Sunshine, Rainfall and Cloudiness over Bombay

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ABSTRACT. The relationship between sunshine over Bombay and the factors (i) cloudiness, (ii) rainfall and (iii) rainy days has been examined for the rainy months, May to November. All the C.Cs. are negative. For cloud the magnitude is 0·8 to 0·9. The C.Cs. are rather low for rainfall in the most intense monsoon months July and August and statistically insignificant. With rainy days the C.C. is generally improved but July continues to be low. Sunshine in any month is not significantly correlated with the other months.

1. Introduction

While it is generally known that the duration of bright sunshine is negatively associated with cloudiness and rainfall at a place, the extent and magnitude of the relationship are not so well known. There are very few detailed studies of the subject. Bilham (1938) has remarked that the relationship between cloud and sunshine is not so simple and direct as might be supposed. In this connection it is also of interest to know whether it is unusual in any month to couple high rainfall with a quota of sunshine above normal. Thus for a proper study of the subject it is necessary to have a long record of sunshine, hourly rainfall and frequent if not hourly observations of cloud during day time. While the first two are available for some stations in India for a long period, the same is not the case with cloud observations. In fact, till about two decades back very few Indian stations recorded even two observations daily. Fortnuately Bombay (Colaba) has a long record of five to six observations of cloud amount daily during day hours.

In the present paper it is proposed to examine the aspects mentioned above for Bombay which has an annual average rainfall of over seventy inches. The main rainy months are June to September. May, October and November have also been considered as these receive some rainfall. After indicating the extent of Bombay records for purposes of analysis brief description of the principal features of sunshine, cloud and rainfall is given in the next three sections with the aid of relevant tables. In Section 6 the distribution of sunshine in the five wettest years is considered followed by a list of years when sunshine and rainfall were both above average. Correlation among the different elements is studied in Section 8. Inter-correlations are given in Section 9. A comparison is then made with similar results for England. The paper concludes with a summary of the main results of the paper.

2. Data

2·1. A Campbell-Stokes sunshine recorder is in regular operation at Colaba Observatory, Bombay (Lat. 18° 54′N, Long. 72° 49′ E) since 1926. The monthly means and frequencies are published in the annual volumes of the observatory. The data of hourly rainfall recorded at the same site and occurring between 06 to 19 hours local mean time only have been considered. In addition to rainfall, rainy days have also been examined. A day of rain is one on which a measurable amount has been recorded between 06 and 19 hours local time. The average rainfall during May and November is about 0·3″ and the average number of days of rain less than 1.

2·2. *Cloud observations* — At Colaba the total amount of cloud is being recorded daily six times during the day-light hours.

1926–29 : 6, 8, 10, 12-30, 14 and 16 hrs (Local Time)

1930–41 : 6, 8, 10, 12-30 and 16-30 hrs (Local Time)

1942–46 : 6-30, 8-30, 10-30, 12-30 and 17 hrs IST

1947–48 : 6-30, 8-30, 10-30, 12-30, 14-30 and 17 hrs IST

1949 to date : 6-30, 8-30, 10-30, 11-30, 14-30 and 17-30 IST.

As the observation at 14-30 hours were not taken during the years 1930–46, the monthly means for each of these years were corrected by using the mean from 1947–1960. The mean daily cloud for 06 to 19 hours is taken simply as the arithmetic mean of the six different observations mentioned above. While this may not appear entirely satisfactory, yet the average is not likely to be much out from the average for the period 06 to 19 hours, as the observations are well distributed. The period

