Secular Fluctuations in the Rainfall Climate of Colombo

INTRODUCTION

THE demonstration of short-period (decadal and poly-decadal) climatic fluctuations using evidence from climatic 'indicators' such as glacier regimes, varve chronologies, tree-rings, lake-levels etc., has been substantiated by analyses of instrumentally recorded meteorological data. Such investigations, while being numerous from mid and high latitudes, are but meagre in respect of tropical areas. Perhaps the more notable recent studies of tropical secular changes are those for Mexico[1] and the more integrated study[2] covering the tropical area as a whole. The latter made yet another contribution,[3] attempting to bring out the relationship between the monsoonal circulation (with its incidental rainfall) and the zonal circulation.

The rainfall data used in this study covers the period 1870—1952 with interruptions in 1936 and 1942. The site of the station—Colombo Fort (6° 54' N.L. ; 79° 52' E.L.) has remained unchanged since 1870. But the rain-guage has been shifted twice ; in 1936 it was moved from its roof-position to the ground and subsequently in November 1942 it was replaced on the roof. However, the gauge remained in the same position on the roof from 1870 to 1935 and would therefore present a homogenous record. In 1910 the headquarters of the Ceylon Meteorological Department was moved to a new site (the pesent Colombo Observatory) a short distance away. Since 1911 observations were made from both sites up to the present day. A comparison of the 1911—1952 data of rainfall at both stations show (Fig. 2*a*) that though the amounts naturally differ (being lower at Colombo Fort in view of the elevated position of the gauge) the fluctuation-patterns are similar. A recent study[4] using the roof-position gauge data for Bristol did not seem to affect the fluctuation-trends demonstrated for that region.

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1. C. C. Wallen, " Climatic Fluctuations in Mexico," *Geogr. Ann.*, 37 (1955), pp. 57—63.
2. E. B. Kraus, " Secular Changes of Tropical Rainfall Regimes," *Quart. Jour. R. Met. Soc.*, 81, (April, 1955), pp. 198—210.
3. E. B. Kraus, " Secular Changes of the Standing Circulation," *ibid.*, 82 (July, 1956), pp. 289—300.
4. F. G. Hannell, " Climatic Fluctuations in Bristol," *Adv. Sci.*, XII, 48 (March, 1956), pp. 373-386.

