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Solar effect on rainfall in West Bengal

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सार — वर्षा की सामान्य विशेषताएं तथा पश्चिमी बंगाल के 8 स्थानों पर 1931-81 के दौरान सूर्य धब्बे (कलंक) से इसके सहसंबंध का अध्ययन किया गया है । घटते अक्षांश की बढ़ती प्रवृत्ति के साथ ≈ 20 प्रतिशत औसत प्रसार देखा गया है । तीन वर्ष के गतिमान औसत विश्लेषण से पता चलता है कि जब भी सूर्य धब्बे की संख्या बढ़ी है या घटी है उसी के साथ अधिकतम सौर वर्षों को छोड़कर वर्षा भी बढ़ी या घटी है । किन्तु वर्षा चक्र की औसत अवधि सौर चक्र की अवधि 5.5 वर्ष से आधी है । यह अवधि दक्षिणी दोलन के अनुरूप है । इसके अतिरिक्त अधिकतम एस एस वर्षों में एस एस संख्याओं की वृद्धि के साथ वर्षा कम हो जाती है । विभिन्न सूर्य धब्बे चरणों के दौरान औसत वर्षा की गणना से यह संकेत मिलता है कि वर्षा की वार्षिक दर न्यूनतम से अधिकतम सौर चरण की अपेक्षा अधिकतम से न्यूनतम सौर चरण के दौरान अधिक होती है । तथापि वार्षिक दरों में अन्तर अधिक नहीं है, दो स्थानों के लिए 15 प्रतिशत तथा अन्य स्टेशनों के लिए इससे भी कम विकास दर निदर्श के उपयोग से यह पाया गया है कि 69 प्रतिशत मामलों में सूर्य धब्बे संख्या के घटने के साथ ही वर्षा भी घट जाती है । इसके बाद, जब उप-हिमालयी पश्चिमी बंगाल तथा गांगेय पश्चिमी बंगाल क्षेत्रों की विकास दर तथा अन्य बातों का अलग से अध्ययन किया गया तो यह पाया गया कि इन दो स्थानों की वर्षा सौर गति-विधियों से उल्टी दिशा में प्रभावित होती है । उसी वर्ष, पिछले वर्ष तथा दो वर्ष पहले की वर्षा और सूर्य धब्बे के मध्य सह-संबंध गुणांक $\leqslant +0.35$ आया जो अधिकांशतः धनात्मक होता है । इसके अलावा, आगामी वर्ष की वर्षा पर सूर्य धब्बों का प्रभाव सबसे अधिक दिखाई पड़ता है ।

ABSTRACT. The General characteristics of rainfall and it's correlation with sunspot during 1931-81 over 8 stations in West Bengal have been studied. An average dispersion of $\approx$ 20% has been noticed with an increasing tendency for decreasing latitude. Three years moving average analysis reveals that whenever the sunspot number increases or decreases the rainfall does so almost simultaneously except during solar max. years. But average period of rainfall cycle is half of the period of solar cycle, *i.e.*, 5.5 years, a period compatible with the southern oscillation. Moreover, in SS maximum years the rainfall decreases with the increase of SS number. Calculations of average rainfall during different sunspot phases indicate that the annual rate of rainfall is greater during solar maximum to minimum phase than that during minimum to maximum phase. However, the difference in the annual rates is not much, only 15% for two stations and much less for other stations. Using a growth rate model it is found that in 69% cases the rainfall decreases as sunspot number decreases. Further when the growth rate and other studies of rainfall in Sub Himalayan West Bengal and Gangetic West Bengal are made separately it appears that the rainfall of these two regions are oppositely affected by solar activities. The correlation coefficients between rainfall and sunspot of same year, of previous year and of two years before have come out as $\leqslant +0.35$ and mostly it is positive. Further, sunspot's influence seems to be most effective on rainfall of the following year.

