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Trends and periodicities in annual rainfall in monsoon areas over the northern hemisphere

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ABSTRACT. Trends and periodicities in annual rainfalls in monsoon areas over the northern hemisphere have been examined. Stations selected for Southeast Asia are Colaba (Bombay), Trivandrum and Colombo; for West Africa they are Accra, Warri, Tower Hill (Freetown) and Dakar; and for Central America, Quito and Colon*. The data were mostly collected from World Weather Records. For finding out long term trends a 25-point ultra low pass sine terminated filter was used to cut off all periods below 12 years. In Southeast Asia, Colaba showed a rise between 1910 and 1955 and then a fall. Trivandrum does not show any significant variation whereas the trend at Colombo is oscillatory. In West Africa amongst the places to the south of Sahara, Accra and Dakar do not show any trend, a general decrease is noticed at Tower Hill and Warri shows an increase. In Central America Colon shows an oscillatory trends whereas Quito does not show any significant variation. There does not appear to be current decrease in the rainfall over African monsoon countries and over India as has been reported by Winstanley (1973). As regards periodicities, analysis were confied to only 11-year and 22-year cycles. Besides being of physical significance these two cycles have long enough period to cause imbalance in drought prone areas. These periods seem to be present everywhere but they do not show and systematic correlations with sunspot numbers. The amplitudes of the oscillation do not exhibit any systematic dependence either on latitude or on longitude. Large differences were noticed even at neighbouring places. Rainfall in these areas because of its strong dependence on local geography, is modulated strongly by other factors to show a poor correlation with sunspot number.

1. Introduction

The drought devastating the Sahel, India and Ethiopia prior to 1973 caused widespread concern. Winstanley (1973) has shown that the rainfall over African monsoon countries and also over India are having a decreasing tendency. Winstanley's conclusions since then have been contradicted at many places. The Indian Meteorological Society (1974) in its journal *Vayu Mandal* states that "studies of rainfall time series in India for more than 100 years by various Indian meteorologists have not indicated any significant periodicity or trend except along the west coast north of 13°N where there has been increase of monsoon rainfall since the beginning of the century till 1960 after which a downward trend began".

The trends in rainfall in West African Sahel have drawn considerable attention following the predictions of Winstanley. In a recent paper Bunting *et al.* (1976) after analysing rainfall data at quite a few stations in this region found that the records do not establish trends or periodicities which can

*Quito and Colon do not fall under monsoon area, yet we have included them to study the trends in Latin American region. At both places the rainfall is quite high. Quito (Lat. 0°13′S) though falls south of geographic equator, it is north of magnetic equator and hence has been included in the analysis.

be used as a basis for extrapolation. Their (Bunting *et al.*) analysis does not include any station in the area surrounding Sierra Leone. Since, it is known that periodicities and trends in rainfall have a marked space dependence, we will discuss here the results of analysis of rainfall records at Tower Hill, Freetown, Sierra Leone. One of the authors (Mukherjee) has collected and compiled the meteorological data for this station and now the series is complete beginning from the year 1875 (Mukherjee and Massaquoi 1973).

The climate has long been known to be dependent on the output of solar radiation. There are long term variations of solar disturbances shown by differences of various kinds. The suggested period lengths are 11, 22-23, 80-89, 178, about 400 and 1700 years. All these cycles will naturally have their influence on climatic conditions, but with the rainfall data presently available, we can only hope to establish the presence in them of 11-year and 22-year cycles and possibly of long term trends.

For our present study we have selected stations covering the monsoon areas of the northern hemisphere. Stations selected for Southeast Asia are : Colaba (Bombay), Trivandrum and Colombo, for West Africa they are Accra, Warri, Freetown (Tower Hill) and Dakar, and for Central America : Quito and Colon (Fig. 1). Analysis were done to locate 11-year and 22-year cycles in these rainfalls and presence of the long term trends.

