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A STUDY OF RAINFALLS RECORDED AT THE CHERRAPUNJI OBSERVATORY

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ABSTRACT

The maximum rainfalls recorded at the Cherrapunji Observatory raingauge during various periods within the 57 years from 1903 to 1959 have been studied and the equation of the enveloping line has found to be $R = 49\ D^{0.485}$ where R is the rainfall in inches and D is duration in days. One-day maximum rainfalls for different periods from two to 100 years have also been worked out and the 100-year value has been found to be 2·1 times the 2-year value. The daily probable maximum precipitation (*PMP*), estimated by the Hershfield technique, is 78 in. A study of annual and monsoon rainfalls did not show any general linear trend but there was a gradual increase in amounts from 1944 to 1954.

RÉSUMÉ

Les averses maximales enregistrées par le pluviomètre de l'Observatoire de Cherrapunji pendant des périodes diverses au cours des 57 ans de 1903 à 1959 ont été étudiées et on a trouvé que l'équation de la ligne qui les enveloppe est $R = 49\ D^{0.485}$, là où R est l'averse mesurée en pouces et où D est la durée mesurée en journées. Les averses maximales d'un seul jour pour des périodes différentes d'entre 2 et 100 ans ont été calculées aussi et on a trouvé que la valeur pour la période de 100 ans égale la valeur pour la période de 2 ans multipliée par 2·1. La précipitation maximale quotidienne probable (*PMP*) estimée par la technique Hershfield est de 78 pouces. Une étude des averses annuelles et des averses pendant les moussons ne montrait pas de tendance linéaire générale mais il y avait un accroissement graduel des quantités de 1944 à 1954.

Introduction

Cherrapunji (lat. 25° 15′ N, long. 91°44′ E) which is one of the rainiest stations in the world is located at an elevation of 1313 m a.s.l. on the southern slopes of the Khasi hills overlooking the plains of the Sylhet district in Bangladesh. According to Blanford (1886) Cherrapunji stands on a little plateau of thick bedded sandstones, bounded on two sides by precipices of about 600 m sheer descent, which terminate in gorges, debouching southwards on the plains. In the past, raingauges maintained by the following agencies have been recording rainfall at this station for varying periods of time:

(1) Raingauge located at the local Police Station and maintained by the State authorities;
(2) raingauge maintained by the Welsh Mission;
(3) raingauge maintained by the Roman Catholic Mission and
(4) raingauge maintained at Mr Shadwell's house.

Of these four raingauges, daily records are continuously available in the archives of the Meteorological Department at Poona for the raingauge located at the Police Station from 1871. On 14 June 1876 this station recorded 40·80 in. in 24 h which is the highest recorded rainfall for this duration for any station (plain or hilly) in India.

TABLE 1

Mean monthly and annual rainfall (in inches) for the Cherrapunji Observatory during 1903–1959

	Jan.	Feb.	March	April	May	June	July	Aug.	Sept.	Oct.	Nov.	Dec.	Annual	Monsoon (June–Sept.)
Mean of 57-year period (in.)	0·8	1·9	7·7	26·5	58·0	107·4	96·1	72·6	44·7	19·5	2·6	0·4	438·3	320·7
Coefficient of variation (%)	165	88	89	57	54	32	36	36	45	80	157	355	17	19
Percentage of the mean annual rainfall (%)	0·2	0·4	2	6	13	25	22	17	10	4	0·6	0·1	100	73

Meteorological Observatory

The meteorological observatory started functioning at Cherrapunji on 1 June 1902 in the compound of the local Post and Telegraph Office. Since a meteorological observatory uses standard instruments under proper exposure conditions and is periodically inspected by trained meteorological inspectors, one can, naturally, place a high degree of reliance on its data. With this fact in mind daily rainfalls recorded at the observatory raingauge (i.e. a Symon's raingauge of 5 in. diameter) have been utilized in this study. These data are continuously available from June 1902 to the end of 1959. Thereafter the data are not continuously available and hence have not been considered in the present study.

Earlier Studies of the Rainfall of Cherrapunji

In the past, various research workers have studied the causes of the abnormally high rainfall at this station. According to Blanford (1886), the dynamic cooling of the saturated southwest winds which are forced to rise vertically due to the steep slopes of the region is the main cause of the enormous rainfall at this station. J. C. Das (1951), however, feels that besides orography, the high rainfall at this station is due to its proximity to the line of discontinuity between the comparatively dry easterlies and north easterlies and the moist southerlies and south westerlies. P.K. Das (1968) has explained the incidence of nearly 35 per cent of rainfall in the morning hours at this station as due to early morning lifting of the moist air trapped in the valley at night. Ramaswamy (1972) feels that westerly circulations and perturbations, meso scale factors and variation in the mixing ratio play an important part, besides orography, in causing heavy rainfall.