1. Introduction

The possible influence of solar activity on weather and climate has become an important scientific topic of this century. Many scientists possess a critical view to this (*vide*, *e.g.*, the review article by Pittock 1978), but some others strongly believe that there exists relationship between solar activities (*e.g.*, magnetic structure, solar wind and radiation) and the earth's atmosphere and climate (*e.g.*, Wilcox 1973, Bucha 1980, 1983). With reference to the work in India, Jagannathan and Bhalme (1973) arrived at conclusion that south west monsoon circulation in India has a periodicity nearing sunspot cycle. Sengupta (1957) found an inverse relationship between sunspot cycle and days of excessive heavy precipitation over Tamilnadu (south India). Bhalme and Mooley (1981) with the help of Power spectrum and cross spectrum analysis have correlated the flood area fluctuation with 22 years (double) sunspot cycle. However, it is true that the results of these works on the influence of solar activity on weather/climate are yet to appear as fully consistent. For example, for Addis-Ababa (in Ethiopia) a positive correlation (max + 0.33) was obtained between sunspot and rainfall of 2 years before, whereas for Asmara (another station in Ethiopia) a negative correlation has been

TABLE 1

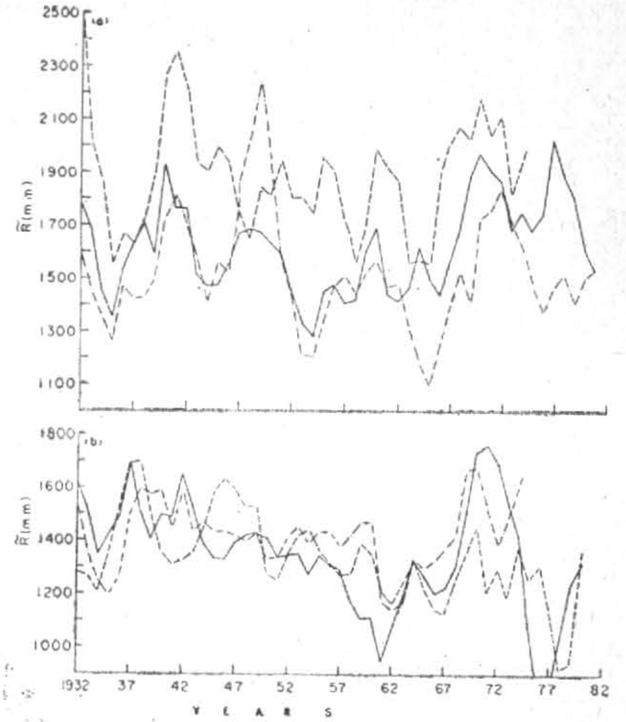
Station	$(\overline{R})$ (mm)	(σ) (%)	Max. rain (mm)	Min. rain (mm)
(A) Darjeeling	2773	15.4	3792 (1950)	2098 (1976)
(B) Jalpaiguri	3244	17.2	4292 (1938)	2278 (1947)
(C) Malda	1344	21.9	1938 (1981)	601 (1972)
(D) Krishnagar	1424	18.3	1960 (1974)	949 (1972)
(E) Burdwan	1356	21.9	2044 (1971)	690 (1976)
(F) Calcutta	1630	19.1	2429 (1978)	909 (1935)
(G) Midnapore	1529	22.8	2480 (1949)	761 (1954)
(H) Sagar Island	1899	20.4	2753 (1931)	1382 (1957)

observed (Wood and Lovett 1974). However, in the present study also we take up the problem of same type, namely, the solar effect on rainfall.

Rainfall and other meteorological parameters though depend on different factors, *e.g.*, Orography, pressure distribution, air pollution etc, but many, in turn, may depend upon solar activities. Now a good measure for solar activities is sunspot (SS) number. Thus it is worthwhile to find correlation between the rainfall and SS number, and also to find the characteristic features of rainfall during SS_{max} phase and SS_{min} phase. The present study is the analysis of rainfall pattern over West Bengal* during 1931-1981 for which eight stations in different districts have been chosen. The analysis has two parts. In the first part the mean, dispersions, the variation of three year's moving average of rainfall with that of SS number, average rate of rainfall and growth rate (GR) of rainfall during max. to min. and min. to max. phases of sunspot have been calculated. In the second part, correlation between rainfall of different stations with SS number have been found out. Lastly the dependence of this correlation factor on latitude have also been calculated. The present analysis ends at the conclusions and remarks which are in favour of saying that solar influence is there on the rainfall pattern over West Bengal which is, however, not similar everywhere. Further, a few suggestions and long term forecasts are also made.