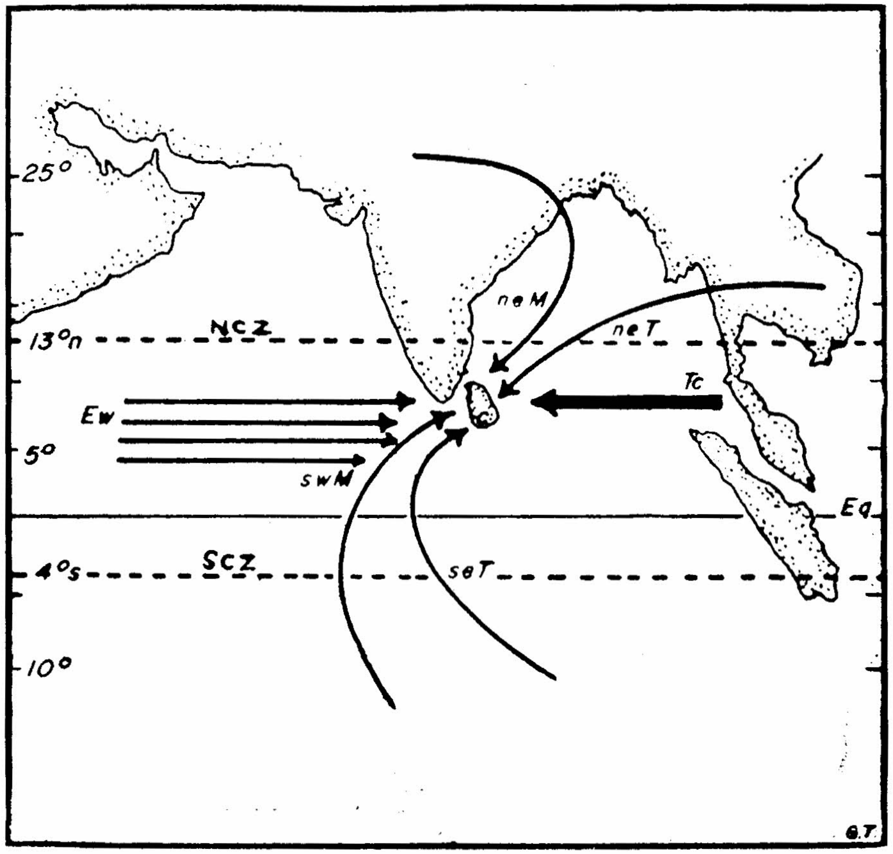

Fig. 1 Climatic "controls" in Ceylon.

Ew	equatorial westerlies
neT	northeast trades
seT	southeast trades
neM	northeast monsoon
swM	southwest monsoon
Tc	tropical cyclones
NCZ	northern convergence zone
SCZ	southern convergence zone.

Rainfall Characteristics

Colombo (Fort) is situated on the west coast of Ceylon and is therefore subject to the diurnal sequence of alternating land and sea breezes throughout the year, except from June to mid-September, when the SW monsoon dominates the climatic scene ; the seasonal counterpart,—the NE monsoon (December to February) is of less relative significance to the rainfall of Colombo (Fig. 1). It has become an unfortunate habit for rainfall in Ceylon to be immediately associated with the monsoons ; an attempt[5] was recently made to clear this misconception. A detailed analysis[6] of the nature and incidence of rainfall in Ceylon has already been made; however, it would not be irrelevant at this stage, to outline briefly the main rainfall features of Colombo.

The analysis is best begun in March, which marks the initiation of the 'climatic year' in Ceylon[7] ; this is the equinoctial period and the island is suited for convectional activity. The diurnal sequence of clear mornings and afternoon thunderstorms at Colombo, is interrupted only when the northern convergence zone (NCZ) is active over the island to produce rapid deterioration of weather at any time of day. If the NCZ (Fig. 1) is at some distance from Ceylon, then widespread stratiform and high clouds with occasional rain will be the main features. When the island comes within the zone of the equatorial westerlies (EW) i.e., the inter-tropical convergence zone (ITCZ), ideal conditions prevail to permit intense convectional activity ; it is then that markedly unstable conditions over inland valley locations provide the impetus for cumuli development. The cumulo-nimbus clouds then move towards the coast (with the setting -in of the land breeze) releasing sudden thundershowers in the process ; in April these features are accentuated. In May however, these conditions are wont to change ; while the still persistent convectional circulation vies *pari passu* with the weak and nascent monsoonal currents trying to gain control, the weather is generally variable. The NCZ may yet persist in the island's vicinity, so as to even inaugurate the SW monsoon ; the latter prevails from June to mid-September, with an all-day rain tendency. October and November are months of convectional-convergence weather, when the equatorward returning NCZ passes over the island. However,

5. G. Thambyahpillay, "Thunderstorm Phenomena in Ceylon," *University of Ceylon Review*, XII (July, 1954) pp. 164—176.

6. Thambyahpillay, "Rainfall Rhythm in Ceylon," *ibid* XII (October, 1954), pp. 224—273.

7. Thambyahpillay, "Climatic Controls in Ceylon" *ibid.*, XI (July-October, 1953), pp. 171—180.

the heavy and highly variable rainfall so characteristic of October—November months in particular, can be attributed to the frequent incursions of cyclonic and depressional storms, from the Bay of Bengal area (Fig. 1). The NE monsoon prevails from December to February, though convectional activity is clearly evident at Colombo.

