaminated, but the exact pollution levels at these cities from period to period is not known. However, it may be safely assumed that the air pollution over these cities is gradually increasing due to more and more urbanization, industrialization, traffic etc and the increase in return period values for the two 42-year periods and the three 28-year periods for Delhi and Bombay may be due to increase in air pollution over these cities.

Except for the two cases mentioned above, no other systematic variation in return period values from period to period could be found. As there may be sampling errors in the estimation of return period values, in place of these values average annual rainfall for different periods may be considered. In fact a linear relationship has been found between the maximum one-day rainfall values of different return periods and the corresponding mean annual rainfall by Rodda (1967) and Dhar and Kulkarni (1971). It is seen from Table 1 that the average annual rainfall for the 42-year period (1933-74) is more than that for the previous 42-year period (1891-32) for Calcutta, Delhi and Bombay. As already seen, for Delhi and Bombay the return period values for the 42-year period (1933-74) are also more than for the period (1891-32.)

TABLE 1(b)

One-day maximum rainfall (mm) for different return periods for 10-year record
(Figures in brackets below the rainfall value are percentage errors)

Return period (years)	10 years							
	1895-1904)	(1905-1914)	(1915-1924)	(1925-1934)	(1935-1944)	(1945-1954)	(1955-1964)	(1965-1974)
				CALCUTTA				
2	120·8	131·4	125·6	112·9	113·0	108·8	111·0	103·5
	(+7)	(+17)	(+12)	(+0)	(+0)	(−3)	(−1)	(−8)
5	214·1	215·8	180·6	151·6	140·6	148·7	152·7	136·2
	(+33)	(+34)	(+12)	(−6)	(−13)	(−7)	(−5)	(−15)
10	275·9	271·7	217·0	177·3	158·8	175·1	180·3	157·7
	(+44)	(+44)	(+13)	(−8)	(−17)	(−9)	(−6)	(−18)
25	354·0	342·3	263·1	209·7	181·9	208·5	215·1	185·0
	(+52)	(+47)	(+13)	(−10)	(−22)	(−11)	(−8)	(−21)
50	411·9	394·6	297·3	233·8	199·0	233·3	241·0	205·3
	(+57)	(+50)	(+13)	(−11)	(−24)	(−11)	(−8)	(−22)
100	469·4	446·6	331·2	257·7	216·0	257·9	266·7	225·4
	(+60)	(+53)	(+13)	(−12)	(−26)	(−12)	(−9)	(−23)
Average annual rainfall (cm)	157·8	161·2	165·7	163·3	162·5	153·4	150·9	173·8
				NEW DELHI				
2	69·8	113·5	91·0	98·4	89·1	97·6	124·6	88·0
	(−27)	(+20)	(−4)	(+4)	(−6)	(+3)	(+32)	(−7)
5	115·3	161·0	131·7	153·7	150·1	143·1	197·9	121·7
	(−17)	(+15)	(−6)	(+10)	(+8)	(+3)	(+42)	(−13)
10	145·3	192·4	158·6	190·3	190·4	173·3	246·3	144·0
	(−14)	(+14)	(−6)	(+12)	(+13)	(+2)	(+45)	(−15)
25	183·4	232·2	192·6	236·5	241·5	211·4	307·6	172·2
	(−11)	(+12)	(−7)	(+14)	(+17)	(+2)	(+49)	(−17)
50	211·6	261·6	217·9	270·8	279·3	239·7	353·1	193·1
	(−10)	(+11)	(−7)	(+15)	(+19)	(+2)	(+50)	(−18)
100	239·5	290·9	242·9	304·8	316·9	267·7	398·2	213·9
	(−9)	(+11)	(−7)	(+16)	(+21)	(+2)	(+52)	(−19)
Average annual rainfall (cm)	61·8	69·1	65·0	64·4	63·4	68·2	85·5	73·8
				BOMBAY				
2	139·8	157·6	189·4	199·6	156·7	209·5	172·5	227·8
	(−20)	(−10)	(+8)	(+14)	(−11)	(+19)	(−2)	(+30)
5	168·2	235·6	265·0	325·7	203·6	302·8	221·4	379·6
	(−33)	(−7)	(+5)	(+29)	(−19)	(+20)	(−12)	(+51)
10	187·0	287·2	315·0	409·3	2[illegible]4·7	364·6	253·7	(480·1
	(−38)	(−5)	(+4)	(+35)	(−23)	(+20)	(−16)	(+58)
25	210·8	352·5	378·1	51[illegible]·8	274·0	442·7	294·6	607·1
	(−43)	(−4)	(+3)	(+40)	(−25)	(+21)	(−20)	(+65)
50	228·5	400·9	425·0	593·0	303·1	500·6	325·0	701·3
	(−45)	(−3)	(+2)	(+43)	(−27)	(+21)	(−22)	(+69)
100	246·0	448·9	471·5	670·7	332·1	558·1	355·1	794·8
	(−47)	(−3)	(+2)	(+45)	(−28)	(+21)	(−23)	(+72)
Average annual rainfall (cm)	174·2	161·7	176·4	188·0	172·0	216·6	231·6	193·7
				MADRAS				
2	123·6	139·0	138·2	129·7	125·0	119·4	122·0	132·2
	(−2)	(+11)	(+10)	(+3)	(−1)	(−5)	(−3)	(+5)
5	199·0	166·8	2[illegible]1·3	171·2	182·3	168·1	172·9	183·2
	(+17)	(−2)	(+19)	([illegible]1)	(+8)	(−1)	(+2)	(+8)
10	248·9	185·2	243·1	198·7	220·3	200·3	206·6	217·0
	(+26)	(−7)	(+23)	(+0)	(+11)	(+1)	(+4)	(+9)
25	312·0	208·4	295·9	233·4	268·2	241·1	249·3	259·7
	(+33)	(−11)	(+26)	(−1)	(+14)	(+3)	(+6)	(+11)
50	358·9	225·6	335·1	259·1	303·8	271·3	280·9	291·4
	(+37)	(−14)	(+28)	(−1)	(+16)	(+4)	(+7)	(+11)
100	405·3	242·7	373·9	284·7	339·1	301·3	312·3	322·8
	(+40)	(−16)	(+30)	(−1)	(+17)	(+4)	(+8)	(+12)
Average annual rainfall (cm)	128·7	124·2	139·7	125·7	131·3	108·1	130·5	127·4