2. General characteristics of rainfall

To understand the rainfall pattern over West Bengal* eight representative stations in different districts have been chosen. The stations are (A) Darjeeling (27° 03′N, 88° 16′ E), (B) Jalpaiguri (26° 32′ N, 84° 43′E), (C) Malda (25° 02′ N, 88° 08′ E), (D) Krishnagar (23° 24′ N, 88° 31′ E), (E) Burdwan (23° 14′ N, 87° 51′ E), (F) Calcutta (22° 32′ N. 88° 20′ E), (G) Midnapore (22° 25′ N, 87° 19′ E) and (H) Sagar Island (21° 45′ N, 88° 03′ E).



Figs. 1(a&b). Three years running average rainfall *vs.* years about which means have been calculated

For Fig. 1(a). Sagar Islands — — — —
Calcutta ————
Midnapore —.—.—.—

For Fig. 1(b). Malda — — — — —
Burdwan ————
Krishnagar —.—.—.—

[For Burdwan the value of R corresponding to the years 1976 and 1977 are 825 mm and 893 mm respectively]

The yearly rainfall data collected for all these stations are for 51 years from 1931 to 1981 except the stations (D) and (H) for which data upto 1975 were taken.

2.1. *Mean and dispersion*

The mean rainfall $(\overline{R})$, dispersion (σ) about the mean rainfall (obtained from standered deviations) and the amount of maximum as well as minimum rainfall (with corresponding years) have been shown in Table 1. It could be observed that (*i*) the mean rainfall decreases as the latitude increases from Bay of Bengal towards Himalaya. But suddenly the rainfall becomes very large at Jalpaiguri (B) and Darjeeling (A) which are very close to Himalaya, (*ii*) The average dispersion is $\approx$ 20% while the station G has maximum dispersion (23%). Further, there exists a weak tendency of decreasing dispersion with increasing latitudes, (*iii*) Darjeeling (A) and Jalpaiguri (B) have highest maximum or minimum rainfall and also have max./min. rainfall which are much greater than the max./min. rainfall of other stations.

*A state in eastern India having an area 87,853 sq km and betwee 21° 45′N & 27° 03′N.