The annual average (1871—1940) rainfall amounts to 81.20 inches. The data for the period 1941—1952 has been omitted in computing the average, in view of interruptions in the record due to shifting of the gauges. The SW monsoonal period rainfall amounts to 20.42 inches which is only 25 percent of the total. At the onset of the monsoon in June, Colombo and western coastal stations receive heavy rain because the currents are yet at surface level, but by July when the monsoon is fully established, and the currents are flowing at higher levels, the 'lifting agency' so necessary to induce the moisture to be deposited, is provided by the western flanks of the Highland, lying athwart the monsoonal currents.[8] The NE monsoon rainfall of 10.60 inches (13 percent of total) is low because unlike the SW monsoonal currents, those of the NE counterpart, are weak, modified NE trades and impinge upon the island along a broad zone; by the time they reach Colombo little moisture is left and often local convectional currents are responsible for much of the rainfall. It is however, not often realized that the rainfall received during the convergence-convectional periods, amount to as much as 38.74 inches which is nearly 48 percent of Colombo's total.

Techniques of Analysis

(i) *Moving Averages Curves*

The method of moving averages, or otherwise termed "overlapping" or "running" means, has now come to be adopted as almost a *sine qua non* in investigations of climatic fluctuations. By this technique, the attempt is made to 'smoothen' the highly irregular components of the graph, in the plotting of which only the single values have been empolyed. It is assumed that these irregularities are incidental and therefore tend to mask the main features of the graph. The process of smoothing tends to diminish the incidental deviations in proportion to the length of the available period. The resulting graph would then take on a firmer and more harmonious outline.

The method consists, as is well-known, of computing the consecutive and overlapping mean values, e.g., for 10-year means of 1881—1890, 1882—1891 1883—1894, etc., and then plotting these values in a graph against the

8. Thambyahpillay, "Rainfall Rhythm......", *op. cit.*

middle values, thus, 1885+, 1886+, 1887+, etc. In adopting this sequence, it is natural that on the moving average curve, the maxima and minima are displaced from the maxima and minima respectively, of the non-overlapping means. Nevertheless, the graph so obtained by such a simple smoothing process, does give a good and detailed representation of the fluctuations that have taken place, thereby revealing 'hidden' trends. In the choice of the time-interval to be adopted for smoothing, consideration must be given to the approximate periodicity of the 'trend' that is hoped to be revealed; for, if the time-interval chosen is too short, then the means would be affected by the incidental deviations but, on the other hand, if the time-interval is too long, then the 'periodicity' may be suppressed. In this study, the 10-year period has been used in the light of suggestions made by experienced investigators.

Despite these advantages, two serious shortcomings are inherent in using this technique, namely :—

(*a*) Since each of the values plotted represents the mean for a number of years, the resulting graph obscures the precise date of each phase change. Thus, a climatic fluctuation setting suddenly would be represented by a smooth variation.

(*b*) When using a short time-interval for the means, it is possible that a single extreme term in a series may have a marked effect on successive values and would thus indicate a fluctuation, which is purely fictitious.

In view of these disadvantages, the moving averages curves are used in the present investigation in conjunction with residual mass curves.

(ii) *Residual Mass Curves*

Residual mass curves were first employed in the investigation of hydrological problems, especially in connection with the determination of excess or deficit of stream flow over a prolonged period. This technique was adopted in investigations of climatic fluctuations, pioneered by the engineers Keele and Barnes.[9] More recently, the effective use of this method has been demonstrated in the investigations of climatic fluctuations.

The residual mass curve, in effect represents cumulative deviations from the mean. In compiling this curve, the value of each year is first expressed as a deviation (plus or minus) from the mean. The value to be plotted against an individual year is then obtained by the simple algebraic summation of all the separate deviations which had occurred up to that year inclusive. In this graph, therefore, upward-or downward-trending curves would indicate positive (increasing) or negative (decreasing)

9. A. A. Barnes, "Rainfall in England: The True-Long Average as Deduced from Symmetry," *Quart. J. R. Met. S.*, 45 (1919), p. 209.

TABLE I

Percentage deviations from average (1871—1940) of the Annual and Monsoonal Rainfall at Colombo during 1870—1952.