TABLE 1

Distribution of mean monthly sunshine 1926—62

Hours	May	June	July	August	September	October	November
0·1—1·0			1				
1·1—2·0			21	4			
2·1—3·0		2	8	13	1		
3·1—4·0			6	18	3		
4·1—5·0		11	1	2	10		
5·1—6·0		11			16	1	
6·1—7·0		8			4	2	1
7·1—8·0	2	4			3	11	4
8·1—9·0	4	1				17	6
9·1—10·0	15					6	22
10·1—11·0	13						4
11·1—12·0	3						
Average (Av) (1926—62)	9·8	5·6	2·2	2·9	5·2	8·2	9·3
Median	9·7	5·6	1·8	3·2	5·2	8·2	9·5
Highest % of Av	114	145	191	148	148	117	112
Lowest % of Av	80	43	45	38	52	70	67
Range %	34	102	146	110	96	47	45
SD	·92	1·25	·85	·75	1·08	·82	·84
Coefficient of variation (%)	9	22	39	26	21	10	10
DECADE MEANS							
1926—35	10·7	6·2	2·5	3·2	5·5	8·1	9·5
1936—45	9·9	5·4	2·1	3·3	5·6	8·7	9·4
1946—55	8·4	5·1	2·1	2·7	4·5	8·1	9·3
Linear trend	—0·64	—0·12	—0·05	—0·05	—0·26	—0·38	—0·04

TABLE 2

Diurnal variation of bright sunshine (1951—60)

	Local Time											
	6—7	7—8	8—9	9—10	10—11	11—12	12—13	13—14	14—15	15—16	16—17	17—18
May	·14	·64	·82	·87	·90	·90	·93	·93	·93	·93	·89	·41
June	·09	·33	·46	·51	·54	·53	·52	·56	·54	·53	·45	·21
July	·01	·09	·23	·28	·26	·25	·27	·29	·28	·22	·15	·04
August	·01	·09	·24	·27	·28	·28	·27	·27	·25	·24	·16	·04
September	·01	·21	·47	·55	·57	·60	·61	·62	·60	·59	·40	·11
October	·10	·54	·76	·81	·84	·85	·89	·87	·87	·79	·64	·13
November	·03	·73	·89	·93	·92	·92	·92	·90	·90	·90	·86	·14

TABLE 3

Distribution of mean monthly cloud amount (1926-62)

Octa	May	Jun	Jul	Aug	Sep	Oct	Nov
0·1—1						1	7
1·1—2	9					6	16
2·1—3	19					11	10
3·1—4	6	1			1	17	4
4·1—5	3	10			9	2	
5·1—6		19			21		
6·1—7		5	13	29	6		
7·1—8		2	24	8			
Average cloud amount (octa), 1926–55	2·26	5·5	7·1	6·7	5·5	2·8	1·8
Coefficient of variation (per cent)	27	15	5	5	11	33	50

of data used for sunshine and cloud is from 1926–62 and for rainfall 1926–55.

3. Sunshine

Frequency distribution of monthly means of sunshine together with mean, median, extremes and standard deviation (SD) are given in Table 1. Decade means and C.Cs. between sunshine and years are also included.

3.1. July with the lowest monthly average sunshine of 2·2 hrs/day is the most variable with 40 per cent. The extreme monthly means have ranged between 191 and 45 per cent of average, giving a range of 146 per cent — the highest for any of the months. This large variation in sunshine may account for the poor association with rainfall in July. In 21 out of 37 years (about 60 per cent), the monthly means varied between 1·1 and 2·0 hrs/day with a median value of 1·8 which is 20 per cent less than the average. During August the position is reversed. 86 per cent of the years had monthly averages ranging between 2·1 and 4·0 hrs/day and the median 3·2 is higher than the mean by 10 per cent. Such a feature is not noticed in the other months. In fact, the mean and median are nearly the same in May, June and September to November.

3.2. The non-monsoon months May, October and November have highest monthly average sunshine. A point of interest is the very low variability of 10 per cent in these months. During 37 years the highest monthly mean was 11·3 hrs/day in May which is only 115 per cent of the average.

3.3. The highest monthly mean for any of the months has not exceeded twice the corresponding monthly average. The lowest was 38 per cent of the average in August. The range is least for non-monsoon months, being ony 34 per cent in May. August with a slightly higher average than July,

has recorded only 50 per cent higher than the corresponding monthly average.

3.4. *Diurnal variation of sunshine* — The difference between the lowest and highest hourly means of sunshine between 9 and 16 hrs L. T. is less than 5 minutes suggesting near uniformity in these hours. It is, therefore, difficult to fix the hour of maximum, though the hour 13–14 has generally the highest hourly mean.