Mean Monthly Rainfall and the Seasonal Variation of the Maximum Rainfall in Different Months

Using the daily rainfall data of the Cherrapunji Observatory, mean monthly and annual rainfall have been calculated from the 57 years of continuous rainfall data (Table 1). It can be seen from Table 1 that the mean annual rainfall of the Cherrapunji Observatory is of the order of 438 in. Normally, the monsoon sets in over this region by about the first week of June and withdraws by about the middle of the second week of October. June receives the highest monthly rainfall, about 25 per cent of the annual total. Table 1 also shows that the rainfall received during the month of May, a non-monsoon month, is more than that received in September which is a monsoon month. Monsoon rainfall is about 73 per cent of the mean annual total and the main rainy season for this station is the period from April to October when nearly 93 per cent of the annual rainfall is registered.

Coefficients of variation of the monthly and the annual rainfalls are also indicated in Table 1. It is seen that the coefficients of variation of the different rainy months from April to October vary from 32 to 80 per cent, the month of June having the lowest value (32 per cent) and the month of October having the highest value (80 per cent).

During the period under study, the Cherrapunji Observatory received 624 in. in 1951 (142 per cent of the mean annual total) and 283 in. during 1908 (64 per cent of the mean): these totals were the extremes of the annual amounts.

Monthly variation of maximum rainfalls for durations from one to 15 days has also been worked out for the 12 months of a year. Table 2 gives the maximum amounts recorded in each month for a particular duration together with the date and the year of occurrence. It has been noticed from an examination of Table 2 that for each month there is generally one particular spell of rain which contributed all the maximum rain depths in that month for the majority of the durations. For example, in the month of January the spell from 15 to 29 January 1929 contributed the maximum rainfalls for durations from one to 15 days during the 57-year period. It is also evident from Table 2 that from February the rainfall goes on increasing for all durations to the month of

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Monthly variation of maximum rainfall (in inches) for diffe

Duration (days)		January	February	March	April	Ma
1	*R*	3·36	3·62	12·05	18·20	31·'
	D/*Y*	18/1929	27/1907	22/1910	28/1922	25/19
2	*R*	6·20	3·76	17·17	30·02	48·:
	D/*Y*	17–18/1929	16–17/1913	21–22/1910	27–28/1922	24–25/
3	*R*	6·39	4·44	20·77	37·56	63·(
	D/*Y*	17–19/1929	16–18/1913	21–23/1910	15–17/1904	27–29/
4	*R*	6·49	4·51	21·42	42·15	74·
	D/*Y*	16–19/1929	15–18/1913	20–23/1910	14–17/1904	24–27/
5	*R*	6·59	4·53	21·82	44·46	86··
	D/*Y*	17–21/1929	14–18/1913	20–24/1910	13–17/1904	23–27/
6	*R*	7·54	4·54	24·44	46·84	89·.
	D/*Y*	17–22/1929	13–18/1913	21–26/1910	12–17/1904	25–30/
7	*R*	7·64	4·59	26·74	48·83	95··
	D/*Y*	16–22/1929	12–18/1913	21–27/1910	11–17/1904	21–27/
8	*R*	7·66	4·59	28·39	50·68	98·.
	D/*Y*	16–23/1929	11–18/1913	21–28/1910	12–19/1904	20–27/
9	*R*	7·66	4·91	29·37	52·67	99··
	D/*Y*	15–23/1929	11–19/1906	21–29/1910	11–19/1904	20–28/
10	*R*	7·66	5·26	30·02	56·01	99·'
	D/*Y*	14–23/1929	11–20/1906	20–29/1910	15–24/1904	19–28/
11	*R*	7·66	5·37	30·27	60·60	100·:
	D/*Y*	13–23/1929	11–21/1906	20–30/1910	14–24/1904	19–29/
12	*R*	7·76	5·37	30·39	64·93	107·
	D/*Y*	17–28/1929	10–21/1906	20–31/1910	14–25/1904	17–28/
13	*R*	7·96	6·40	30·44	68·03	112·:
	D/*Y*	17–29/1929	11–23/1906	19–31/1910	14–26/1904	17–29/
14	*R*	8·06	6·42	30·44	70·34	114·:
	D/*Y*	16–29/1929	11–24/1906	18–31/1910	13–26/1904	17–30/
15	*R*	8·06	6·42	30·44	72·72	115·:
	D/*Y*	15–29/1929	10–24/1906	17–31/1910	12–26/1904	16–30/

Note: *R* = Total rainfall in inches, *D* = Date, *Y* = Year.