Year	Annual	SW Mon.	NE Mon.
1870	+ 12.51	— 36.45	— 26.89
1871	— 21.37	— 40.88	— 18.21
1872	— 36.33	— 37.33	— 46.41
1873	— 13.79	— 46.21	+ 2.35
1874	— 36.45	— 56.53	— 71.24
1875	— 3.41	+ 12.29	— 29.71
1876	— 0.67	— 55.06	— 40.19
1877	+ 32.92	+119.46	+165.84
1878	+ 72.04	+264.25	+ 1.60
1879	+ 3.84	— 27.53	+ 51.23
1880	— 12.07	— 72.27	— 27.45
1881	+ 10.92	— 10.47	+ 41.13
1882	— 1.93	+ 17.60	+ 15.90
1883	+ 27.59	+ 77.13	— 21.88
1884	+ 1.15	— 20.64	+ 58.39
1885	+ 5.39	+ 45.57	— 14.90
1886	+ 7.15	+ 27.82	— 35.28
1887	+ 3.46	— 30.72	— 3.11
1888	+ 24.45	— 29.20	+ 23.49
1889	+ 33.80	+ 94.19	— 1.60
1890	— 10.34	— 63.52	+ 20.00
1891	+ 46.58	+ 0.54	+ 92.16
1892	— 25.08	— 47.29	— 18.49
1893	+ 10.43	— 20.30	— 31.41
1894	— 4.60	— 27.82	— 14.52
1895	+ 13.58	— 4.03	+ 20.00
1896	+ 24.48	+ 40.41	+ 62.73
1897	+ 1.88	+ 42.82	+ 24.43
1898	+ 26.98	+ 22.71	+ 21.84
1899	— 9.50	— 38.83	— 17.07
1900	+ 3.42	+ 27.58	+ 94.90
1901	— 4.40	— 27.04	— 6.41
1902	+ 46.18	+ 25.02	+ 37.16
1903	— 2.22	+ 27.97	— 5.66
1904	— 5.64	+ 1.17	— 15.38
1905	— 19.27	+ 16.32	— 28.11
1906	— 11.88	— 31.21	— 38.21
1907	— 13.02	— 0.34	— 33.39
1908	— 28.06	— 48.86	— 64.63
1909	— 18.55	+ 10.66	— 69.90
1910	— 43.73	— 51.03	— 12.36
1911	— 28.25	— 47.43	+ 6.98
1912	— 0.50	+ 0.63	+ 7.16
1913	— 7.21	— 30.53	+ 17.45
1914	— 31.83	— 30.07	— 23.49
1915	— 5.68	— 1.42	— 74.90
1916	+ 3.01	+ 24.97	— 29.52
1917	— 23.32	— 19.61	— 2.16
1918	— 28.25	— 61.45	— 41.03
1919	— 9.10	+ 2.94	— 12.45
1920	— 14.39	— 19.76	+ 15.37
1921	— 41.18	— 62.53	— 56.50
1922	— 15.84	— 41.19	— 13.39
1923	+ 9.00	+ 63.47	+ 37.36
1924	+ 14.76	+ 48.32	— 9.62
1925	+ 24.75	+ 24.68	0.00
1926	+ 5.20	+ 74.58	+ 10.37
1927	— 5.35	— 11.06	— 1.88
1928	+ 3.92	— 20.20	+ 70.09
1929	— 4.58	+ 16.32	+ 16.32
1930	+ 22.85	— 22.07	— 20.09
1931	+ 11.80	+ 72.41	+ 17.54
1932	+ 34.53	+ 4.42	+ 13.39
1933	+ 16.21	+ 64.79	+ 24.33
1934	+ 17.27	— 16.22	— 61.32
1935	+ 5.60	+ 18.87	+ 20.94
1936	+ 5.48	— 15.43	+104.34
1937	+ 11.24	+ 5.85	+ 20.37
1938	— 27.48	— 39.97	+ 8.02
1939	— 4.40	+ 7.03	— 81.88
1940	— 12.51	— 9.98	— 30.18
1941	— 0.91	+ 21.38	+ 32.88
1942	— 19.16	— 25.71	+ 84.45
1943	+ 6.15	— 14.50	+ 61.15
1944	— 4.00	— 15.63	— 71.22
1945	— 7.19	— 0.49	— 43.37
1946	+ 19.35	— 4.12	
1947	?	?	— 19.43
1948	— 16.93	— 2.80	— 25.94
1949	+ 9.74	— 0.34	+ 49.43
1950	— 10.16	— 13.66	+ 1.60
1951	+ 14.23	+ 46.20	+ 23.39
1952	— 19.91	— 40.80	?

