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Nature of the frequency distribution of Indian rainfall : Monsoon and annual

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ABSTRACT. The frequency distribution of southwest monsoon season and annual rainfall of about 500 rain-recording stations (1901-1960) forming a close and representative network in India was examined by statistical methods. It is seen that Indian rainfall does not differ significantly from normal except in a few small areas. Most of the country, excluding the western arid and semi-arid areas, has values of coefficient of variation (annual) between 20 to 30 per cent irrespective of the amount of rainfall.

1. Introduction

Questions are being frequently asked on the nature of the frequency distribution of Indian rainfall. Studies so far made in India are based on analysis of limited number of stations or of a few sub-divisions. Some of the recent studies are included under references at the end.

The object of the present paper is to examine the frequency distribution of annual and southwest monsoon season (June-September) rainfall by using statistical methods. For this purpose, about 500 rain recording stations in India and neighbourhood, forming a close and representative network have been chosen. Rainfall records of these stations for about 60 years (1901-1960) have been utilised, for computing the relevant statistical parameters on variability, skewness etc. A map of India showing rainfall stations for which analysis has been made is presented in Fig. 1. As in the process of testing the normality, a number of statistical parameters have been computed, their analysis is also included in the paper.

2. Method of analysis

2.1. *Standard Deviation (SD)*

If $x_1, x_2 \ldots\ldots\ldots\ldots x_n$ are n observations and $\bar{x}$ its arithmetic mean, Standard Deviation (SD) is estimated as the square root of variance, defined by —

$$\text{Variance} = \frac{1}{n-1} \sum_{r=1}^{n} (x_r - \bar{x})^2 \qquad (1)$$

As n is large, SD (σ) has been estimated from —

$$\sigma = \left\{ \frac{1}{n} \sum_{r=1}^{n} (x_r - \bar{x})^2 \right\}^{\frac{1}{2}} \qquad (2)$$

The error involved in using (2) instead of (1) is $(1/2n).\sigma$. When $n = 60$, the error is $(1/120).\sigma$ or less than 1 per cent of SD which is negligible.

2.2. *Coefficient of Variation (CV)*

This is defined as standard deviation expressed as percentage of mean,

$$\text{CV} = \frac{\text{SD}}{\bar{x}} \times 100 \qquad (3)$$

(The error involved in computing SD as indicated in 2·1 above is less than 1 per cent of CV).