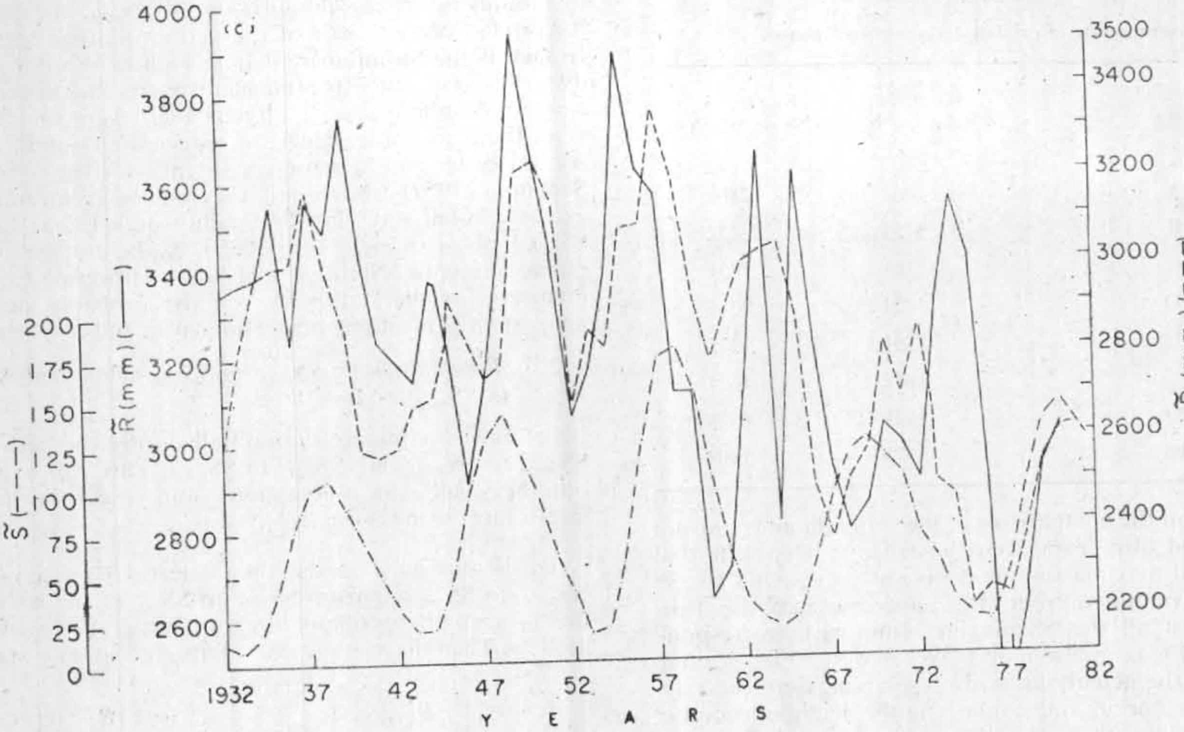


Fig. 1(c). Three years running average *vs.* years about which means have been calculated ——— Darjeeling, - - - - Jalpaiguri, —. —. —. sunspots (SS) [For Jalpaiguri the value of R for the year 1977 is 2412 mm]

TABLE 2

Moving avg. value of SS max	Years	Moving avg. values of rainfall (mm) for							
		A	B	C	D	E	F	G	H
104.3	1937-39	3005	3488	1695	1596	1509	1704	1428	1727
125.4	1968-70	2571	2852	1349	1667	1512	1890	1409	2031
140.9	1947-49	2779	3471	1530	1401	1419	1689	2021	1650
145.7	1979-81	2616	3022	1369	—	1325	1617	1504	—
178.0	1957-59	3195	3116	1280	1420	1181	1420	1444	1561

2.2. *Three years' moving average*

The three years moving average values of rainfall ($\widetilde{R}$) and sunspot no. ($\widetilde{S}$) have been calculated by taking the mean for consecutive three years, *i.e.*, for any year n with corresponding value R_n; the moving average is given by $\widetilde{R}_n = \frac{1}{3} [R_{n-1} + R_n + R_n + {}_1]$. These values are plotted to find the overall mode of variation fof $\widetilde{R}$ with $\widetilde{S}$. In general the rainfall curves in Figs. 1(a), 1(b) and 1(c) indicate the following :

(a) During the period under consideration there are 9 maxima and 9 minima in the rainfall curves whereas for sunspot curve there are [*see* Fig. 1(c)—. —.] 5 maxima (1937, 47, 57, 70, 79) and 5 minima (1933, 44, 54, 64 76). Thus approximately 3 years is the time required for rainfall to reach from maxima to next minima or minima to next maxima of rainfall, and between two consecutive sunspot maxima or minima there occurs roughly two peaks and two troughs for rainfall, *i.e.*, in general *5.5 years is the time interval between two consecutive maxima or minima of rainfall.* This period is most probably due to southern oscillation. However, many astronomers claim that there exists sub-periodicity of solar activities of 5-6 years. It is, therefore, not yet possible to denounce the bearing of such solar periodicity on the observed 5.5 years periodicity of rainfall.

TABLE 3

Average rate of rainfall during sunspot phases

Stations	$\dot{R}_T$ (mm/yr.) SS_{max} to SS_{min}	$\dot{R}_T$ (mm/yr.) SS_{min} to SS_{max}
A	2804	2801
B	3255	3232
C	1361	1331
D	1454	1385
E	1461	1272
F	1652	1624
G	1628	1416
H	1879	1908

(b) From the comparison of the rainfall and sunspot curves and also from above discussion it is clear that all rainfall maxima (minima) do not correspond to SS maxima (minima), but the converse may be true, *i.e.*, almost all the SS maxima (minima), correspond to rainfall maxima (minima). What we find in general, is that in the neighbourhood of solar maxima the rainfall maxima occur and similarly in the neighbourhood of solar minima the rainfall minima occur. There is, however, one or two years difference between the peaks of the moving average curves of some of the stations.