tendencies, respectively. Hence, a " wet " phase would be represented by an upward-trending curve and a " dry " phase by a downward curve. Since the graph is unsmoothed, it would be formed of irregular components, and this would enable the location of the dates of phase-changes easily. Furthermore, in addition to the general ' trends ' clearly evident, every single anomaly would be represented on the graph. Thus, on an upward curve, a single exceptional year of negative anomaly would be seen as a kink ; this special feature thereby serves to emphasize the fact that climatic phases do incorporate exceptional years.

In order to facilitate comparisons of the seasonally differing regimes of rainfall, all residual mass curves used in this study have been compiled from deviations expressed as percentages of the mean.

Rainfall Fluctuations

(*a*) *Annual trends*

The pattern of the annual fluctuations is represented by curves of moving averages (Fig. 2*a*) as well as by residual mass curves (Fig. 3). Even a cursory examination of the moving averages graph brings out quite unmistakeably the fluctuation-pattern of the rainfall climate. The curves bear evidence of positive and negative anomalies ; these anomaly-curves representing " wet " and " dry " rainfall phases, seem to conform to a definite phase—pattern. It is thus seen, that by the 1880s the rainfall has certainly recovered from a previous " dry " phase ; the " wet " phase on the other hand seems to have been inaugurated by the abnormally heavy rainfall of the years 1877 (108 inches) and 1878 (140 inches). These values, in fact, represent as much as over +36 and +76 percent, respectively. That the two decades 1881—1900 were years of positive rainfall anomalies can be realized from Table 1 as well as from Table IIA.

From the beginning of the present century, until about the mid-1920s, there had been a tendency for low rainfall as seen in Fig. 2a and Table 1. Thus, during the period 1903 to 1922, there was only a single year (1916) of positive rainfall anomaly and which amounted to only 3.01 percent. This phase was notable in Ceylon for continuous drought periods ; this is seen from Table IIB showing those years with nearly or more than 20 percent negative anomalies.

The next " wet " phase, is again clearly evident by the upward trending curve (Fig. 2*a*) since 1922 ; positive anomalies are therefore increasingly evident (Table. 1). This trend continued upto the 1940s and the average