June. All the durations from one to 15 days in this month (June) have recorded the highest rain depths in 57 years. From July to January the rain depths decrease for the various durations, February being the month with the minimum depths of rain during the 57-year period.

Envelope Depth–Duration Relationship of Observed Rainfall

Jennings (1950) studied the greatest observed point rainfall depths from different parts of the world for different durations from one minute to two years. Paulhus (1965), using as a basis rainfall data from all over the world, found that some of the previously accepted world records have been surpassed. As an example, in Jennings' study, the world record for the 24-h duration was held by Baguio (Philippines) which recorded 45·99 in. on 14–15 July 1911. Paulhus found the rainfall at some stations on islands in the Indian Ocean and on Taiwan have exceeded Jen-

E 2

durations from 1 to 15 days for Cherrapunji Observatory (1903–1959)

June	July	August	September	October	November	December
38·34	33·00	33·60	24·89	23·25	13·08	7·47
5/1956	12/1910	10/1955	14/1951	7/1919	1/1917	28/1926
61·45	55·02	51·43	49·14	36·20	13·08	9·29
20–21/1934	9–10/1915	23–24/1932	19–20/1938	4–5/1934	1–2/1917	28–29/1926
32·80	65·40	62·73	59·50	42·35	13·08	9·29
19–21/1934	8–10/1915	23–25/1932	18–20/1938	12–14/1911	1–3/1917	27–29/1926
92·19	83·15	70·93	65·20	44·58	13·08	9·29
19–22/1934	7–10/1915	22–25/1932	17–20/1938	11–14/1911	1–4/1917	26–29/1926
97·34	92·90	72·82	65·98	46·15	13·08	9·29
13–17/1914	6–10/1915	23–27/1951	17–21/1938	10–14/1911	1–5/1917	25–29/1926
100·81	96·92	75·90	66·18	46·99	13·08	9·29
17–22/1934	5–10/1915	22–27/1951	17–22/1938	10–15/1911	1–6/1917	24–29/1926
116·52	106·61	76·84	66·24	47·26	13·08	9·29
15–21/1934	9–15/1906	21–27/1951	16–22/1938	9–15/1911	1–7/1917	23–29/1926
125·91	109·99	77·33	66·94	48·19	13·08	9·29
15–22/1934	8–15/1906	21–28/1951	14–21/1938	7–14/1911	1–8/1917	22–29/1926
131·51	114·30	78·06	67·67	49·24	13·08	9·29
14–22/1934	7–15/1906	18–26/1932	7–15/1953	6–14/1911	1–9/1917	21–29/1926
134·18	116·61	81·16	70·66	50·08	13·08	9·29
14–23/1934	6–15/1906	16–25/1932	9–18/1953	6–15/1911	1–10/1917	20–29/1926
135·47	118·82	88·81	74·29	50·11	13·08	9·29
13–23/1934	6–16/1906	15–25/1932	9–19/1953	6–16/1911	1–11/1917	19–29/1926
136·54	119·02	94·88	76·10	50·11	13·30	9·36
12–23/1934	5–16/1906	11–22/1935	8–19/1953	5–16/1911	9–20/1924	18–29/1926
140·40	123·10	103·00	77·42	50·15	13·32	9·36
12–24/1956	5–17/1951	10–22/1932	7–19/1953	4–16/1934	9–21/1924	17–29/1926
141·88	127·63	111·46	77·82	50·69	13·32	9·36
11–24/1956	5–18/1951	9–22/1935	7–20/1953	3–16/1934	8–21/1924	16–29/1926
144·38	139·23	117·59	78·08	51·23	13·32	9·36
3–17/1956	2–16/1951	8–22/1935	6–20/1953	2–16/1934	7–21/1924	15–29/1926

nings' point rainfall values in recent years. He found that the highest 24-h rainfall of 73·62 in. was recorded at Cilaos (1200 m a.s.l.) in the La Reunion Island (which is about 400 miles east of Madagascar) on 15–16 March 1952. If we examine the list of stations which have recorded the highest rainfalls in different durations as prepared by Paulhus (1965), we find that Cherrapunji holds the world record for the durations from 15 days to two years. The rainfall data for these durations, however, pertain to non-observatory raingauges some of which have been functioning at Cherrapunji since 1832. According to these data, in July 1861, a record rainfall of 366·14 in. was observed at this station which has not been surpassed up to present times.