In general, the rainfall appears to increase with SS number. But if we now want to pinpoint the behaviour of rainfall in the solar maximum years we find that usually the rainfall is not maximum.

(c) The effect of solar activities appear as opposite (to that described in 'b') in nature if rainfall of solar maximum year only are compared, namely, the rainfall of those years become less and less as the SS number is greater and greater. The station G, however, exihibit non-consistent behaviour during 1947-49. This effect becomes most prominent in 1957-59 when SS no. reached a record mark. In fact, at that time the rainfall of all the stations except A & B was significantly less.

This effect is particularly prominent for the stations C to H where one can find that average values of rainfall of these stations are 1610, 1643, 1618, 1454 and 1384 mm for the SS nos. in ascending order as in the Table 2. These values suggest that there may be some critical value ($\geqslant$141) of SS no. above which the said effect is prominent.

Comparison of rainfall at solar max. years indicate that there could exist a tendency to decrease the rainfall with increase of SS number (*see* Table 2). This being the opposite in nature to that observed in previous section implies that the SS number reduces the rainfall provided it exceeds some critical value.

Thus summarising one can *say except a few cases the increase of SS number enhances the rainfall of any year provided the year under consideration is not a solar maximum year*. Therefore, the duration from SS_{min} to SS_{max} cannot be same as the duration from min. rainfall to max. rainfall. Rather there being a decrease of rainfall in the neighbourhood of SS_{max}, the period for rainfall curve is half of the period of solar activity. In fact, if the SS number is quite high or if solar wind disturbes very much the magnetosphere and hence the lower atmosphere (*see*, *e.g.*, Bucha 1980) as in solar max. year, there arise a tendency, to reduce the rainfall. The second result is in a sense consistent with the result of Sengupta (1957) who found the regular recurrence of excess rainfall days in Tamilnadu (south India) during SS_{min} phase from 1906 to 1955 (*i.e.*, before the occurrence of record SS number of 1957). However, the discrepancy for the station A is most probably due to geographical positions near Himalayan hills.

2.3. *Rainfall during SS_{max} to SS_{min} phase and SS_{min} to SS_{max} phase*

Let us now compare the rainfall during the periods : SS_{max}. to SS_{min} and SS_{min} to SS_{max}. This will average out the small scale fluctuations, and reveal the trends prevailing during those two phases.

To do this let n_i is the time interval (in year) from SS_{max} to SS_{min} or from SS_{min} to SS_{max} * and let there are '*m*' such phases of any category during the year 1931-1981. Then the average rate of rainfall at any station is defined by $\dot{R}_T = \frac{1}{m}\sum\frac{R_{T_i}}{n_i}$ where R_{T_i} represents the total rainfall during n_i years. Using the above formula and taking rainfall date the average values $\dot{R}_T$ for all stations have been calculated (*vide* Table 3). We note the following salient features :

(*i*) For all stations the average rainfall is greater during SS_{max} to SS_{min} than that during SS_{min} to SS_{max} except for the station (H). Of course, only for E & G stations the difference of the rates is 15% otherwise the difference is much smaller.

(*ii*) The rate is almost same over the region C to G but suddenly increased at the stations B and A which are close to Himalayan hills.

(*iii*) The difference of rainfall rates between SS_{max} to SS_{min} and SS_{min} to SS_{max} phases tends to increase with decrease of latitudes.

2.4. *Growth rate* (*GR*)

In this section the variational tendency of rainfall in solar maximum year with respect to that in solar minimum year or *vice versa* has been studied by a growth rate model.

$C_{n+i} = C_i\,(1 + \dot{C}_{n+i})^n$ where C_i and C_{n+i} represent the rainfall or sunspot value in *i*th year and $(i+n)$th year, $\dot{C}_{n+i}$ represents the growth rate at $(i+n)$ th year and *n* represents the interval in year from one maxima (or minima) to next minima (or maxima). The Table 4 consists of such values for the eight different stations in West Bengal with a time span 1933 to 1979.

The following are the main observations ;

(1) During sunspot maximum to minimum phase the GR of rain comes out to be negative in 69% cases which implies that in 69% cases the rainfall decreases as sunspot no. decreases.