2. Analysis

The geographical location of the stations and source of the data are shown in Table 1. The Table also lists the length of the series. We did not follow the usual method of power spectrum in identifying peaks. It is known from various earlier studies that the phase relationship between sunspot numbers and rainfall have undergone marked changes at certain epochs. A phase change of this type is bound to suppress the power and hence the identification of the peaks. Instead we designed suitable band pass filter to allow only fluctuations of desired period to pass through. For 11-year cycle a 31-point band pass filter was designed following the method described by Behannon and Ness (1966). For 22-year cycle we used a 41-point filter. For long term trends the series was filtered with a 25-point ultra low-pass since terminated filter having a zero response for periods below 12 years. The filter lengths were largely dictated by the length of the available data.

The filtered series along with the sunspot number are shown in Figs. 2, 3 and 4. Fig. 2 shows the series obtained after applying the 11-year band pass filter. Fig. 3 is the series left after applying the 22-year band pass filter and Fig. 4 is the series left after completely suppressing all fluctuations of period 12-years and below. In Fig. 2 we have also plotted the relative sunspot number. For comparing the features of the 22-year cycle in rainfall variations, we plot in Fig. 3 the double sunspot cycle obtained by changing the sign of sunspot numbers in alternate cycles (Bracewell 1953, Bain 1975). In Fig. 4, the sunspot series given in Fig. 2 is filtered with the same filter that was applied to the rainfall series.

3. Results

The 11-year cycle seems to be present in all series, but its amplitude does not show any systematic dependence either on latitude or on longitude. Even at the same place it undergoes marked changes from time to time. We list in Table 2 the range of the minimum to the maximum fluctuation for each station. The range was estimated for the largest fluctuation observed. The ranges differ widely for different places but when their ratios are taken with the average rainfalls we notice a marked constancy. The fluctuations in either direction consistently fall within 10 to 15 per cent of the average annual rainfall. This is a strong point to suggest that they all have a common mechanism, but some other controlling factors are also operative to modulate their amplitude. Dakar is the only station which shows a big difference from others in this aspect. Here the change is as much at 33 per cent.

We also notice marked differences in behaviour at neighbouring places. Dakar and Tower Hill are good examples. In 1930's when Tower Hill has largest fluctuations, the fluctuations at Dakar are completely suppressed. Almost all places show change in phase with sunspot numbers during differing periods.

The 22-year cycle too is present in most of the series. The ratio of its range with the average rainfall is also shown in Table 2. The ranges for this period are consistently smaller than the range of the 11-year cycle. However, at Colombo and

TABLE 1

Table showing the geographical location of the stations and the sources from which the yearly mean rainfalls have been obtained

Station	Country	Lat.	Long.	Length of series	Source of data
Quito	Ecuador	0° 13′S	78° 30′W	1891—1960	World Weather Records
Accra	Ghana	5° 12′N	0° 12′W	1888—1960	—do—
Warri	Nigeria	5° 31′N	5° 44′E	1909—1960	—do—
Colombo	Sri Lanka	6° 54′N	79° 53′E	1887—1960	—do—
Tower Hill (Free Town)	Sierra Leone	8° N	13° W	1885—1974	Mukherjee and Massaquoi (1973)
Trivandrum	India	8° 29′N	76° 57′E	1890—1972	India met. Dep.
Colon	Panama	9° 21′N	79° 54′W	1882—1960	World Weather Records
Dakar	Senegal	14° N	17° 4W	1887—1974	Landsburg (1973)
Colaba (Bombay)	India	18° 54′N	72° 49′E	1849—1974	India met. Dep.