2.3. *Skewness and Kurtosis*

If μ_3 and μ_4 are third and fourth moments from the mean respectively,

$$\mu_3 = \frac{1}{n} \sum_{r=1}^{n} (x_r - \bar{x})^3 \qquad (4)$$

$$\mu_4 = \frac{1}{n} \sum_{r=1}^{n} (x_r - \bar{x})^4 \qquad (5)$$

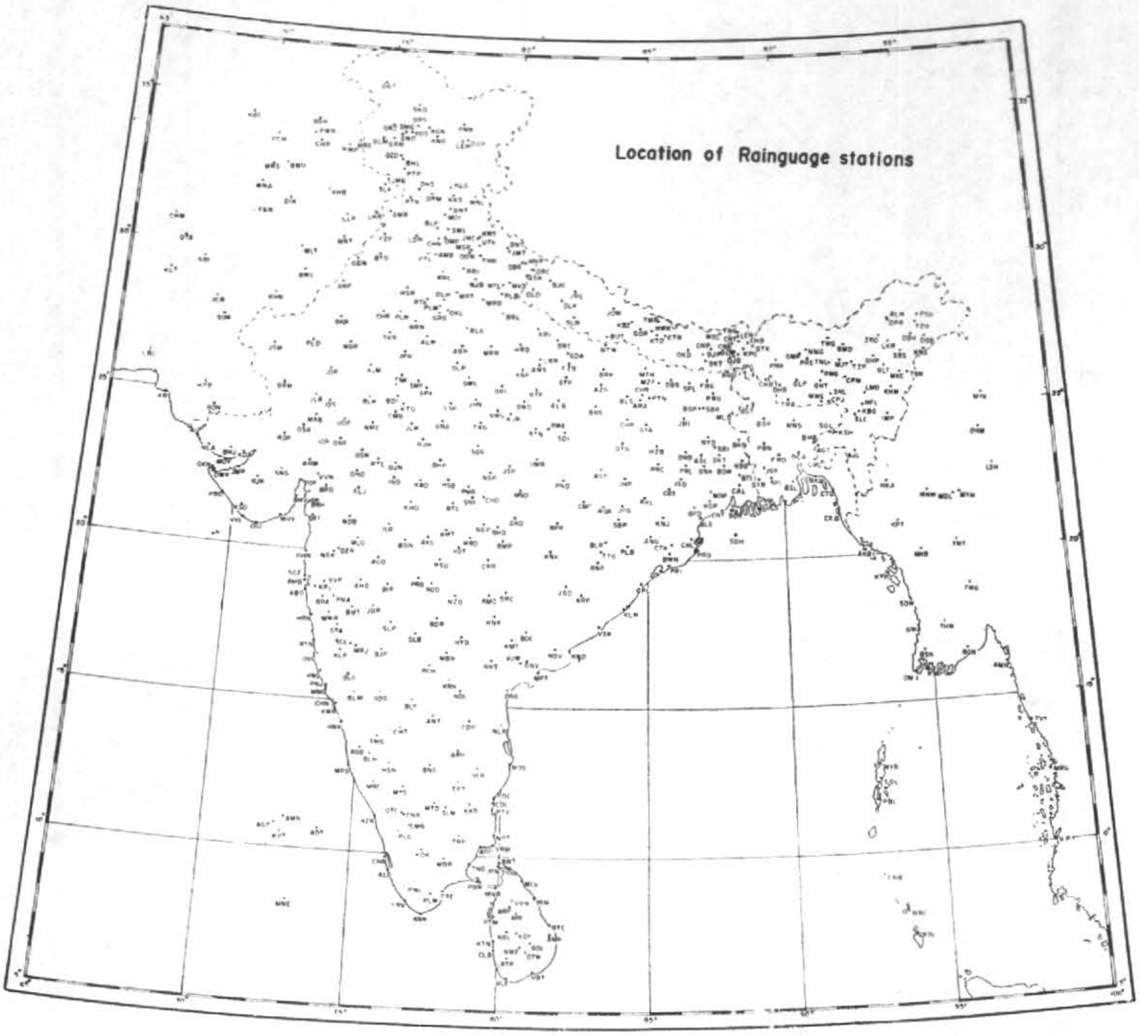

Fig. 1

Skewness (γ_1) and kurtosis (γ_2) are defined as —

$$\gamma_1 = \mu_3/\mu_2^{3/2} \quad (6)$$

$$\gamma_2 = (\mu_4/\mu_2^2) - 3 \quad (7)$$

2.4. *Normality*

For testing normality, we use Fisher's statistics g_1 and g_2 divided by their respective standard errors. These expressions take the form (Rao 1952):

$$\omega_1 = \frac{g_1}{\mathrm{SE}(g_1)} = \gamma_1 \left\{ \frac{(n+1)(n+3)}{6(n-2)} \right\}^{\frac{1}{2}} \quad (8)$$

$$\omega_2 = g_2/\mathrm{SE}(g_2)$$

$$= \left(\gamma_2 + \frac{6}{n+1} \right) \left\{ \frac{(n+1)^2 (n+3)(n+5)}{24\, n\, (n-2)(n-3)} \right\}^{\frac{1}{2}} \quad (9)$$

$g_1/\mathrm{SE}(g_1)$ and $g_2/\mathrm{SE}(g_2)$ should exceed 2 for 5 per cent level of significance and 2·6 for 1 per cent level of significance.

2.5. *Data*

All the parameters explained in 2·1 to 2·4 above have been worked out for about 500 stations. Maps showing the various parameters have also been prepared and are given in Figs. 2 to 15.

3. Discussion

In the following paragraphs the main features of the distribution in space of standard deviation (SD), coefficient of variation (CV); skewness and kurtosis and normality of Indian rainfall are analysed and discussed.