*SS_{max}. year to one year before SS_{min}. is defined as the period SS_{max} to SS_{min} and also SS_{min} to one year before SS_{max} as SS_{min}. to SS_{max}.

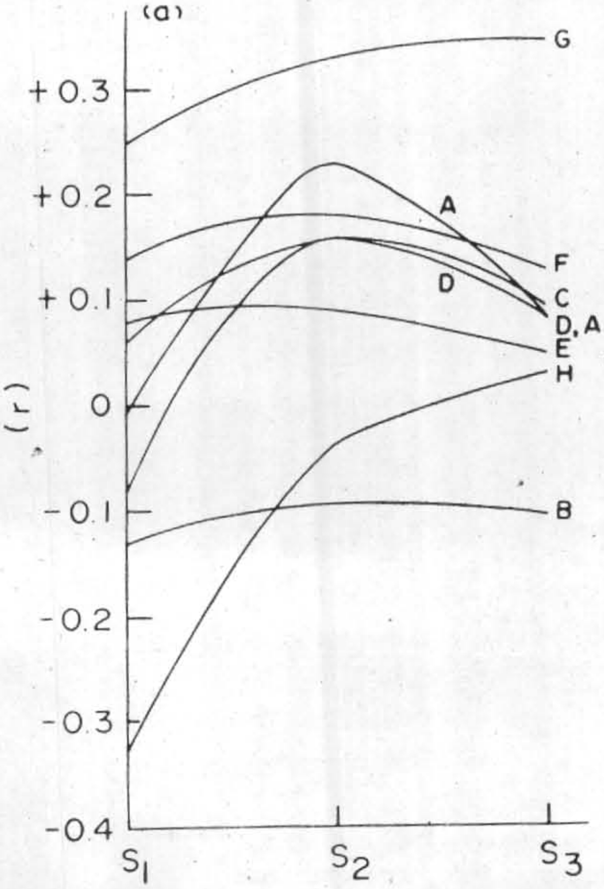


Fig. 2(a). Variation of correlation factor (r) between sunspots and rainfall of different stations

TABLE 4

Growth rates of SS number and rainfall during different SS phases

SS phase	GR of SS no. (%)	GR of rainfall (%)							
		A	B	C	D	E	F	G	H
1933-37 min-max.	+112	—3.2	—2.0	+8.0	—7.4	—4.9	—2.0	—2.0	—11.1
1937-44 max-min	—30	—0.3	+2.0	—2.8	+1.1	—0.4	—3.6	—2.0	+0.4
1944-47 min-max	+15.1	—4.0	—11.1	+3.4	0	—0.2	+4.8	—3.3	—4.1
1947-54 max-min	—40	+3.5	+6.5	—3.8	—0.5	—2.7	—4.8	—7.2	—0.1
1954-57 min-max	+251	+0.4	—8.5	—3.8	+0.3	—2.7	+2.3	+15.3	—3.8
1957-64 max-min	—34	+0.6	+6.2	+3.5	—2.1	+3.7	+3.0	—0.8	—0.5
1964-70 min-max	+54	—5.3	—4.4	+0.6	+9.5	+4.5	+4.2	+2.1	+9.0
1970-76 max-min	—32	—2.2	—3.8	—1.2	—7.0	—15.0	—2.8	—3.1	—4.8
1976-79 min-max	+123	+6.1	+9.5	—21.9	—	+18.4	—8.4	+5.2	—

(2) In general the GR of rainfall fluctuates with time similar to that of sunspot. Of course, the fluctuation for sunspot no. varies from—30% to+251% while that for rainfall varies only from —22% to +18%, and in most of the cases this fluctuation is ⩽ + 10%.

(3) If we compare the values of GR in any sunspot phase (*say*, max. to min.) with its previous phase (*i.e*, min. to max.) then the following pointsappeared as important :

During sunspot min. to max. phase the GR decreases in 53% cases and during sunspot min. to max. phase the GR increases in 53% cases. But these results are not very much conclusive. So let us divide the stations.