The greatest observed rainfalls for all the durations from one day to two years for the Observatory raingauge at Cherrapunji were listed from the daily data for the period 1903–1959. These data are presented in Table 3 for certain selected durations. It is worth noting that among the values given by Paulhus (1965) for which Cherrapunji recorded the highest rainfall in the world is the 188·88 in. for the 15 days from 24 June to 8 July 1931. During this period the Observatory

raingauge was also functioning and recorded only 119·96 in. of rain for these 15 days. The highest 15-day rainfall for the Observatory raingauge was recorded during the period 3 June–17 June 1956 when 144·38 in. were recorded (Table 3). During this period the rainfall recorded at the Police Station raingauge was 138·42 in.

TABLE 3

Greatest observed rainfall at the Cherrapunji Observatory for selected durations (1903–1959)

Duration	Rainfall (in.)	Date and year	Duration	Rainfall (in.)	Date and year
1 day	38·34	5/6/1956	15 days	144·38	3–17/6/1956
2 days	61·45	20–21/6/1934	20 days	201·06	4–23/6/1956
3 days	82·80	19–21/6/1934	25 days	223·20	2–26/6/1956
4 days	92·19	19–22/6/1934	30 days	231·16	26/5–24/6/1956
5 days	104·81	27/6–1/7/1939	2 months	338·49	May–June, 1956
6 days	112·81	27/6–2/7/1939	6 months	599·87	May–Oct., 1951
7 days	117·47	26/6–2/7/1939	12 months	681·88	July, 1955–June, 1956
10 days	134·18	14–23/6/1934	2 years	1191·30	July, 1954–June, 1956

The greatest observed rainfall for all the durations from one day to two years was then plotted on log log paper (Fig. 1) and an enveloping straight line has been drawn through the highest points (curve II in Fig. 1). The equation for this line was found to be

$$R = 49\,D^{0\cdot485} \tag{1}$$

where R is the rainfall in inches and D is the duration in days. Paulhus (1965) obtained a similar enveloping line on the basis of world record rainfall data which is shown by way of comparison as curve I in Fig. 1. The equation for this line is

$$R = 77\,D^{0\cdot475} \tag{2}$$

where R and D denote the same units as in equation (1).

The enveloping depth–duration relationship for the Cherrapunji Observatory shown in Fig. 1 gives an idea of the highest observed point rainfall for this station for different durations from one-day to two years on the basis of available data from 1903 to 1959. According to equation (1), the highest one-day rainfall can be of the order of 49 in. at this station. If we examine the rainfall records prior to 1903 for this station, it will be observed that a rainfall of the order of 41 in. did occur in 24 h in 1876.

Return Period of Maximum One-Day Rainfall

The maximum rainfalls recorded for a one-day duration were subjected to a frequency analysis using the Gumbel (1954) technique. The return periods (T) of the extreme annual values were calculated using the formula $T = (N+1)/m$, where N represents the total number of years of record and m is the rank number of the annual series when arranged in descending order. The plotting of the observed points and the computed straight line for the one-day duration is shown in Fig. 2. It can be seen from Fig. 2 that the highest observed one-day rainfall of 38·3 in. (during the period 1903–1959) has a return period of about 40 years while a one-day rainfall of 41 in.