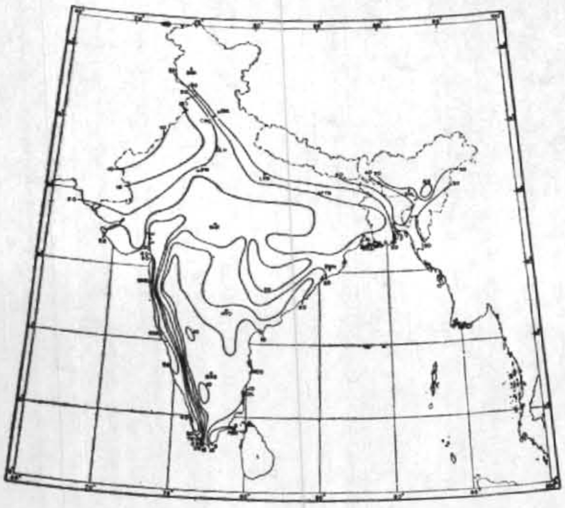

Fig. 2
Standard deviation of monsoon (Jun-Sep) rainfall
(Isolpleth in cm)

Fig. 3
Standard deviation at annual rainfall
(Isopleth in cm)

4. Standard Deviation (SD)

(*a*) *Southwest monsoon season* (*Jun-Sep*)— *Fig. 2*

Coastal Areas — SD is 40 cm at Cochin, 52 cm at Bombay, 60 cm at Dahanu and 39 cm at Surat. Along the west coastal belt SD varies generally between 40 to 60 cm. Trivandrum is only 25 cm. Between Calcutta (Lat. 22°N) and Kalingapatnam (Lat. 19° N) SD varies from 20 to 30 cm. South of Lat. 19°N, SD decreases from 17 cm at Visakhapatnam (Lat. 18°N) to 12 cm at Madras and 10 cm at Cuddalore. SD again decreases considerably further south to 5 cm at Pamban, 4 cm at Palayamkottai and 3 cm at Tuticorin. Of course, this area receives very scanty rainfall — hardly a few cm during this season. Saurashtra Kutch coasts have SD values in the range 20 to 25 cm. Dwarka SD is 21 cm, Bhavnagar 22 cm, Jamnagar 25 cm and Mandvi 24 cm.

Peninsula (*interior*) — South of Lat. 15°N and in Madhya Maharashrra SD ranges from 10 to 15 cm. Small pockets of 10 cm or less are also noted near Mysore and Gadag. Andhra Pradesh, Marathwada and Vidarbha have higher values of SD, 20 to 25 cm. The highest SD values of 25-30 cm are noticed in the adjoining areas of Madhya Pradesh.

Rest country — East of Long. 75°E SD is between 20 to 30 cm. West of Long. 75°E, SD values are mostly between 10 to 20 cm. Stations close to the Himalayas have SD ranging between 30 to 40 cm and at some places higher. Mussoorie is 60 cm and Dehra Dun 49 cm.

(*b*) *Annual* — *Fig. 3*

SD values are higher in general all over the country as compared to the southwest monsoon season.

Coastal — Along the west coast north of Cochin, SD ranges mostly between 50 and 60 cm. Bombay is 53 cm and Dahanu 61 cm. East coast range in SD is 25 to 35 cm. In the extreme south it is 20 to 25 cm.

Peninsula (*interior*) — Except in the areas adjacent to Ghats, SD values are between 15 to 25 cm mostly increasing in northeast part — Vidarbha and east Madhya Pradesh, SD is 25 to 35 cm.

Rest country — East of Long. 70°E excluding west Rajasthan and Punjab, SD ranges 25 to 35 cm. Some stations at the foothills and in the hills have high values 50 to 60 cm. Dhubri is 49 cm, Mussoorie 63 cm and Nainital 61 cm. Over west Rajasthan and adjoining Punjab and Haryana, SD is 10 to 20 cm.