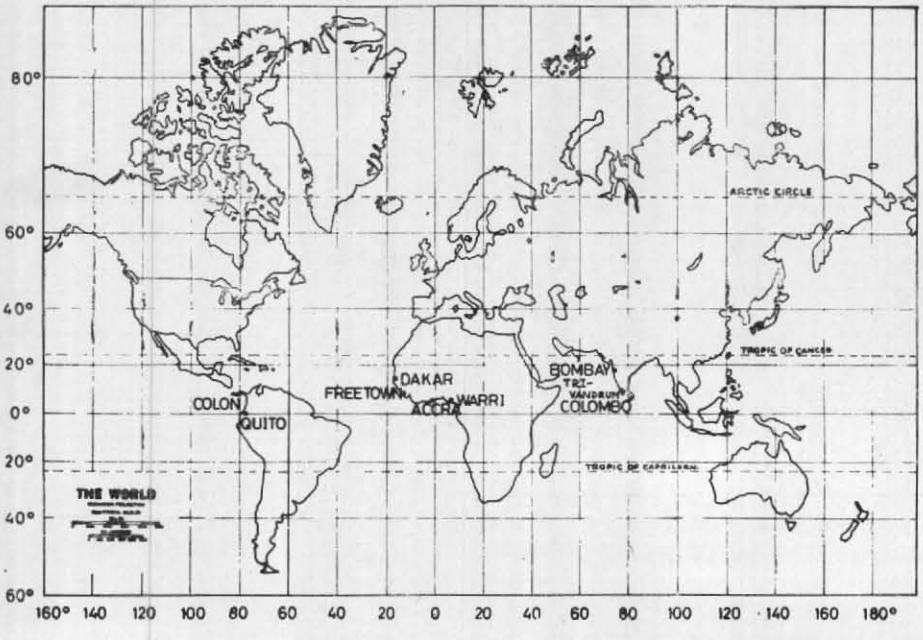

Fig. 1. Map showing the geographical locations of the stations from where the rainfall data have been taken for analysis

Tower Hill the variations for this period are the largest and nearly equal to the 11-year period variation. In general the 22-year amplitude is 5 to 10 per cent of the average rainfall. A marked difference between oscillations at Dakar and Tower Hill are again found and to the contrary Tower Hill shows close resemblance to Colombo, a place far removed from it. Conclusions are of limited value, since the length of the data does not permit the study to extend over a significant number of cycles. King (1976) has reviewed the relationship of smoothed annual rainfall and 22-year and 11-year cycle of normalised annual sunspot numbers. In the high and mid latitudes for which extensive results are available, good correlations have been noticed. The results obtained here do not show such strong correlation. Perhaps more stations in selected areas need to be taken and the analysis

TABLE 2

Table showing the ratio of the range of 11-year and 22-year and cyclic variations with the average rainfall. Range has been defined as the range of the largest fluctuation noticed for the cycle

Station	Average annual rainfall (cm)	11-year cycle		22-year cycle	
		Range (cm)	Range/Average	Range (cm)	Range/Average
Quito	156	—13 to + 16	—·10 to + ·13	—11 to + 11	—·09 to + ·09
Accra	72	—10 to + 10	—·14 to + ·14	— 3 to + 3	—·04 to + ·04
Warri	280	—34 to + 34	—·12 to + ·12	—16 to + 10	—·06 to + ·04
Colombo	220	—34 to + 30	—·15 to + ·14	—34 to + 42	—·15 to + ·19
Tower Hill	376	—40 to + 40	—·11 to + ·11	—48 to + 45	—·13 to + ·12
Trivandrum	178	—30 to + 30	—·17 to + ·17	— 6 to + 14	—·04 to + ·08
Colon	334	—34 to + 40	—·10 to + ·12	—30 to + 30	—·09 to + ·09
Dakar	54	—18 to + 18	—·33 to + ·33	— 4 to + 4	—·07 to + ·07
Colaba	187	—20 to + 20	—·11 to + ·11	—14 to + 16	—·07 to + ·08