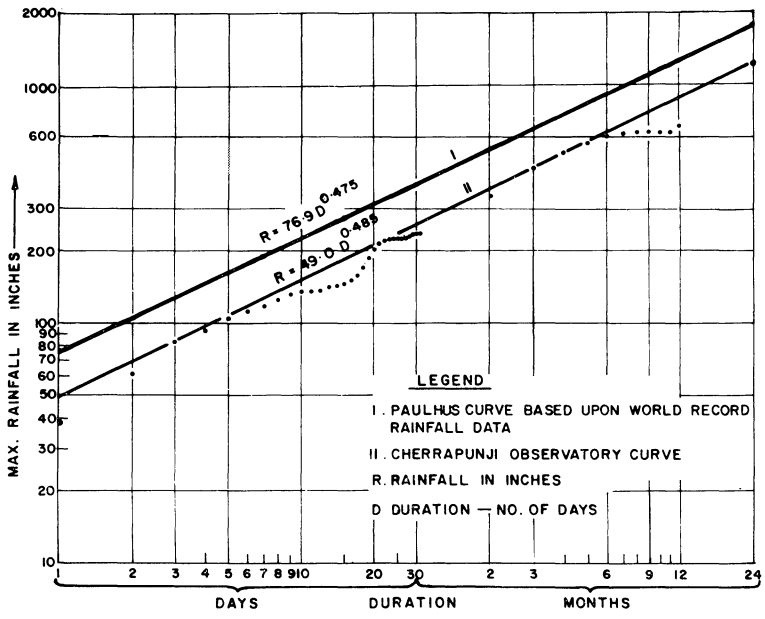

Fig. 1 — Greatest recorded rainfall at the Cherrapunji Observatory (1903–1959).

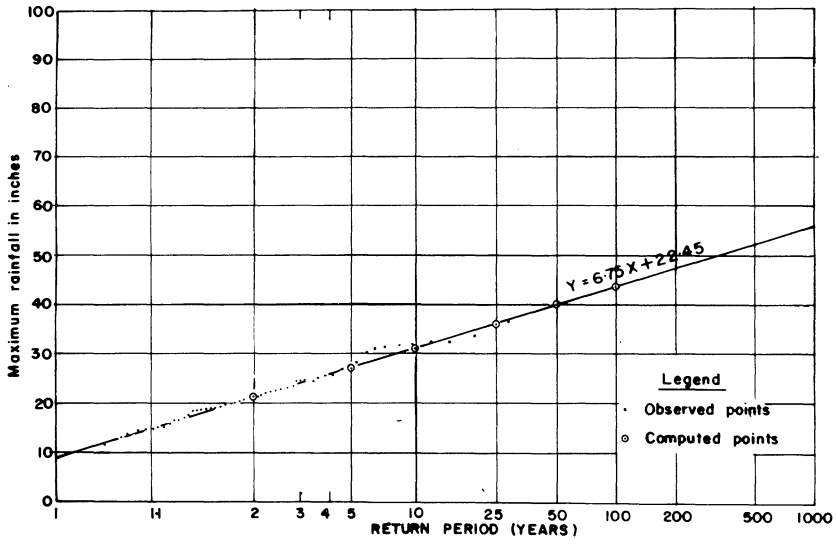

Fig. 2 — Frequency curve for the maximum one-day rainfall recorded at the Cherrapunji Observatory.

(observed in 1876 at the Police Station raingauge) has a return period of about 62 years. The magnitudes of rainfalls corresponding to different return periods from two to 100 years have been picked out from Fig. 2 and the same are given in Table 4.

TABLE 4

Magnitudes of one-day rainfall (in inches) of different return periods for the Cherrapunji Observatory

Return period (years)	Rainfall (in.)
2	21·0
5	27·0
10	31·0
25	36·0
50	40·0
100	43·5

Probable Maximum Rainfall of Cherrapunji

Probable maximum precipitation (*PMP*) has been defined as that magnitude of rainfall for a given duration which should not be exceeded over a long period of years. In other words it is that theoretical greatest depth of rainfall for a given duration that is physically possible over a particular drainage area at a certain time of year (Huschke, 1959). In recent years Hershfield (1961) has developed a statistical model for obtaining point values of the *PMP*. His method has been found to give results comparable with those obtained from the conventional methods of storm transposition and storm maximization (Myers, 1967; Bruce and Clark, 1966; Wiesner 1970). The WMO Guide to Hydrometeorological Practices (1970) and the WMO Technical Note on Estimation of Maximum Floods (1969) have also recommended this method for obtaining *PMP* estimates for point rainfalls or small basins for which daily rainfall data are available for a long period.

Dhar and Kamte (1969, 1971) and Dhar *et al.* (1972) in their studies of *PMP* for the Indian regions based on the Hershfield technique, have not used Hershfield's world envelope value of the frequency factor (i.e. $K_m = 15$) in the equation

$$X_{PMP} = \bar{X} + K_m \cdot \sigma \tag{3}$$

where $\bar{X}$ and σ respectively are the mean and the standard deviation of the annual series of maximum one-day rainfall and K_m is the envelope frequency factor. On the other hand, they used separate regional envelope values of the frequency factor based on the rainfall data of different homogeneous regions in order to obtain realistic values of *PMP*. The enveloping K_m value for the Assam region in which Cherrapunji is located, has been found to be of the order of $K_m = 9$ (Dhar and Kamte, 1973). Using this value of K_m in equation (3) the following values of $\bar{X}$ and σ were obtained on the basis of the 57-year rainfall data of the Cherrapunji Observatory

$$\bar{X} = 22{\cdot}32 \text{ in.}$$
$$\sigma = 6{\cdot}21 \text{ in.}$$

The one-day *PMP* estimate obtained from substituting these values in equation (3) is 78·21 in. It has been found that this estimate of *PMP* for Cherrapunji has a return period of the order 2×10^5 years.