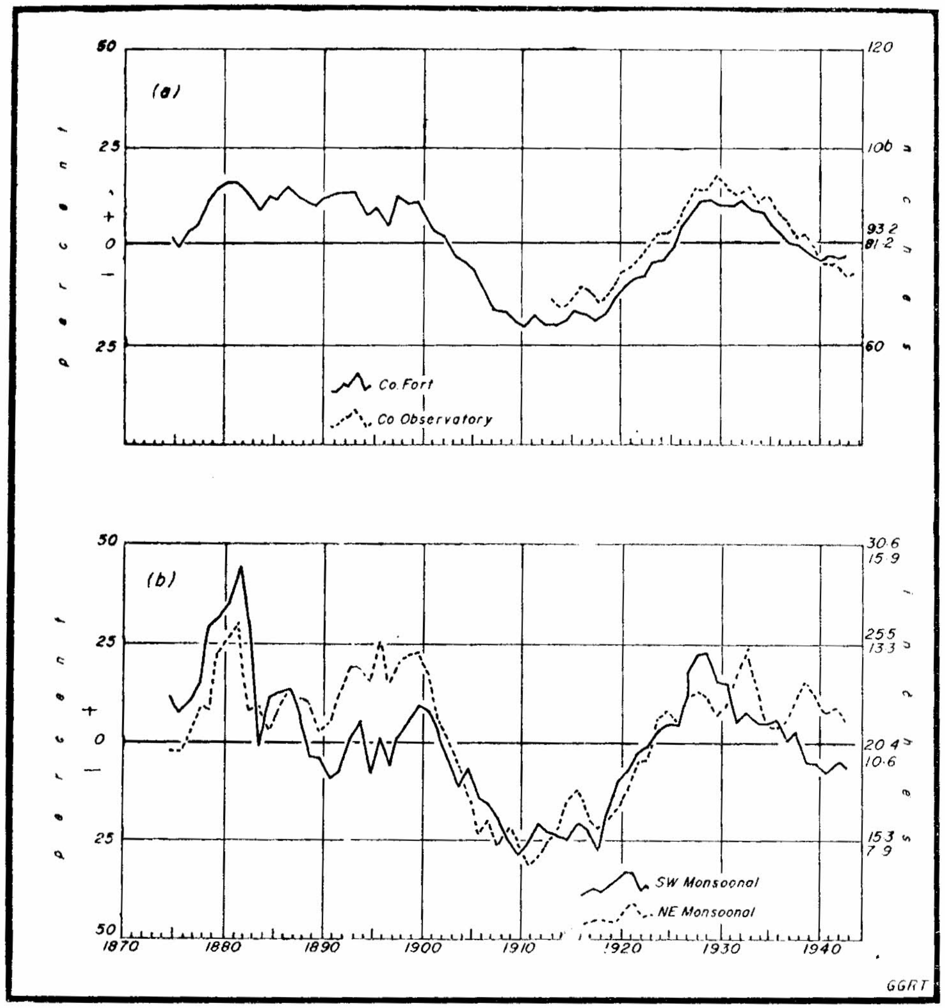

Fig. 2 (*a*) Ten-year moving averages curve of annual rainfall at Colombo Fort. The corresponding curve for the Colombo Observatory is also indicated.

(*b*) Ten-year moving averages curves of SW and NE monsoonal rainfall at Colombo Fort.

value for the period 1944—1952 indicates the tendency for deficient rainfall. In view of the incompleteness of the data and interruptions of records, the graph is not continued after 1944.

TABLE IIA

Years of Heavy Annual Rainfall During 1881—1902.

Year	Amount (inches)	Percentage deviations from average
1883	103.6	+ 27.59
1888	101.1	+ 24.45
1889	108.1	+ 33.80
1891	119.0	+ 46.58
1896	101.1	+ 24.45
1898	118.7	+ 46.18
1902	118.7	+ 46.18

B

Years of Low Annual Rainfall During 1903—1925

Year	Amount (inches)	Percentage deviations from average
1905	65.5	— 19.27
1908	58.4	— 28.06
1909	66.1	— 18.55
1910	45.7	— 43.73
1911	58.3	— 28.25
1914	55.3	— 31.83
1917	62.3	— 23.32
1918	58.3	— 28.25
1921	47.8	— 41.18

The evidence for alternating "wet" and "dry" rainfall phases, is further substantiated by the residual mass curves (Fig. 3). The upward and downward curves indicate positive and negative rainfall tendencies or "wet" and "dry" phases, respectively. It is seen (Fig. 3) that during the upward-trending curve from 1877—1902, representing a "wet" phase, the deficient rainfall years of 1890, 1892 and 1901 are indicated as kinks on the curve. The other upward ("wet") and downward ("dry") curves also bring out these features ; the "wet-dry" phases correspond to those shown by moving averages graph.

A statistical presentation of the annual data in respect of 10-year and 20-year periods, brings out the interesting feature of approximate 20-year phases (Table III) in the rainfall climate, reflecting "wet-dry" phases.