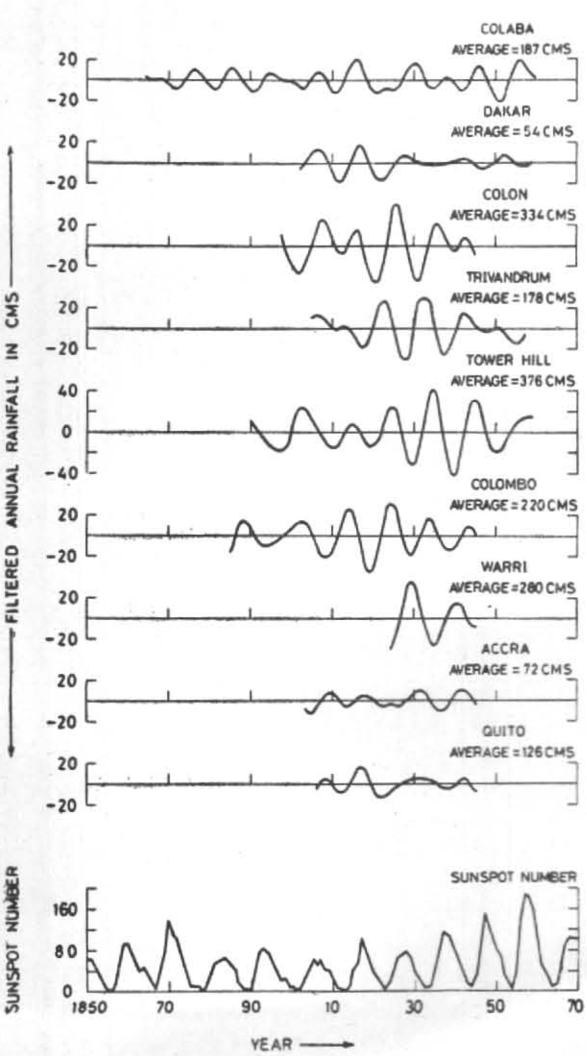

Fig. 2. Annual rainfalls filtered with a 11-year band pass filter. Average yearly rainfalls are also given in the figure. At the bottom, unfiltered sunspot numbers are plotted

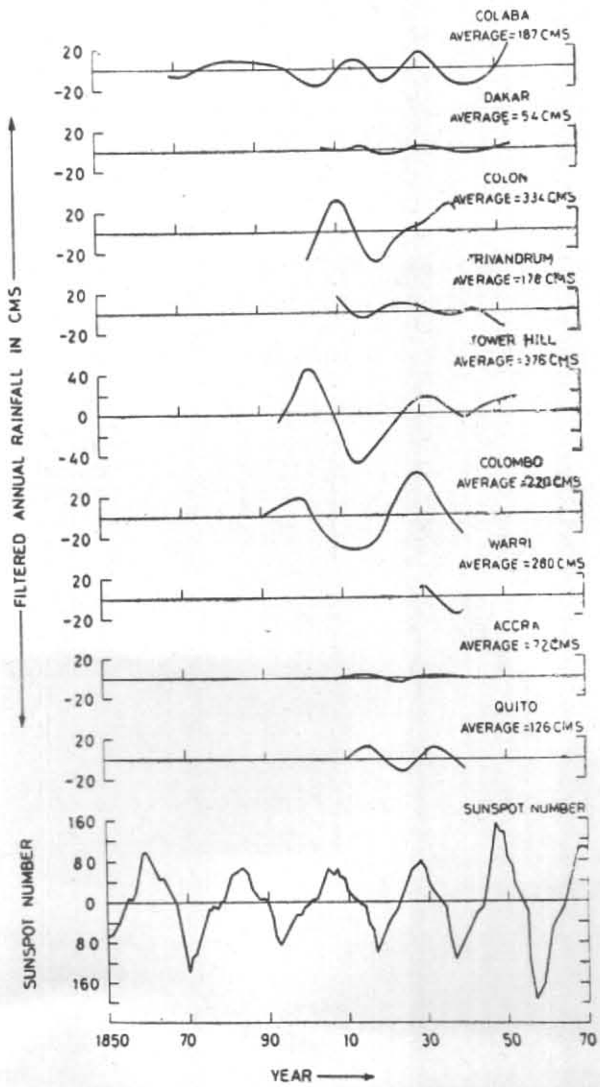

Fig. 3. Annual rainfalls filtered with a 22-year band pass filter. Average yearly rainfalls are also given in the figure. At the bottom are plotted the double sunspot cycle obtained by changing the sign of sunspot numbers in alternate cycles (Bracewell 1953, Bain 1975)