Trend Analysis of Monsoon and Annual Rainfall

An analysis of trends in the monsoon (June–September) and annual rainfalls was also carried out for the rainfall data from the Observatory. In Fig. 3 values of monsoon as well as annual rainfalls have been plotted for each year of the 57-year period. To understand the nature of the trend, both these rainfall series were subjected to the low pass filter technique (WMO, 1970) in order to suppress the high frequency oscillations. The weights used were of ordinates of the

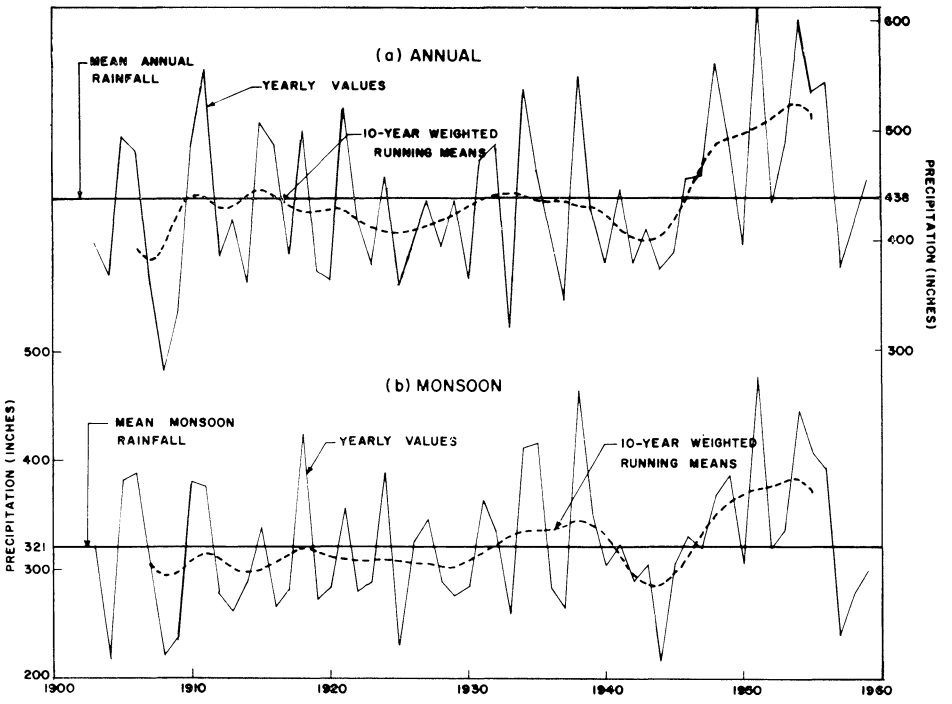

Fig. 3 — Rainfall at Cherrapunji and the smoothing effects of running means.

Gaussian probability curve (Barry, 1969). The 10-year weighted moving averages both for monsoon as well as for the annual rainfall series were plotted on a graph showing the actual yearly fluctuations. It is observed from Fig. 3 that there is no linear trend in the series but the curves show oscillations having wavelengths of the order of 10 years or so. It is also seen that in both the curves that there is an abrupt change near about the year 1944 which indicates that from 1944 to about 1954, there was a tendency for totals to increase.

Conclusions

The maximum rainfalls at the Cherrapunji Observatory for durations of one-day to two years when plotted on log log paper delineate a straight line whose equation is $R = 49\ D^{0.485}$. The highest one-day rainfall observed during the period 1903–1959 was 38 in. and it has a return period of about 40 years. The 100-year rainfall is estimated to be of the order of 43 in. The *PMP*

estimated for a one-day duration has been found to be of the order of 78 in. which has a return period of 2×10^5 years. Analysis of trends in annual and monsoon rainfall data has shown that there is no linear trend in the series, but some sort of oscillation having wavelengths of the order of 10 years or so are seen in the rain profiles. It is to be noted, however, that there was an abrupt rise in totals from about 1944 which continued to about 1954.

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