A STUDY OF FORTY-THREE YEARS OF RAINFALL IN CALCUTTA, 1893—1935

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[S. S. Bose had prepared the draft of this paper some considerable time ago in 1937; but did not have any opportunity of revising it for publication. Besides minor additions and alterations the article is published practically in its original form.—*Editor*].

INTRODUCTION

Rainfall in Calcutta used to be recorded in Alipore Central Jail till August, 1892. The Meteorological Office took over charge from September, 1892 and since then observations are being recorded in a Symon's rain gauge in the present site of the Observatory in Alipore. Readings taken at 8 A.M. everyday represent the total rainfall of the twentyfour hours preceding 8 A.M. of the date in question.

The distance between Alipore Central Jail and the present Observatory is roughly half a mile ; but the accuracy of the Jail readings is not comparable to the present readings in precision. Rainfall observations in Calcutta are available for more than a century if the readings of the two sites are pooled together, but it has been considered desirable to study them separately.

In the present note, we have discussed the observations at Alipore Observatory for a period of forty-three years from 1893 to 1935 ; and we propose to study the rainfall at the Alipore Central Jail between 1829-1892 in a subsequent note.

Monthly rainfall data were obtained from the Records of Indian Meteorological Department. Dividing each figure by the number of days in the month, the data were converted to mean rainfall per day which form the material for the present analysis.

When the mean rainfalls per day were tabulated for 12 months over the period 1893-1935, it was found that the September rainfall* in 1900 was more than 4 times the mean rainfall for the month. Naturally this was due to some local influence ; but lest this should disturb the estimate of normal mean and variance, it was omitted and Yates' formula[1] for estimating missing values was utilised for restoring orthogonality.

The chief objects of the present note are to investigate :—

(1) The secular trend of rainfall, if any, during the period ;

(2) the distribution of rainfall within years ; and

(3) the change, if any, in the period of maximum rainfall in the year.

*This was 45·55 inches for the whole month, whereas the normal rainfall for the month is 9·87 inches.

[1] YATES, F. : The Analysis of Replicated Experiments when the Field Results are Incomplete. Emp. J. Expt. Agri., Vol. (1), 1933.

General Analysis of Variance

The analysis of variance of the rainfall data is shown in Table 1.

Table 1. Analysis of Variance of Rainfall in Calcutta: (1893-1935)

Due to	D. F.	Sum of Squares	Variance
Secular Trend ...	1	0·000242	0·000242
Deviation	41	0·583488	0·014231
Years	42	0·583730	0·013898
Harmonic Curve ...	2	12·243083	6·130596
Deviation	9	1·440383	0·158030
Months	11	13·683466	1·243952
Residual	461	5·500609	0·011932
Total ...	514	19·767805	...

When the variations between years and between months are eliminated, the residual variance is found to be 0·011932, so that the standard deviation of daily rainfall is 0·109 inches; the mean during the period is 0·172 inches and hence the variability is 63·3 per cent of mean. The variance between years is 0·013898 and is of the same order as the residual variance, while the variance between months is about 104 times that of the residual. We thus found that the variation of rainfall from year to year was not appreciable, while the variation between months was highly significant which of course was expected.

Secular Trend of Rainfall

The mean annual rainfall ($a_0 \times 10^{-3}$ inches) for each individual year is given in Table 4. The sum of squares between years that can be accounted for by a linear regression is shown in Table 1. The coefficient of regression is 0·000,124 inches per day or 0·045 inches per year; while the normal annual rainfall in Calcutta is 62·54 inches, so that the change per year is less than 1 per cent. In fact, the regression coefficient is only half its standard error, and is thus quite insignificant. The regression coefficients for individual months shown in Table 2 are also all insignificant.

Table 2. Secular Trend of Rainfall in different Months: Regression Coefficients

Month	$(b \pm S.E.) \times 10^3$	Month	$(b \pm S.E.) \times 10^3$
January ...	0·080 ± 0·222	July ...	1·142 ± 2.057
February ...	−0·155 ± 0·664	August ...	2·226 ± 1·790
March ...	−0·071 ± 0·626	September ...	1·065 ± 1·575
April ...	0·001 ± 0·636	October ...	0·741 ± 1·847
May ...	−1·783 ± 1·297	November ...	1·141 ± 0·688
June ...	−2·910 ± 2·585	December ...	0·021 ± 0·099

Annual $(0·124 \pm 0·423) \times 10^3$

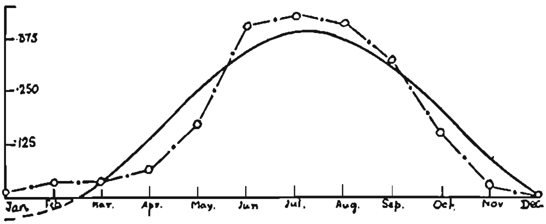
We conclude that during the last 43 years, there has not been any steady change in rainfall in any of the twelve months of the year in Calcutta ; and naturally the annual rainfall also did not show any secular trend.