3.5. The average frequency distribution of daily totals in hours of bright sunshine using data for 1951–60 has also been examined. On an average, there are twelve days in July and eight in August with no sunshine. Such occasions are very rare in May, October and November. During a ten-year period, the highest sunshine on any individual day was 11·9 hrs. In June the frequency distribution is nearly uniform in the range from 1·1 to 10 hrs.

3.6. Decade means and linear trend C.Cs. suggest that in May there has been a steady decrease. A lower order of trend is noticed in August and September.

4. Cloudiness

A feature of interest is the very low variability-only 5 per cent — for July and August with a cloud average of 7 octa. In July, 24 of the 37 years had monthly means between 7·1 and 8 octa and rest between 6·1 to 7 octa. For August, the corresponding frequencies are 8 and 29.

5. Rainfall

5.1. Rainfall during day is heavier in June than in August or September. July receives (15″) nearly double of that in August or September. In spite of good rainfall in the monsoon months the variability is high being 43 per cent in July and 91 per cent in September. The months, May to November, practically account for almost the entire annual rainfall.

TABLE 4

	May	Jun	Jul	Aug	Sep	Oct	Nov
Average daytime (6–19 hrs L.T.) rainfall (inches)	0·29	10·73	14·76	7·96	6·62	1·43	0·29
Coefficient of variation (per cent)	290	51	43	58	91	139	210
Average No. of rainy days (6–19 hrs)	0·8	15·4	25·7	22·1	14·2	3·2	0·9
Coefficient of variation (per cent)	173	28	13	20	38	90	163

TABLE 5

				Percentage of average sunshine			
	<60	61—70	71—80	81—90	91—100	101—110	111—120	>120
May				1	4			
June	1		1	1	1	1		
July	2			2				1
August	1					2	2	
September	1	2		1		1		
October		1		1	3			
November		1		1	2	1		

TABLE 6

Year	Percentage of average		Year	Percentage of average	
	Rain	Sunshine		Rain	Sunshine
	JUNE			AUGUST (contd)	
1927	185	108	1946	269	118
1928	140	106	1945	154	114
1935	118	114	1949	143	111
1952	152	103	1954	166	108
	JULY			SEPTEMBER	
1926	117	173	1930	258	111
1928	108	160	1935	123	103
1945	120	124	1942	107	109
1949	115	119		OCTOBER	
1952	107	109	1941	108	115
1953	151	124	1943	137	106
			1933	166	101
	AUGUST			NOVEMBER	
1928	116	141			
1933	112	128	1931	593	103
1938	172	111			

5.2. *Rainy days* — Table 4 shows that July with 26 days is the highest. Although August (22 days) has a fifty per cent higher average than June (15 days), June gets about 30 per cent more rainfall than August. The variability is much less than for rainfall and it is as low as 13 per cent for July.

6. Sunshine in five wettest years

The distribution of sunshine as percentage of average, for the five wettest years in each of the months May to November, is given in Table 5. While the mean of August in these five years is almost the same as the thirty-year average, in four of these, both sunshine and rainfall were above average. In two of these years when the number of days of rain was nearly the same, sunshine was 13 and 17 per cent above the average. Actually in one of these two years rainfall was highest being 269 per cent of average and sunshine was also highest being 117 per cent of average. There was, however, only one such year in each of the months June, July, September and November. In October and May, there were no years when both rainfall and sunshine were simultaneously above the average.

7. Rainfall and Sunshine above average

The years in each of the months when rainfall and sunshine were simultaneously above average are given in Table 6.

Table 6 shows clearly that the frequency of simultaneous positive deviations of sunshine and rainfall from their respective averages is rather large. In July and August these have been most frequent and have occurred even in the same year in both the months. It is difficult to account for this frequency particularly in the monsoon when the skies are nearly overcast.

Hawke (1958) in a similar study has found a dozen calender months from 1909 to 1948 combining more than average general sunshine with general rainfall exceeding the average by at least 40 per cent over England and Wales. In Bombay a dozen such occasions have occurred in a 30-year period.