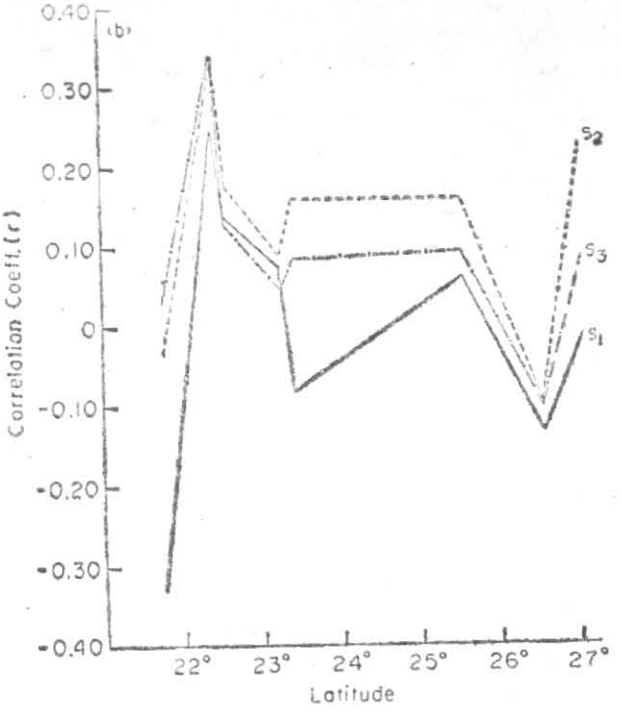


Fig. 2(b). Latitudewise variation of r for SS nos. S_1, S_2, S_3

TABLE 5

Correlation coefficients between sunspot and rainfall of different stations

Sunspot	Stations							
	A	B	C	D	E	F	G	H
S_1	—.013	—.130	+.063	—.080	+.076	+.140	+.250	—.330
S_2	+.230	—.096	+.160	+.160	+.092	+.180	+.330	—.035
S_3	+.085	—.100	+.095	+.085	+.050	+.130	+.350	+.030

into two main groups : Group SHWB, *i.e.*, Sub Himalayan West Bengal consisting of stations A and B and Group GWB, *i.e.*, Gangetic West Bengal consisting of stations C, D, E, F and G.

It is found for "Group SHWB" : that during sunspot max. to min. phase the GR increases in all cases and during min. to max. the GR decreases in 75% cases. But for "Group GWB" during sunspot max. to min. phase the GR decreases in 75% cases and during sunspot min. to max. the GR increases in 68% cases. Evidently the results for groups SHWB and GWB are just opposite in nature.

The stations A, B and C are usually grouped in SHWB. But in our analysis station "C" has been found to have more symmetry with GWB group. Similarly station H although is considered in Gangetic West Bengal, it is not included in GWB because it does not resemble other. Rather it has characteristics quite opposite to that of Group GWB. Nevertheless, we do not treat it as a member of group SHWB because the station H and group SHWB stations are at the two ends of group GWB region separated by 5°18′ latitude. Thus the station H may be considered as a different group and such peculiarity may be due to its geographical position on the Bay of Bengal.

There are two cases, however, when the GR does not show any change. But these two cases occur during sunspot min. to max. phase during 1954-57, when the GR of SS was 251% (max. of all time).

However, the need of present grouping has already been felt in 1.3 (*see* Table 3), 1.2c & 1.1 (Table 1), and it was so prominent that needs no illustration.

3. Correlation between sunspot and rainfall of different stations stations

3.1. Correlation coefficient with sunspot of different years

The value of correlation coefficient (r) between rainfall and SS number of the same year (denoted by S_1), SS number of one year before (S_2) and SS number of two years before (S_3) have been calculated (Table 5) and plotted (Fig. 2a). The table shows that in 71% cases there exists positive correlation.

However, the comparison of the curves in Fig. 2(a) indicate that the sunspot of one year before has comparatively better enhancing effect on rainfall. In other words, the sunspots' influence takes one year to propagate to the region of rainfall (W.B.). In this connection the results observed by Wood and Lovett (1974) may be mentioned. Their analysis for 72 years reveals that in Addis-Ababa maximum positive correlation was $+0.33$ and it exists between SS and rainfall of 2 years before, whereas for Asmara — a negative correlation was obtained. Evidently, this result is not better than the result obtained here at least in one case.