(*b*) *SW monsoonal trends*

The techniques used in analysing the annual rainfall data are applied to the SW monsoonal period rainfall as well. It is again seen (Fig. 2*b*) that in 1877, the " wet " phase was inaugurated, recovering from a previous " dry " phase ; this recovery is marked by the heavy monsoon rainfall of 44.60 inches (1877) and 74.09 inches (1878), which correspond to over +119 and +264 percent, respectively of the average. These anomalies are the highest recorded in Colombo since observations were begun ; it is now known that during this period Ceylon and peninsular India (south of Madras) experienced one of the most violent cyclones[10] recorded in this area. The smoothed curve shows in general above average rainfall up to the turn of this century but shows deficient rainfall since then and continuing up to the 1930s. It is seen from Table 1, that deviation values are higher than those shown for annual values ; this is due to the smaller mean value of SW monsoonal rainfall (20.42 inches). This would also explain the larger minor fluctuations seen on the monsoonal curves; it has been shown[11] that occasional depressional activity and " monsoon surges," increase the rain potentiality of this period. Since 1902, drought incidence during the monsoonal period was high, as evident here from the high percentage negative rainfall anomalies of forty-nine (1908), fifty-one (1910), forty-seven (1911), sixty-one (1918), sixty-two (1921), and forty-one (1922). As shown by the annual rainfall curves, it is not until 1923 that recovery takes place and again the " dry " phase is indicated only in the early 1940s. The above trends are further demonstrated by the residual mass curve (Fig. 3). Here again, the data may be analysed into 10-year and 20-year ' wet-dry ' phases (Table IV).

TABLE III

10-Year and 20-Year percentage deviations of Annual Rainfall from Average (1871—1940) at Colombo

A. 10 year		**B.** 20 year	
1871—1880	— 1.53	1881—1900	+ 9.50
1881—1890	+ 10.18	1901—1920	— 12.31
1891—1900	+ 8.81	1921—1940	+ 3.56
1901—1910	— 10.07		
1911—1920	— 14.54		
1921—1930	+ 1.35		
1931—1940	+ 5.77		
1941—1950	— 2.45		

(*c*) *NE monsoonal trends*

In computing the NE monsoonal rainfall it was necessary to overlap the years ; in other words, the 1870 value corresponds to the rainfall of December 1870, and those of January and February of 1871, and so on.

10. J. Eliot, *India Meteorological Memoirs*, Vol. IV, Part IV (1887).
11. Thambyahpillay, " Rainfall Rhythm....", *op. cit.*