5. Coefficient of variation of rainfall (CV)

(*a*) *Southwest monsoon season* (*Jun-Sep*)— *Fig. 4*

CV of monsoon rainfall is low (15 to 20 per cent) over parts of west coast between Lat. 10 to 15°N, northeast Madhya Pradesh and adjoining Bihar Plateau and northeastern Assam, *viz.*, Mangalore 16, Ranchi 19, Sambalpur 19 and Sibsagar 18%. CV is over 50 per cent in Saurashtra-Kutch, west Rajasthan and southeast Tamil Nadu. In Kutch and extreme western areas of Rajasthan, CV is 60 to 80 per cent, while over southeast Tamil Nadu (Tirunelveli region), it exceeds 80 per cent. But for southeast Tamil Nadu, this is not the main rainy season. Pamban CV is 94 per cent and

Fig. 4
Coefficient of variation of monsoon (Jun-Sep) rainfall
(Isopleth in %)

Fig. 6
Coefficient of variation of annual rainfall
(Isopleth in %)

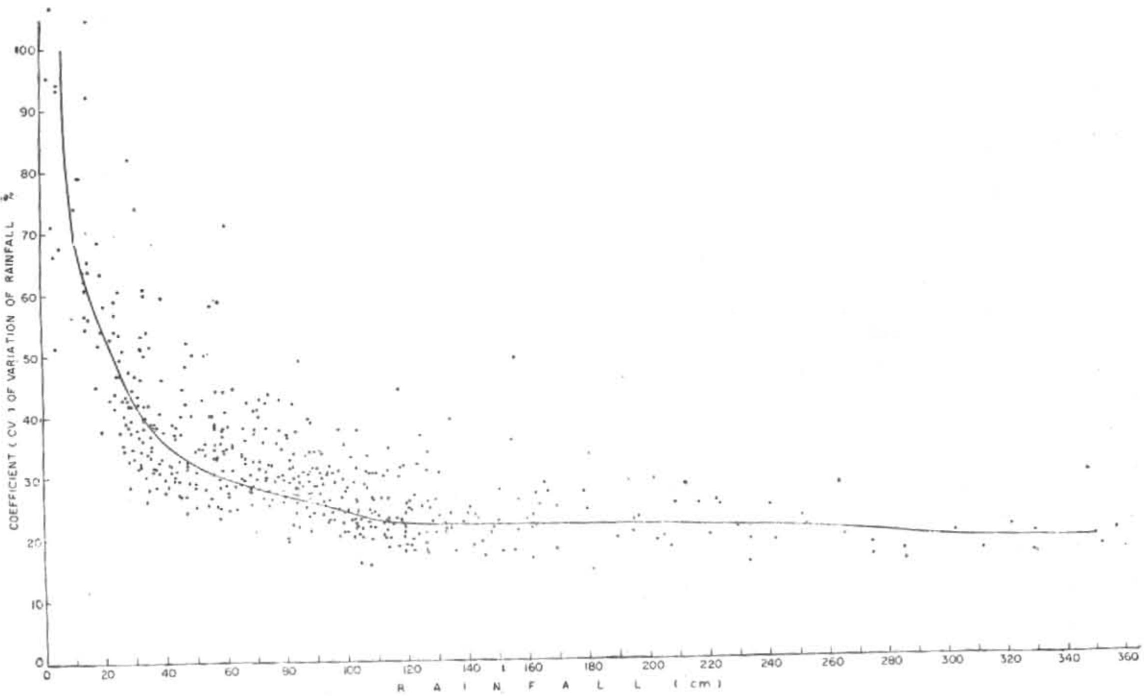

Fig. 5
Coefficient of variation and rainfall amounts in monsoon season

Tuticorin 106 per cent. Summing up, CV is less than 30 per cent over the country, excluding areas to the west and northwest of line joining Bombay to Motihari and most of the interior of the Peninsula east of the Ghats.

Fig. 5 shows CV of monsoon rainfall plotted against rainfall amount. The curve (median) shows that generally CV decreases with increasing rainfall amounts up to about 100 cm and CV does not vary much above 100 cm. For low rainfall amounts less than 40 to 50 cm, CV is much higher than 30 per cent. However scatter is quite large.