The discussion in sec. 1.2a, b, c indicate that the correlation between SS number and rainfall is not a linear one, rather, after appearance of greater number of SS there arise two opposite tendencies in rainfall. Most probably this is why C.F. had come out as low as $\leqslant +0.35$.

3.2. *Dependence of correlation coefficient* (r) *on latitudes*

The variation of r with latitude could be found in Fig. 2(b) corresponding to the three sets of values of SS number S_1, S_2, and S_3. Following is the observation : Within the zone of our analysis (from 21° 45′ N to 27° 03′N) the curves exhibit wavy tendency. For all three curves one peak occur at latitude 22°25′ N and one trough at Lat. 26° 32′N. In general, fluctuation occurs at about 2° interval but two prominent peaks or troughs occur at an interval 4° 35′. This implies that SS number influences the rainfall in opposite manner at an interval 4° 35′. This effect is almost same in principle as the effect obtained by Wood and Lovett (1974).

4. Conclusion and remarks

The results of the present study lead to the following general conclusions :

(i) The yearly variations in the rainfall over eight districts of West Bengal are not random even it is true that there exists influence of local conditions. Generally, the rainfall rate is directly proportional to the SS no. But if we compare the rainfalls during solar max. years only then rainfall appears to become less and less as the SS number is greater and greater. Thus either the large number of SS greater than some critical value, or other activities of sun during solar max. phase seems to be resposible for reversing the normal influence of sun on rainfall. However, in general the period for rainfall comes out to be 5.5 years which most probably coincide with southern oscillation period.

(ii) Average rate of rainfall is, in general, greater during SS_{max} to SS_{min} phase than that during SS_{min} to SS_{max} phase. But the difference of the rates is not much for most of the stations (2 stations out of 9 have difference 15%). However, this difference becomes insignificant in higher latitudes.

(iii) Growth Rates in most of the cases are not more than $\pm 10\%$. But 70-80% cases imply that rainfall decreases as SS number decreases. This picture is particularly true for the stations in GWB, while for the stations in SHWB the opposite picture is obtained. In this connection it is found that Darjeeling and Jalpaiguri behaved like Sub Himalayan West Bengal and Malda, Krishnagar, Burdwan, Calcutta, Midnapore all have similar behaviour and hence should be called Gangetic West Bengal. This station Sagar Island's rainfall does not coincide with Gangetic West Bengal's rainfall and hence would be considered separately.

However, the opposite behaviour of SHWB and GWB w.r.t. rainfall may be due to local conditions. But it has to be kept in mind that the local condition itself may be affected by solar activities in such a manner that its influence on rainfall is just opposite to the influence of solar activities on rainfall.

(iv) The correlation coefficient between SS number and rainfall comes out to be $\leqslant +0.35$. But the SS number of one year before appears to have a better influence on rainfall and sunspot in general, has an enhancing effect on rainfall. This effect has found to depend on latitude. Most probably due to non-linear behaviour of rainfall the C.F. is as low as $\leqslant +0.35$. Better results could be achieved if one can study the correlation of rainfall in different phases of SS number like SS_{min} to one year before SS_{max} etc.

(v) There are many districts in West Bengal. So the study of rainfall of West Bengal perhaps requires some more districts to be considered. Evidently the periodicity of rainfall can not coincide with the 11-yr. solar cycle due to the reasons (i)-(iii). Nevertheless, the influence of solar activities on this regional rainfall is difficult to be ignored. Of course, the role of solar activities will be understood in a better way if the effect of solar activities on monsoon and iceberg on the Himalaya could be understood. However, it is always true that the uncertainty hidden in the statistical analysis could be removed only when the exact mechanism of solar action on weather is clear.

(vi) There is every likelihood of decreasing the rainfall from 1983 until the sunspot will be minimum (perhaps in 1985-86). After that although the rainfall will slowly increase, during solar maximum (1990-91) it is expected to be greater than that in 1985-86 and also greater than that in 1979 (since in 1990-91 at the 11-yr. cycle the SS number is expected the less than that in 1979). However, all these may occur provided there does not arise any unusual event on sun.

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