TABLE 2

One-day maximum rainfall (mm) for different return periods for different periods of record (Omitting the outliers)
(Figs. in brackets below the rain fall values are percentage errors)

Period of record	Return period (Years)					
	2	5	10	25	50	100
			CALCUTTA			
82 years	109·0	147·1	172·3	204·2	227·8	251·3
(1891-1974)						
40 years	110·6	157·5	188·5	227·7	256·8	285·7
(1891-1932)	(+1)	(+7)	(+9)	(+11)	(+13)	(+14)
42 years	108·1	139·4	160·1	186·2	205·6	224·9
(1933-1974)	(—1)	(—5)	(—7)	(—9)	(—10)	(—11)
26 years	104·3	152·1	183·8	223·7	253·4	282·3
(1891-1918)	(—4)	(+3)	(+7)	(+10)	(+11)	(+12)
28 years	118·7	158·7	185·3	218·8	243·6	268·3
(1919-1946)	(+9)	(+8)	(+8)	(+7)	(+7)	(+7)
(1947-1974)	105·1	138·4	160·5	188·4	209·1	229·6
	(—4)	(—6)	(—7)	(—8)	(—8)	(—9)
19 years	102·4	158·5	195·8	242·8	277·7	312·3
(1891-1911)	(—8)	(+8)	(+14)	(+19)	(+22)	(+24)
21 years	119·1	161·6	189·7	225·3	251·6	277·8
(1912-1932)	(+9)	(+10)	(+10)	(+10)	(+10)	(+11)
(1933-1953)	111·4	142·6	163·2	189·2	208·6	227·8
	(+2)	(—4)	(—5)	(—7)	(—8)	(—9)
(1954-1974)	105·5	139·3	161·7	189·9	210·9	231·7
	(—3)	(—5)	(—6)	(—7)	(—7)	(—8)
9 years	100·1	144·9	174·5	212·0	239·8	267·4
(1895-1904)	(—8)	(—1)	(+1)	(+4)	(+5)	(+6)
(1905-1914)	116·3	176·7	216·8	267·3	304·8	342·1
	(+7)	(+20)	(+26)	(+31)	(+34)	(+36)
10 years	125·6	180·6	217·0	263·1	297·3	331·2
(1915-1924)	(+15)	(+23)	(+26)	(+29)	(+31)	(+32)
(1925-1934)	112·9	151·6	177·3	209·7	233·8	257·7
	(+4)	(+3)	(+3)	(+3)	(+3)	(+3)
(1935-1944)	113·0	140·6	158·8	181·9	199·0	216·0
	(+4)	(—4)	(—8)	(—11)	(—13)	(—14)
(1945-1954)	108·8	148·7	175·1	208·5	233·3	257·9
	(—0)	(+1)	(+2)	(+2)	(+2)	(+3)
(1955-1964)	111·0	152·7	180·3	215·1	241·0	266·7
	(+2)	(+4)	(+5)	(+5)	(+6)	(+6)
(1965-1974)	103·5	136·2	157·7	185·0	205·3	225·4
	(—5)	(—7)	(—8)	(—9)	(—10)	(—10)
			NEW DELHI			
27 years	100·1	140·8	167·8	201·9	227·2	252·3
(1947-1974)	(+6)	(+1)	(—1)	(—2)	(—3)	(—4)
20 years	88·8	128·9	155·5	189·0	213·8	238·5
(1933-1953)	(—6)	(—8)	(—8)	(—9)	(—9)	(—9)