(b) *Annual — Fig. 6*

A major and significant feature is that the annual CV is less than 30 per cent in the areas of the country to the east and south of the line joining Bombay and Gorakhpur (U.P.). Another aspect for

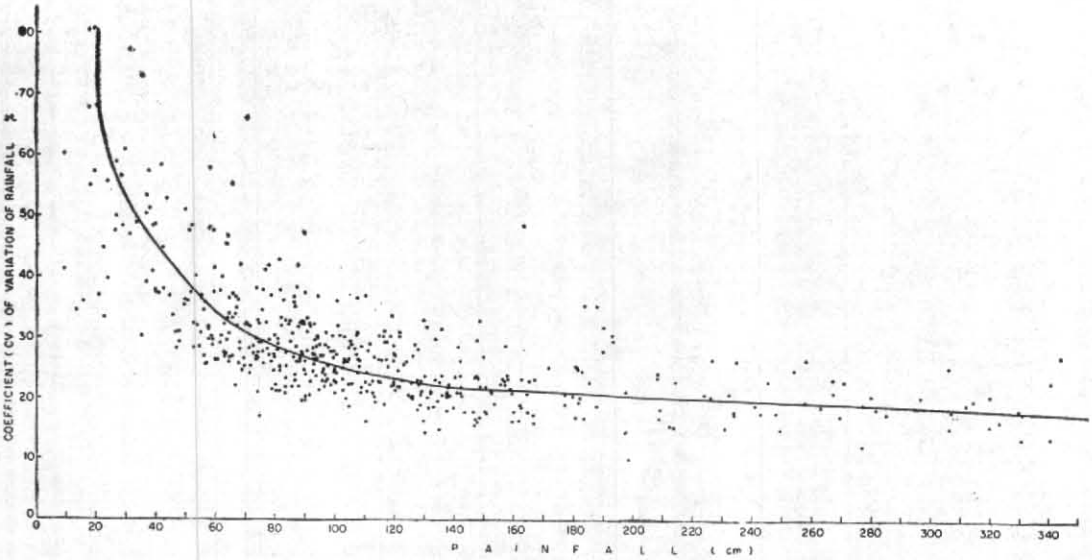

Fig. 7

Coefficient of variation and rainfall amounts — annual

emphasis is that the interior of the Peninsula which during the southwest monsoon shows high variability has now values similar to many other areas in the country, between 20 to 30 per cent only. A few small areas near Mangalore and in northeast Assam have the lowest values of CV in the country of less than 15 per cent — Mangalore CV is 14 per cent, Dibrugarh 12 per cent and Sibsagar 15 per cent. The west coast belt south of Lat. 16°N, Assam, West Bengal and adjoining areas, Bihar Plateau and east Orissa and portions of east Madhya Pradesh areas have CV ranging between 15 to 20 per cent. Kutch and extreme west Rajasthan have the highest CV ranging from 65 to 80 per cent. In extreme southeast Tamil Nadu in Tuticorin, Pamban region, CV is about 30 to 40 per cent only as compared to nearly 100 per cent in the southwest monsoon season in this area.

Fig. 7 shows CV plotted against annual rainfall amounts. The curve (median) shows the same features as that of the monsoon season, namely CV decreases with increasing rainfall upto about 100 cm and above this amount variations in CV are not large.

6. Skewness and kurtosis

(a) Southwest monsoon season (Jun-Sep)— Figs. 8 and 9

Over most of the country, values of γ_1 and γ_2 of the monsoon season are between $-1\cdot0$ and $+1\cdot0$. Monsoon season rainfall of the country, by and large, therefore, does not show skewness and kurtosis. There are large areas of the country having small negative γ_2 value, suggesting that monsoon rainfall is slightly platy-kurtic. Areas, where γ_2 has small positive value showing slightly leptokurtic monsoon rainfall, are small.

Principal areas, where γ_2 is greather than $+1\cdot0$ are : (1) Saurashtra-Kutch, (2) west Rajasthan, (3) northern parts of Uttar Pradesh, (4) Tezpur-Imphal-Aijal area in the northeast and (5) extreme southeastern portion of the Peninsula in Tamil Nadu. In these areas, the monsoon rainfall is leptokurtic.

