TREND ANALYSIS OF ANNUAL INDIAN RAINFALL

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Abstract. The average annual rainfall of the Indian area (excluding the island territories in the Arabian Sea and the Bay of Bengal) has been calculated for each year of the 60-year period from 1901 to 1960 by using data from about 3 000 raingages distributed uniformly throughout the country. This time series of rainfall has been subjected to statistical analysis. It was found that the mean annual rainfall is of the order of 1 190 mm with a standard deviation of 95 mm. The southwest monsoon season (June-September) rainfall contributes about 75 per cent of the mean annual rainfall. The wettest year (1917) had a rainfall 22 per cent in excess of the mean annual rainfall, and this was immediately followed by the driest year (1918) which was lower than the mean annual rainfall by about 19 per cent. The mean values of the annual rainfalls for the 30-year period from 1931 to 1960 showed a significant increase of about 5 per cent.

Analyse de la tendance de précipitation annuelle en Inde

Résumé. On a évalué la précipitation annuelle moyenne de la région des Indes (à l'exclusion des territoires des îles dans la mer Arabique et le golfe de Bengale) pour chaque année pendant la durée des soixante ans entre l'an 1901 et l'an 1960. On a utilisé les données disponibles (résultats des 3 000 pluviomètres distribués uniformément sur toute l'étendue de la région). On a soumis cette série de temps des précipitations à une analyse statistique. On a trouvé que la pluie annuelle moyenne revient à 1 190 mm avec un écart-type de 95 mm. Pendant la saison de la mousson du sud-ouest (de juin à septembre) la pluie contribuait 75 pour cent de la pluie annuelle moyenne. L'année la plus humide avait une précipitation de 22 pour cent en plus de la précipitation annuelle moyenne. A cette année a suivi immédiatement l'année la plus sèche (1918) ce qui était plus basse que la précipitation annuelle moyenne de 19 pour cent environ. Les valeurs moyennes des précipitations annuelles pour les trente ans de la période 1931-1960 ont montré une augmentation significative de 5 pour cent à peu près.

INTRODUCTION

Studies of large-scale changes in atmospheric phenomena over wide areas especially for rainfall and temperature are pre-requisites for the planning and development of a country's natural resources. Regional variations of annual rainfall for the British Isles were studied by Gregory (1956) and for Japan by Suzuki (1968). In India, variations in the annual rainfall for some selected stations have been studied by Jagannathan and Parthasarathy (1973). Recently, Parthasarathy and Dhar (1974) have studied secular variations of annual rainfall amounts for the 31 meteorological sub-divisions of India. Monthly and annual rainfalls of the contiguous Indian area have also been worked out by Dhar et al. (1974) using long-term rainfall data from raingauge stations in India. In the present study, the average annual rainfall of the country as a whole has been calculated for trend analysis.

The average annual rainfall has been worked out for the entire country on the basis of about 3 000 raingage stations spread uniformly all over the country for each year of the 60-year period from 1901 to 1960. This study could not be extended to 1970 as rainfall data from all the 3 000 stations are not available in published form beyond 1960 or thereabouts.
STATISTICS OF MEAN ANNUAL RAINFALL OF INDIA

Various statistical parameters were worked out from the 60-year series of the average annual rainfall of India. It was calculated that the mean annual rainfall of the Indian area is 1 188 mm with a standard deviation of 95 mm and a coefficient of variation of 8 per cent. About 75 per cent of the mean annual rainfall occurs in the southwest monsoon season (June-September), and hardly any, 11 and 10 per cent respectively, occurs in the summer season (March-May) and post monsoon season (October-December). The winter months of January and February receive only 4 per cent of the mean annual rainfall.

The average annual rainfall values of the 60-year period were examined in order to obtain an idea of the extreme values of annual rainfalls experienced in the country. From these statistics, the five wettest and driest years have been picked out and these are shown in Table 1.