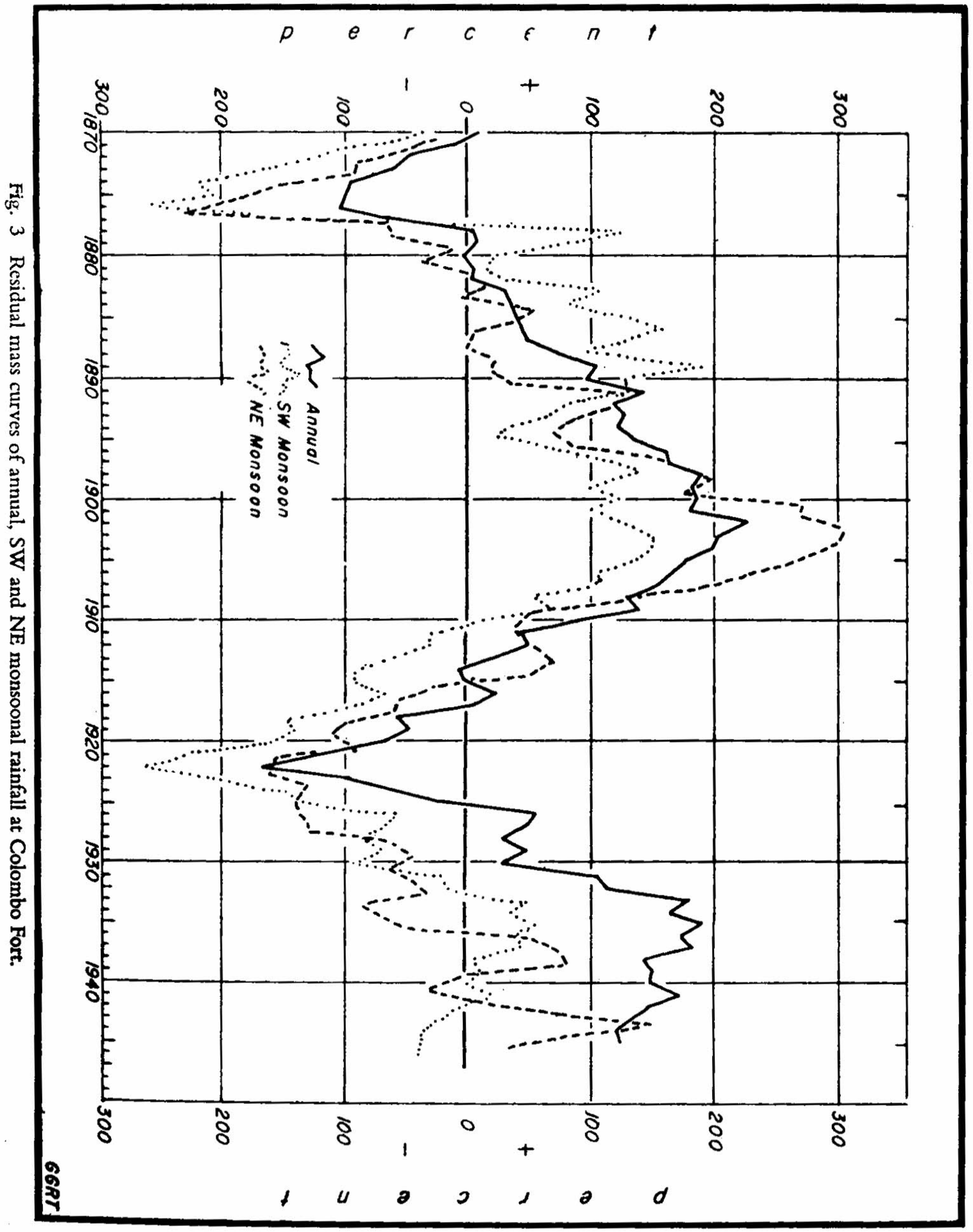

Fig. 3 Residual mass curves of annual, SW and NE monsoonal rainfall at Colombo Fort.

CONCLUSION

It has been made evidently clear that the rainfall climate of Colombo has undergone definite fluctuations, corresponding to unmistakeable " wet " and " dry " phases. It is possible to recognize distinctly two " wet " and three " dry " phases, both in respect of the annual and the seasonal rainfall regimes (Table V).

It must be noted though, that the " dry " phases viz., D1 and D3, have been adduced from insufficiently long-period data ; however, statistical and graphical analyses tend to support their inclusion in Table V, as forming continuities in the " wet "-" dry " sequence of rainfall phases.

TABLE V

Approximate " Wet " and " Dry " phases of the Rainfall climate of Colombo during the period 1870—1952

Phase	Period	Rainfall percentage deviations from average (1871—1940)			
		Annual *(81.20)	SW monsoonal *(20.42)	NE monsoonal *(10.60)	Convergence *(19.37)
D 1:DRY	1870—1876	—14.21	—38.34	—30.28	— 4.85
W 1:WET	1877—1902	+12.50	+14.20	+20.66	+11.40
D 2:DRY	1903—1922	—12.24	—19.83	—26.88	—18.84
W 2:WET	1923—1943	+ 5.44	+11.36	+11.41	+ 0.46
D 3:DRY	1944—1952	—11.49	— 3.77	— 3.37	— 5.11

* Average values in inches.

It has been clearly demonstrated[14] that world-wide tropical rainfall regimes have exhibited unmistakeably the general tendency for a decrease at the turn of the century. Furthermore evidence is also available indicative of a reversal trend i.e., positive anomalies, about the twenties and in turn a tendency for negative anomalies in the forties. It was also found that discharge values of the river Nile[15] conformed to this pattern of alternating "wet" and " dry " phases. It is thus seen that the " wet "-"dry" rainfall phases demonstrated in this paper for Colombo, seem to conform to a fluctuation-pattern of similar phase-intervals, as those indicated in other tropical rainfall regimes. The formulation of a satisfactory meteorological reasoning[16] to account for these fluctuation-trends, must needs await detailed investigations into the dynamics of the flow-pattern of the earth's total atmosphere.

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14. Kraus, " Secular Changes of Tropical Rainfall....", *op. cit.*
15. *ibid.*
16. The author is at present engaged in this investigation, the results of which will appear in a subsequent paper.