8. Correlations

In order to study the relationship between sunshine and (*i*) rainfall, (*ii*) cloudiness and (*iii*) rainy days, correlation coefficients (C.Cs.) were worked out (Table 7).

8.1. *Sunshine and Cloudiness* (r_{sc})

Note the negative association in all the months. The C.Cs. are about $0 \cdot 8$ but for June and July they are nearly $0 \cdot 9$. All of them are highly significant statistically even at 1 per cent level of significance.

8.2. *Sunshine and Rainfall* (r_{sr})

The relationship is also negative for all the months but the magnitudes are much lower than for cloud. The C.Cs. for July and August are not statistically significant even at 5 per cent. May C.C. is not significant at 1 per cent.

8.3. *Sunshine and Rainy days* (r_{sn})

As above, all the C.Cs. are negative. The C.Cs. for June to November excepting July are higher than in the case of rainfall. July C.C. is lower and insignificant as before. May is just significant at 5 per cent. The improvement in C.Cs. for June, August and November over r_{sr} is noteworthy. For June it is as high as r_{sc} and for November it is even higher. Somehow July is low and insignificant though for the comparable August the value is $-0 \cdot 53$. While the negative sign of r_{sr}, r_{sc}, and r_{sn} is explainable in general physical terms, the position completely changes when the magnitudes of the different elements are correlated. For the same degree of sunshine, cloudiness, rainfall and rainy days vary very widely. What is, however, of interest is that in spite of this, all r_{sc} and some of r_{sn} are as high as $0 \cdot 8$. The frequency of like signs of deviations of S, C, R and N from their respective averages irrespective of their magnitudes is given in Table 8.

8.4. The frequency of like signs of rainfall and sunshine deviations is much higher in the monsoon months than for cloudiness and rainy days. The low C.Cs. (r_{sr}) and r_{sn} for July should be attributed to the very large percentage of like signs (50 per cent) for rainfall and 40 per cent for rainy days. The corresponding figure for cloudiness is very small and only 8 per cent, a sixth of the figure for rainfall. The small frequency of like signs gives a much higher negative C.C. for cloud but it is difficult to account for high C.Cs. in the table for r_{sn} with such a large percentage of like signs, as compared with cloudiness.

8.5. The C.C. between July sunshine and number of rain-hours, *i.e.*, hours during which there was measurable rainfall, was also worked out using data of 10 years and it is $-0 \cdot 63$. This is a considerable improvement over rainfall C.C. A similar analysis for August shows the C.C. to be only $-0 \cdot 64$.

8.6. *July correlation*

In order to study whether the type or kind of cloud has any direct connection with sunshine in July, hourly values of each day of July 1962 were critically examined. Information of the kind of cloud is available for three hours only — 0830, 1130 and 1730 IST. The observations on three sample days are given in Table 9. Clearly there is no connection between sunshine and rainfall

TABLE 7

	May	Jun	Jul	Aug	Sep	Oct	Nov
r_{sc} (1926—62)	—0·82	—0·88	—0·86	—0·77	—0·78	—0·78	—0·71
r_{sr} (1926—55)	—0·43	—0·59	—0·29	—0·27	—0·59	—0·58	—0·59
r_{sn} (1926—55)	—0·38	—0·84	—0·21	—0·53	—0·65	—0·68	—0·90

TABLE 8

			May	Jun	Jul	Aug	Sep	Oct	Nov
C—$\bar{C}$, S—$\bar{\bar{S}}$ (1926—62)	—	—	7	2	2	2	1	2	1
	+	+	1	3	1	2	1	3	6
R—$\bar{R}$, S—$\bar{\bar{S}}$ (1926—55)	—	—	10	5	9	5	8	7	5
	+	+	0	4	6	7	3	2	1
N—$\bar{N}$, S—$\bar{\bar{S}}$ (1926—55)	—	—	7	3	7	3	5	8	1
	+	+	2	3	5	5	2	2	2