Within the zones where γ_1 and γ_2 are uniformly less than one, there are a few isolated small pockets, where γ_1 and γ_2 have values numerically greater than one. These pockets either cover small areas or confined to single station and their high γ_1 and γ_2 values may be due to exposure or other recording conditions and too great importance or significance cannot be attached to such values without further detailed examination. This applies to other parameters as well.

(b) Annual — Figs. 10 and 11

Broadly γ_1 and γ_2 for annual show almost the same features as the monsoon season. γ_1 and γ_2 values are small over most parts of the country being between $-1\cdot0$ and $+1\cdot0$ showing that annual rainfall of the country is not highly skewed. Large areas of the country, however, have small negative γ_2 value showing that annual rainfall generally has tendency to be slightly platykurtic. Over the extreme south and southeastern portion of the Peninsula, γ_2 values have become less than $+1\cdot0$ compared to those of monsoon rainfall $+2\cdot0$. The annual rain-

Fig. 8
γ_1 of monsoon (Jun-Sep) rainfall

Fig. 9
γ_2 of monsoon (Jun-Sep) rainfall

(Isopleth-value of parameter)

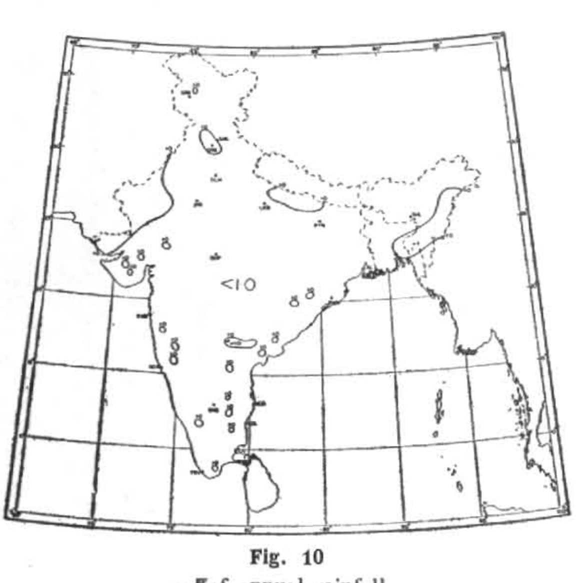

Fig. 10
γ_1 of annual rainfall

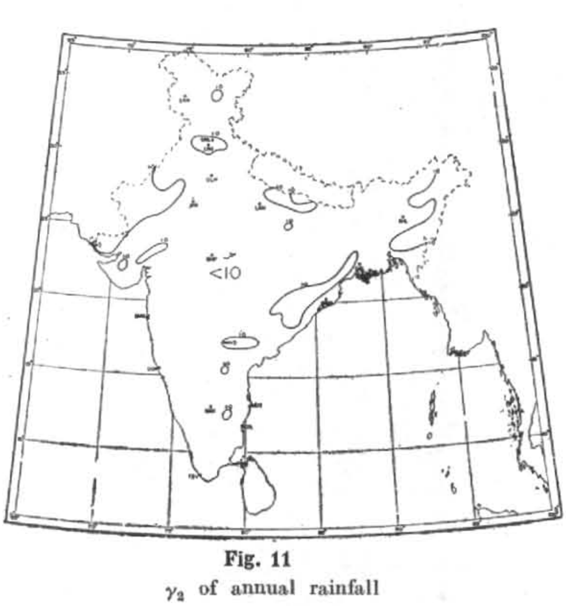

Fig. 11
γ_2 of annual rainfall

(Isopleth-value of parameter)

fall in this area is only slightly leptokurtic, whereas June to September rainfall is highly leptokurtic. The areas, where γ_2 is greater than $+1 \cdot 0$ are : (1) Kutch-west Rajasthan, (2) northern parts of Uttar Pradesh and (3) Tezpur-Imphal-Aijal area.