performed with the series obtained after suitable averaging so as to narrow down the effects arising from local pecularities of stations.

Fig. 4 shows variations with periods greater than 12 years. No common feature is discernible from a comparison of the trends noticed at various stations. Colombo and Tower Hill show largest fluctuations in long period limit followed by Colaba and Colon. This again subjects that the phenomena is not regional. An interesting feature of the comparison of the long term trend with sunspot is the close agreement of the trend at Colaba with the variations in sunspot of periods greater than 12 years. (This has also been reported by Koteswaram and Alvi 1969). However, this aspect can be taken as a coincidence, since all other places do not show any behaviour of this type. In West Africa Dakar and Accra do not show any long term fluctuations but Tower Hill shows a fluctuation from 320 cm to 420 cm. In the American region the series at Quito is flat but Colon shows a variation from 316 cm to 335 cm. In Indian region, Colombo shows very large fluctuations (180 cm to 270 cm), Colaba little less and at Trivandrum the trend is practically flat. Thus we do not find any systematic trend in any region to be of some value in making a long term forecast.

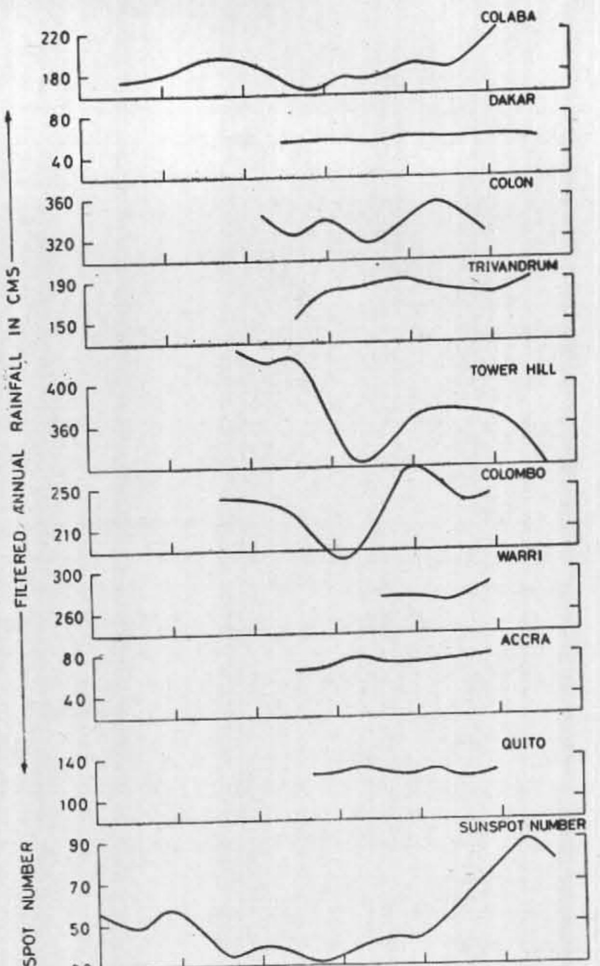

Fig. 4. Annual rainfalls filtered to suppress all fluctuations of period, 12-years and below. The sunspot cycle is also filtered with the same filter

4. Discussion

Our analysis shows that the rainfall has both spatial and temporal dependence on solar cycle. The complexities of the pattern seen in different filtered series, indicate presence of other factors simultaneously modulating the rainfall. Till these factors are isolated and understood, prediction of rainfall in terms of the variation of sunspot number will remain difficult. The dependence of the rainfall on sunspot number is not denied, but the process linking the two has to be investigated by analysing simultaneously the global data.