TABLE 9

		6–7	7–8	8–9	9–10	10–11	11–12	12–13	13–14	14–15	15–16	16–17	17–18	18–19 (hrs)
4 July 1962	S	0	0	·8	1·0	1·0	·7	·9	1·0	1·0	·1	0	0	0
	R	0	0	0	0	0	0	0	0	0	0	·3	·5	3·5
	AC	8		7		4	5			6			7	
	C			Sc 3			Cb 1						Sc 2	
				As 4			Sc 1						Cb 2	
							As 2						Ac 3	
							Cs 1							
5 July 1962	S	0	0	0	0	0	0	0	0	0	0	0	0	0
	R	0	0	0	0	·3	21·0	1·8	·5	2·2	·3	1·0	·1	
	AC	8		8		8	8			8			8	
	C			Sc 1			Cu 2						Fs 3	
				Cb 1			Sc 2						As 3	
							Ns 2							
				As 6			As 2							
26 July 1962	S	0	0	0	0	0	0	0	0	0	0	0	0	0
	R	0	0	0	·2	0	0	·5	1·1	0	0	0	0	·3
	AC	8		8		8	8			8			8	
	C			Cu 2			Fs 4						Cu 2	
				Sc 1			As 3						Sc 1	
				Ac 2			Ns 1						Ac 2	
				As 3									As 3	

S — Sunshine,   R — Rainfall (mm),   AC—Amount of cloud,   C — Kind of cloud

TABLE 10

	Jun	Jul	Aug	Sep	Oct	Nov
May	+0·26	—0·02	—0·01	—0·37	+0·05	+0·15
June		+0·13	+0·03	+0·20	+0·01	+0·41
July			—0·14	+0·21	+0·08	+0·18
August				—0·09	+0·11	+0·10
September					—0·07	—0·03
October						+0·10

TABLE 11

	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
r_{sr}	—0·03	+·08	—·67	—·71	—·61	—·55	—·62	—·56	—·46	—·29	—·15	—·10
Average rainfall (1881—1915)	2·99	2·57	2·67	2·12	2·30	2·44	2·87	3·35	2·54	3·97	3·49	3·92

numerically. This may to some extent account for the very low correlation.

9. Inter-correlations

Is the sunshine of any month related significantly with the other months? Of the 21 inter C.Cs. (Table 10), only two are about 0·4 and just statistically significant at 5 per cent but not at 1 per cent. All the others, a few of them are close to zero, are not significant. It may thus be stated that the sunshine of any month is not an indicator of the sunshine in the preceding or succeeding months.

10. Comparison

There seem to have been very few studies giving the actual C.C. between sunshine and rainfall. One of these is by Hawke (1958). Even he has given only approximate values of the C.Cs. between monthly general rainfall and monthly general sunshine over England and Wales (1908–33).

Although rainfall is so nearly uniformly distributed throughout the year as compared to Bombay, yet five of the twelve C.Cs. are not statistically significant. The C.C. for January is close to 0 while that of February is also very low but is surprisingly positive (Table 11). The association between rainfall and sunshine is rather complex. It has already been remarked how in the case of Bombay, the C.Cs. are very high in the non-

monsoon months and low in the two most intense monsoon months.

11. Summary

1. July has the lowest average number of hours of sunshine (2·2 hours per day) and hence also the largest number of days (12) with no sunshine.

2. The variability of sunshine is least (10 p.c.) in the non-monsoon months May, October and November. There is practically no diurnal variation between 9 and 16 hrs (L.T.), the maximum difference in duration is less than five minutes. July and August have practically the same hourly averages.

3. There were 23 months in the 30 years examined in which the monthly means of sunshine and rainfall were simultaneously above their respective averages.

4. Sunshine is negatively correlated with cloud, rainfall and rainy days. r_{sc} is generally —·8 and —·9 for June and July. (—·2 to —·3) C.C. calculated for hours of rain for July is —0·63.

5. The frequency of like signs of deviations from their respective averages is maximum between sunshine and rainfall and in monsoon months.

6. Sunshine in any month is not significantly correlated with the other months.

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