7. Normality

(*a*) *Southwest monsoon season (June-September)—Figs. 12 and 13*

ω_1 and ω_2 values over most parts of the country are small (less than $2 \cdot 0$) indicating that monsoon rainfall of the country in general is normally distributed. Exceptions, however, are (*i*) Saurashtra-Kutch and west Rajasthan in the northwest, (*ii*) Tezpur-Imphal-Aijal area in the northeast and (*iii*) pockets in Himachal Pradesh, Uttar Pradesh, Orissa, east Madhya Pradesh, Maharashtra, Andhra Pradesh, Tamil Nadu and Kerala, where values are greater than $2 \cdot 0$ (significance at 5 per cent level) and greater than $2 \cdot 6$ (significance at 1 per cent level).

(*b*) *Annual — Figs. 14 and 15*

ω_1 and ω_2 values of annual show most of the features of the monsoon season. There is, however,

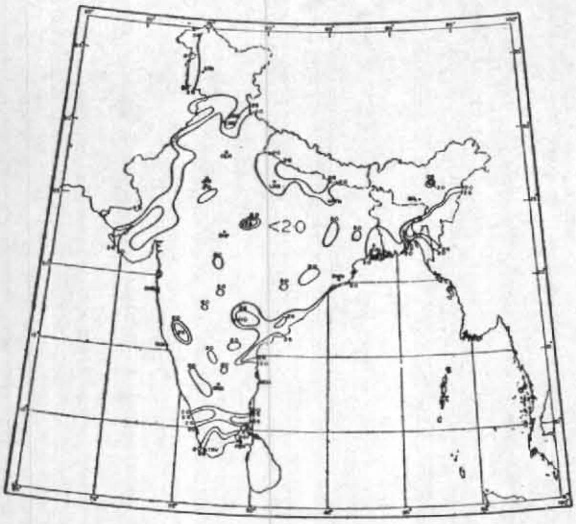

Fig. 12
ω_1 of monsoon (Jun-Sep) rainfall

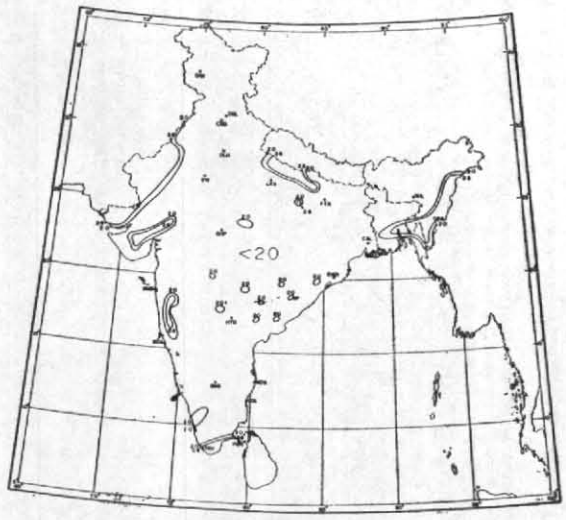

Fig. 12
ω_2 of monsoon (Jun-Sep) rainfall

(Isopleth-value of parameter)