Bunting *et al.* (1976) for studying the trends in rainfall in West African Sahel took average of rainfall recorded at five stations and then analysed the resultant series. They did not notice any significant trend or periodicity. But an analysis of the Addis Ababa rainfall shows a significant peak around 10-year period (Wood and Lovett 1974). One could associate the strong correlation of rainfall at Addis Ababa to it being a volcanic region. Dickinson (1975) has pointed that "since aerosol modulates cloud formation, volcanic activity may be more important for climate than hereto-fore believed". Amongst the stations we have selected, Colon and Quito lie in volcanic regions. Colon shows significant variations in both 11-year and 22-year period range. At Quito this feature is not so pronounced. There are other stations like Tower Hill and Colombo which are away from volcanic regions, yet exhibit fluctuations comparable to Colon.

The large variation in the features noted in the Sahelion region could be due to the strong dependence of the rainfall in that region on the latitude of sub-tropical anticyclones. According to

Bryson (1974) even a 0·2° movement to the south of the subtropical anticyclone will move the intertropical discontinuity 0·6° southwards. Since the annual rainfall gradient south of this discontinuity is about 180 mm per degree of latitude, the effect could be a change in the West African monsoon rainfall by over 100 mm. This change is quite significant in comparison to the usual changes noticed in 11-year and 22-year cyclic variations and may be a partial cause of the temporal and spatial modulation noticed in Figs. 2 and 3 for the West African stations.

Between 1920 and 1930 the atmospheric changes leading to rainfall have responded most effectively to sunspot variations. This is evident in Figs. 2 and 3 where we see fluctuations with largest amplitude around 1930. It has been reported by many others that the early 1930's coincided with several changes in climate and solar correlations. We also know that 1930's have been the warmest decade of this century in terms of mean temperature of the northern hemisphere. A detailed investigation of the changes occurring in this period may give clue to the cause effect mechanism. This study is important since simultaneous enhancement of both 11-year and 22-year period variations can cause tremendous fluctuations to cause crisis. An understanding of the cause leading to maximum variations noticed in rainfall around 1930 may be of use to make forecast of future occurrence of such situations.

Long term trends have also been associated to changes in the earth's magnetic field. Wollin *et al.* (1973) found the winter temperature of Central England to be inversely correlated with the total intensity of the geomagnetic field measured in England. But noticing such widely different trends at places so close as Colaba-Colombo and Dakar-Tower Hill, it may be concluded that trends in rainfall are dependent more on some other geophysical parameters. It is well known that rainfall is highly dependent on circulation and it may be desirable to investigate simultaneously the temperature variations and then combine the two to understand the mechanism. Indian rainfall data has been analysed for their dependence on sunspot numbers by Jagannathan and Bhalme (1973) and the correlation of temperature variations with sunspot cycles has been studied by Bhargava and Bansal (1970a, 1970b). In all these studies correlations have been found to show spatial and temporal modulation.

5. Conclusion

We do not find any decrease in rainfall in Sahelian region or over India as has been reported by Winstanley (1973). As a matter of fact there is no common trend to cause any alarm. Our investigation shows that solar cycle dependence of rainfall is quite significant at low latitudes. However, the variations seen at neighbouring places either on same latitude or on same longitude differ drastically. It is obvious from our analysis that at least at the places considered here the variations are controlled by many factors acting simultaneously. Unless all these operative causes are properly isolated and understood a long term prediction will lack accuracy. Our emphasis has been to look for large period fluctuations, since they are of greater concern in economic planning as the cumulative effect of a persisting drought could be severe. No common feature emerged in the data analysed. A more comprehensive study combining various meteorological parameters may be in order to better understand the fluctuations in the rainfall in the equatorial region.

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