<table>
<thead>
<tr>
<th>Wettest years</th>
<th>Driest years</th>
</tr>
</thead>
<tbody>
<tr>
<td>Sr. No.</td>
<td>Year</td>
</tr>
<tr>
<td>1</td>
<td>1917</td>
</tr>
<tr>
<td>2</td>
<td>1956</td>
</tr>
<tr>
<td>3</td>
<td>1933</td>
</tr>
<tr>
<td>4</td>
<td>1955</td>
</tr>
<tr>
<td>5</td>
<td>1959</td>
</tr>
</tbody>
</table>

From Table 1 it is seen that the wettest year of 1917 was immediately followed by the driest year of 1918. In the case of the five wettest years, the percentage excess of rainfall varied from 12 to 22 per cent while in the case of the five driest years, the percentage deficiency varied from 11 to 19 per cent of the mean annual rainfall.

TREND ANALYSIS

A trend analysis of the average annual rainfall of India for the 60-year period from 1901 to 1960 was carried out by using several statistical tests.

Mann-Kendall rank statistic
The most likely alternative to randomness in a climatic time series is some form of a trend, which may be linear or nonlinear. It is, therefore, necessary to use a test of randomness to check the trend. The Mann-Kendall rank method has been suggested as a powerful test by Kendall and Stuart (1961). In this case, the statistic \( \tau \) was computed by using the formula

\[
\tau = \frac{4 \sum n_i}{N(N-1)} - 1
\]  

where \( n_i \) is the number of values larger than the \( i \)th value in the series subsequent to its position in the time series. The value of \( \tau \) was tested for significance by the statistic \( \tau_r \), which is given by

\[
(\tau)_r = t \left( \frac{4N + 10}{9N(N-1)} \right)^\frac{1}{2}
\]
Fig. 1 – Actual and filtered (low-pass filter) annual rainfall series of India.
where $r_g$ is the value of $r$ at the appropriate probability point in the Gaussian distribution corresponding to the desired level of significance. It is observed that the $r$ value for the average annual rainfall of India is $+0.244$ which (i.e. trend) is significant at the 99 per cent level.

**Student's $t$-test**
The World Meteorological Organization (WMO, 1966) has recommended the use of 30-year means (i.e. 1871-1900, 1901-1930, 1931-1960) for the interpretation of climatological normals. In the present study the rainfall series for the period 1901-1960 was broken into two equal periods: 1901-1930 and 1931-1960. The significance of the difference of the mean between the first and the second period was tested by Student's $t$-test and the magnitude of the gradient was ascertained. The first mean (for the period 1901-1930) was found to be 1.161 mm with a standard deviation of 96 mm and coefficient of variation 82 mm. The second mean (for the period 1931-1960) was found to be 1.216 mm with a standard deviation of 87 mm and a coefficient of variation of 72 mm. The calculated Student's $t$-value was 2.30 which is significant at the 99 per cent level of a one tail test. The percentage of change per 30 years' mean (i.e. difference of means for the periods 1931-1960 and 1901-1930) is $+4.6$ per cent of the 60-year mean.

**Low-pass filter**
To understand the nature of the trend, the time series of annual rainfall was subjected to a 'low-pass filter' in order to suppress the high frequency oscillations. The weights used were nine ordinates of the Gaussian probability curve (i.e. 0.01, 0.05, 0.12, 0.20, 0.24, 0.20, 0.12, 0.05 and 0.01). The response curve of the Gaussian low-pass filter has a response function that is equal to unity at infinite wave length and it tails off asymptotically to zero with decreasing wave lengths (WMO, 1966). It was observed from the filtered series that the trend is not linear but oscillatory consisting of periods of 10 years' length or more. The low-pass filter curves are shown in Fig. 1 along with actual annual rainfall values.

**CONCLUSIONS**
The analysis carried out using data from about 3000 rain gauges for the period from 1901 to 1960 has shown that the mean values of the annual rainfalls for the 30-year period from 1931-1960 showed a significant increase of about 5 per cent.

**REFERENCES**