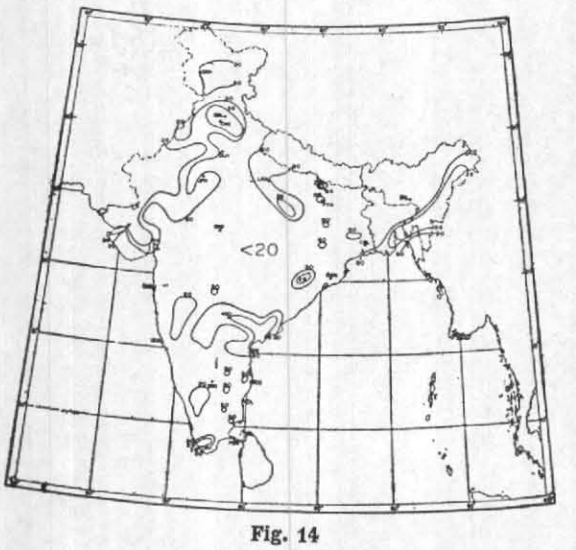

Fig. 14
ω_1 of annual rainfall

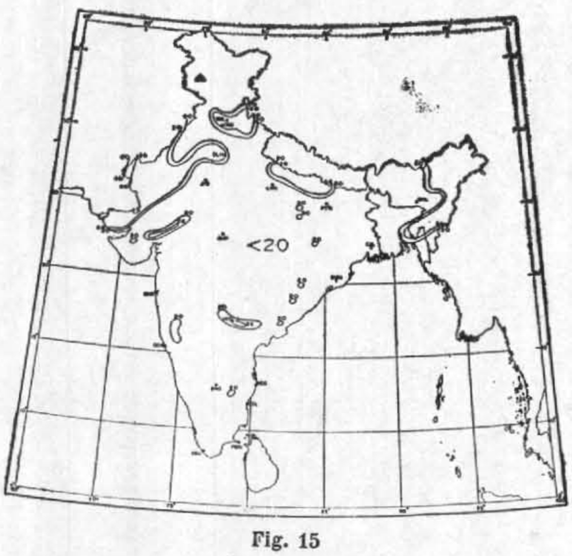

Fig. 15
ω_2 of annual rainfall

(Isopleth-value of parameter)

one major difference. Some of the pockets of high values of ω_2 of the monsoon season in Maharashtra, Kerala and Tamil Nadu do not appear in the annual.

8. Concluding remarks

It will be seen from the above analysis that Indian rainfall does not differ significantly from normal, except in Kutch, west Rajasthan, south and east Assam, certain Himalayan areas, southeast Tamil Nadu and adjoining portions of south Kerala. Considering that data of about 500 stations were examined, the result that monsoon season and annual rainfall is distributed normally over most of the country is of significance. Further for south-east Tamil Nadu, southwest monsoon season is not the main rainy season.

A number of isolated stations show significant departure from normal although several neighbouring stations do not. By combining probabilities of stations in each area, it is likely that areas where seasonal or annual rainfall is non-normal would be considerably reduced.

Besides the above, another important aspect has also to be taken note of. The need for maintenance of sites of meteorologioal observatories under standard conditions uninterrupted over a long period of time is well recognised. The World Meteorological Organisation has, in fact, been recommending the need for maintenance of reference stations without change of site and under the same conditions. The Meteorological Department is trying to ensure that changes of site or exposure conditions should be made only when absolutely necessary and in all such cases recognised procedures for comparative observations should be followed.

If we take into account all these factors, it is remarkable that only a few small regions in India do not satisfy the criteria for normal distribution. We may, therefore, infer that on the whole Indian rainfall (annual and southwest monsoon season) is distributed normally, except in a few small areas. The salient features of variability and skewness have also been analysed. Whatever the variability of individual months — it is very high even in the rainy months of July and August— a significant feature is that most of the country excluding the western arid and semi-arid areas has values of coefficient of variation between 20 to 30 per cent irrespective of the amount of rainfall. This is true even of the semi-arid tracts of the Peninsula.

The above results are important and one can, therefore, in comparing means for different periods etc apply the various statistical tests based on normal distribution.

REFERENCES

Fisher, R. A.	1958	*Statistical Methods for Research Workers.*
Mooley, D .A. and Appa Rao, G.	1971	*Mon. Weath. Rev.*, U.S. Dep. Comm 99. 10.
Mooley, D. A. and Crutcher, H. L.	1968	An application of the Gamma distibution function to Indian Rainfall. U.S. Dep. Comm. ESSA Tech. Rep. EDS-5.
Pramanik, S. K. and Jagannathan, P.	1953	*Indian J. Met. Geophys.*, **4**, 4, pp. 291-309.
Rao, C. R.	1952	*Advanced Statistical Methods in Biometry*, pp. 218-219.
Rao, K. N.	1958	*Indian J. Met. Geophys.*, **9**, 2, pp. 97-116.
	1959	*Mem. India met. Dep.*, **31**, Pt. 2.
Suzuki, E.	1964	*Pap. met. Geophys.*, **15**, 1.