(1954-1974)	101·6	145·3	174·2	210·8	237·9	264·9
	(+8)	(+4)	(+3)	(+2)	(+1)	(+1)
9 years	60·7	87·6	105·5	128·0	144·7	161·3
(1895-1904)	(—36)	(—37)	(—38)	(—38)	(—38)	(—39)
(1935-1944)	76·7	111·5	134·6	163·7	185·4	206·9
	(—19)	(—20)	(—20)	(—21)	(—21)	(—21)
(1955-1964)	112·1	166·4	202·4	247·9	281·5	315·1
	(+19)	(+19)	(+20)	(+20)	(+20)	(+20)

TABLE 2—(*Contd.*)

Period of record	Return periods/ errors					
	2	5	10	25	50	100
			BOMBAY			
82 years	169·4	229·8	269·8	320·3	351·8	395·0
(1891-1974)						
41 years	160·8	216·3	253·1	299·6	334·1	368·3
(1891-1932)	(—5)	(—6)	(—6)	(—6)	(—5)	(—7)
(1933-1974)	178·9	246·8	291·9	348·7	390·8	432·7
	(+6)	(+7)	(+8)	(+9)	(+11)	(+10)
28 years	148·2	196·9	229·2	269·9	300·2	330·2
(1891-1918)	(—13)	(—14)	(—15)	(—16)	(—15)	(—16)
27 years	175·3	231·1	268·1	314·8	349·4	383·9
(1919-1946)	(+3)	(+1)	(—1)	(—2)	(—1)	(—3)
(1947-1974)	189·1	267·4	319·3	384·9	433·4	481·8
	(+12)	(+16)	(+18)	(+20)	(+23)	(+22)
21 years	140·9	191·5	225·1	267·4	298·8	330·0
(1891-1911)	(—17)	(—17)	(—17)	(—17)	(—15)	(—16)
20 years	184·3	240·8	278·3	325·6	360·6	395·5
(1912-1932)	(+8)	(+5)	(+3)	(+2)	(+3)	(+0)
(1933-1953)	164·0	210·7	241·5	280·5	309·5	338·2
	(—3)	(—8)	(—10)	(—12)	(—12)	(—14)
(1954-1974)	186·5	258·5	306·3	366·5	411·2	455·6
	(+10)	(+12)	(+14)	(+14)	(+17)	(+15)
10 years	139·8	168·2	187·0	210·8	228·5	246·0
(1895-1904)	(—17)	(—27)	(—31)	(—34)	(—35)	(—38)
(1905-1914)	157·6	235·6	287·2	352·5	400·9	448·9
	(—7)	(+3)	(+6)	(+10)	(+14)	(+14)
(1915-1924)	189·4	265·0	315·0	378·1	425·0	471·5
	(+12)	(+15)	(+17)	(+18)	(+21)	(+19)
9 years	170·7	226·7	263·8	310·6	345·3	379·9
(1925-1934)	(+1)	(—1)	(—2)	(—3)	(—2)	(—4)
10 years	156·7	203·6	234·7	274·0	303·1	332·1
(1935-1944)	(—7)	(—11)	(—13)	(—14)	(—14)	(—16)
9 years	190·6	244·5	280·2	325·3	358·7	392·0
(1945-1954)	(+13)	(+6)	(+4)	(+2)	(+2)	(—1)
10 years	172·5	221·4	253·7	294·6	325·0	355·1
(1955-1964)	(+2)	(—4)	(—6)	(—8)	(—8)	(—10)
9 years	201·7	287·4	344·2	415·9	469·0	520·8
(1965-1974)	(+29)	(+25)	(+27)	(+30)	(+33)	(+32)