Distribution of Monthly Rainfall

In Table 1 the monthly variation of rainfall was very marked ; this is however just what is to be expected in a monsoon country like Bengal where sixty per cent of the annual rainfall is concentrated within three months of the year (June, July and August). The monthly rainfalls however show a remarkable cyclic pattern ; thus, in Table 1, about 90 per cent of the sum of squares between months is accountable in terms of a simple sine curve. This is also clear from the accompanying chart in which the mean monthly values have been graduated by a sine curve :

$$R = 0{\cdot}172 - 0{\cdot}218 \sin(\theta + 82^\circ 21')$$

Chart. Simple Sine Curve fitted to Mean Daily Rainfall for various Months



The existence of other harmonics may also be calculated. Thus the 12 monthly means may be completely graduated by means of the equation :

$$R = 0{\cdot}172 - 0{\cdot}218 \sin(\theta + 82^\circ 21') + 0{\cdot}071 \sin(2\theta + 67^\circ 13') + 0{\cdot}017 \sin(3\theta - 7^\circ 30')$$
$$- 0{\cdot}015 \sin(4\theta + 31^\circ 14') + 0{\cdot}012 \sin(5\theta + 71^\circ 34') - 0{\cdot}010 \cos 6\theta.$$

Table 3. Analysis of Variance for Harmonic Graduation of Monthly Rainfall

Due to	D. F.	Sum of Squares	Variance
First Harmonic Term ...	2	12·243083	6·121541
Second Harmonic Term ...	2	1·254780	0·627390
Third Harmonic Term ...	2	0·073202	0·036601
Fourth Harmonic Term ...	2	0·056910	0·028455
Fifth Harmonic Term ...	2	0·035320	0·017660
Sixth Harmonic Term ...	1	0·020171	0·020171
	11	13·683466	...
Residual	461	5·500600	0·011932

The adequacy of the different harmonics was tested by the analysis of variance shown in Table 3.

The first three harmonics are significant, although the contributions of the second and third harmonics are together equal to about a tenth of the first.

YEARLY VARIATIONS IN HARMONIC GRADUATION

Sine curves were fitted to the monthly rainfall figures for each year, the equation used being of the form:

$$R = a_0 + a \sin(\theta + \epsilon)$$

The values of the constants a_0, a and ϵ for each of the 43 years are shown in Table 4.

TABLE 4. CONSTANTS OF HARMONIC GRADUATION OF AVERAGE DAILY RAINFALL (IN THOUSANDTH INCH)

Year	a_0	a	ϵ	Date of Max. Rain	Year	a_0	a	ϵ	Date of Max. Rain
1893	233	+271	−75°15′	August 1	1915	179	−207	+79° 5′	August 27
1894	134	−145	+84°16′	August 22	1916	226	−305	+61°20′	Sept. 14
1895	108	−202	+86°55′	August 19	1917	192	−229	+75°37′	August 31
1896	144	−229	+88°45′	August 18	1918	167	+213	−84° 5′	July 31
1897	150	−200	+77°33′	August 29	1919	173	−237	+88°13′	August 18
1898	162	−237	+72°34′	Sept. 3	1920	173	−208	+72°21′	Sept. 8
1899	196	+289	−85°12′	August 11	1921	162	−211	+85°22′	August 21
1900	246	−366	+56°30′	Sept. 19	1922	228	−339	+76°29′	August 30
1901	191	−234	+68°58′	Sept. 7	1923	153	−194	+71° 6′	Sept. 4
1902	161	+199	−84° 8′	August 10	1924	139	−202	+65°46′	Sept. 10
1903	148	−191	+63°10′	Sept. 12	1925	169	−216	+79° 4′	August 27
1904	214	+233	−81°21′	August 7	1926	203	−277	+81°53′	August 24
1905	189	−210	+79°19′	August 27	1927	125	+157	−89°22′	August 5
1906	156	−110	+78°19′	August 28	1928	214	−323	+89°36′	August 17
1907	170	− 97	+87°38′	August 19	1929	163	−186	+59°59′	Sept. 13
1908	220	+335	−58°43′	August 4	1930	192	−283	+82°27′	August 24
1909	196	+264	−83°29′	August 4	1931	179	−181	+67°33′	Sept. 8
1910	140	−184	+76°47′	August 30	1932	171	−171	+72°18′	Sept. 3
1911	119	−145	+84°49′	August 22	1933	223	−271	+81°56′	August 24
1912	155	−138	+86°44′	August 20	1934	148	−206	+65°18′	Sept. 10
1913	235	+311	−81°18′	July 28	1935	97	−129	+64°49′	Sept. 11
1914	163	+209	−88°27′	August 4	All years	172	−219	+82°21′	...

Here a_0 measures the mean level of rainfall in any particular year and a is the amplitude of monthly fluctuation. We can also calculate the period of maximum and minimum rainfall in the year the values of which are shown in col. (5) of Table 4. There is no sign of a short-period cycle in a_0. There is, however, a high correlation ($r = 0.83$) between a_0 and a showing that in a year of high rainfall level, the amplitude of fluctuation is also large.

The period of maximum rainfall fluctuates very widely but it probably undergoes a steady cyclic variation. The incidence of maximum rain seemed to be on or about August 26 in 1895; this became earlier and earlier till about 1913 the rain was maximum in the end of July. Since then it is again being more and more delayed and in 1930, it is again as late as August. We have here only one part of the cycle and during the succeeding period, we expect the other part of the cyclic curve.