For Calcutta probably due to sampling error the increase in return period values is not seen, but the average annual rainfall has certainly increased. Hence for Calcutta, New Delhi and Bombay, there is some evidence to show that return period values increase with increase in air pollution. For Madras, however, no such evidence could be found. Harihara Ayyar (1972) also found no increase of high clouds over Madras as a result of atmospheric-pollution by jet aircraft, though there was an unmistakable increase in high clouds over Calcutta, Delhi and Bombay. This difference was attributed to relatively small traffic through Madras.

5. Discussion

Gumbel's method has been used here to find the return period values of rainfall. This method has been found satisfactory by many workers for moderately high return periods and is used by NOAA for its precipitation-frequency analysis. No claim is made that this method is clearly superior to other methods but such tests as have been made (Hershfield and Kohler 1960, Hershfield 1962) indicate that it yields satisfactory results and might even be slightly conservative.

It is felt that only 4 stations with records of

TABLE 3

Maximum percentage errors

Return period (years)	Length of record							
	42 years		28 years		21 years		10 years	
	With outliers	Without outliers	With outliers	Without outliers	With outliers	Without outliers	With outliers	Without outliers
2	6	6	15	13	20	17	32	36
5	13	7	22	14	28	17	51	37
10	17	9	24	15	37	17	58	38
25	20	11	28	16	44	19	65	38
50	22	13	31	15	48	22	69	38
100	23	14	33	16	51	24	72	40

TABLE 4

Percentage number of cases with errors within $\pm$ 25 per cent

Return period (years)	Length of record							
	42 years (8 cases)		28 years (12 cases)		21 years (16 cases)		10 years (32 cases)	
	with outliers	without outliers	with outliers	without outliers	with outliers	without outliers	with outliers	without outlier
2	100	100	100	100	100	100	91	97
5	100	100	100	100	100	100	81	91
10	100	100	100	100	87	100	78	81
25	100	100	83	100	87	100	72	78
50	100	100	83	100	87	100	72	78
100	100	100	83	100	81	100	69	78

only 84 years are not sufficient for the present study. The results may be checked and modified, if necessary, when more and longer-period reliable data are available.

There can be no doubt that the air pollution found in urban areas have an effect on the local weather. The heavy concentrations of dust, smoke and other aerosols found in city areas have often been related to the frequency with which various weather phenomena occur in those areas. Of all the weather phenomena, rainfall is more difficult to be related to air pollution, because the machanism of rain formation is very complex. Increase of rainfall due to air pollution has been reported by Changnon (1968) at La Porte (near Chicago) where there was 31 per cent more days of rain during the 1951-65 period compared to the previous years. Harihara Ayyar (1971) in his preliminary studies with long period data at Bombay, Calcutta and a few other cities in India, could not find a similar effect. In the present study, there is some indication of increase of return period values and average annual rainfall for Calcutta, Delhi and Bombay from period to period only for long periods of 28 years and 42 years and not for short 10-year or 21-year periods. Rainfall depends on a number of factors and it is possible that the effect of air pollution on it may be shown only when long periods are considered. Further studies need therefore to be made in this direction.

6. Conclusion

To estimate the maximum rainfall values for long return periods, more reliance should be placed on stations with longest records. To have the return period values with error within $\pm$25 per cent in about 80 per cent cases, the extrapolation may be made to five times the period of record and to ten times the period of record if the outliers are excluded from the analysis. If air pollution at a station has increased in recent years, it may be safe to increase the return period values by about 10 percent for that place for design purposes.

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