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# Statistical analysis on the variability of area weighted rainfall over India

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**सार** — 1901 से 1988 तक भारत में मानसून और वार्षिक वर्षा को मौसम वैज्ञानिक उपखण्डों में इसके होने के क्षेत्र के साथ महत्व बताया गया है।

इन आंकड़ो का सांख्यिकीय रूप से विश्लेषण किया गया है। यह पाया गया है कि 1901 से शताब्दी के मध्य तक क्षेत्र वार्षिक और मानसून वर्षा के भारित क्षेत्र में वृद्धि हुई किन्तु बाद में धीरे-धीरे यह कम होता चला गया। वर्षा क्रमों ने किसी प्रकार की प्रवृति और आवृत्ति को नही दर्शाया है। 11 वर्ष के चल औसत में 1958 तक एक सुनिश्चित वृद्धि और बाद में ह्रास दिखाई पड़ता है। ये विभिन्नताएं कुछ मौसम वैज्ञानिक उपखण्डों के लिए महत्वपूर्ण स्तर दर्शाती है।

ABSTRACT. The monsoon and annual rainfall over India from 1901 to 1988 has been given weightage with the area of its occurrence over meteorological sub-divisions. This data have been statistically analysed. It has been found that the area weighted annual and monsoon rainfall increased from 1901 to the middle of the century but started decreasing gradually thereafter. The rainfall series does not show any trend and periodicities. The 11-year moving averages also indicate a definite increase up to 1958 and a fall thereafter. The variates show significant levels for certain meteorological sub-divisions.

## 1. Introduction

The study of variations in the rainfall over a region is of utmost importance for the purpose of food production and water supply for the people and also for agriculture and industry. The study of rainfall over space and time is much more important than the study of amount of rainfall. The areal distribution is easier to calculate and is useful for study of floods and famine. In India about 80 to 85 per cent of annual rainfall occurs during the four months of monsoon period. The inter-annual fluctuations in summer monsoon rains have a profound socio-economic impact. For instance, weak monsoons are associated with drought, crop failure and in extreme cases famine. Strong monsoons are associated with devastating floods and accompanying loss of life, property and crops.

Blanford (1886) made an extensive study of rainfall variability over India following disastrous famine of 1877. A significant trend could not be found for whole of India. Walker (1910) found that there was some increasing tendency for monsoon rainfall over northwest India for a short period. Rao and Jagannathan (1963) studied rainfall for 81 years for 25 meteorological sub-divisions and found a few increasing trends for some sub-divisions. Mooley and Parthasarthy (1984) made a detailed study and found out that there are three major climatic rainfall periods, of which one is a good rainfall period from 1921 to 1964.

The climatologists, John. K. Eischeid and Henry F. Diaz of National Oceanic and Atmospheric Administration's Environmental Research Laboratories in Boulder, Colorado, have studied the variability of annual rainfall over globe (*Los Angeles Times,* 10 July 1987) on the basis of rainfall data throughout the northern hemisphere from 1850 to 1986. They found that the rainfall in the band between 5-degree north and 35-degree north was more or less constant up to middle of this century and has decreased by ten per cent since then. The rainfall in band between equator and 5-degree north remained constant while in the band between 35-degree north and 70-degree north the rainfall has increased significantly (Fig. 1).

An attempt has been made in this paper to study the variability of area weighted annual and monsoon rainfall for the 35 meteorological sub-divisions of India for the period from 1901 to 1988 with a view to find any increase or decrease of rainfall over India.

## 2. Data collection and procedure

Average monthly monsoon and annual rainfall of 35-meteorological sub-divisions of the country is available at National Data Centre of India Meteorological Department, Pune for the period from 1901 to 1988. These include hill stations also. These data are utilised for the calculation of area weighted mean annual and monsoon rainfall for each year from 1901 to 1988. The

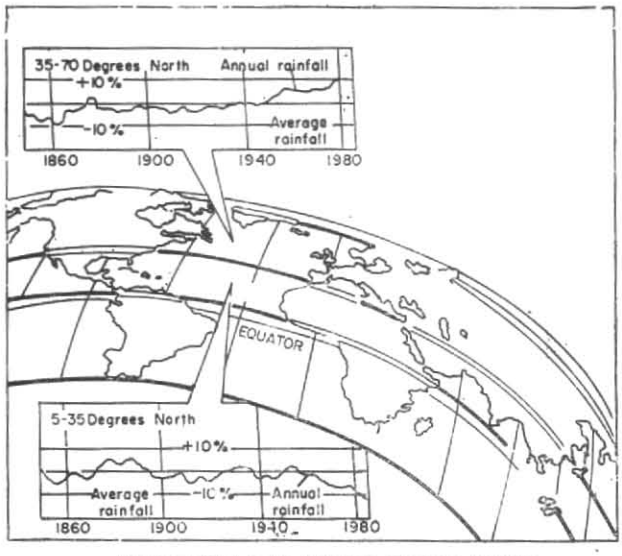


Fig. 1 . Changing rainfall (*From* Don element/ *Los Angeles Times*)

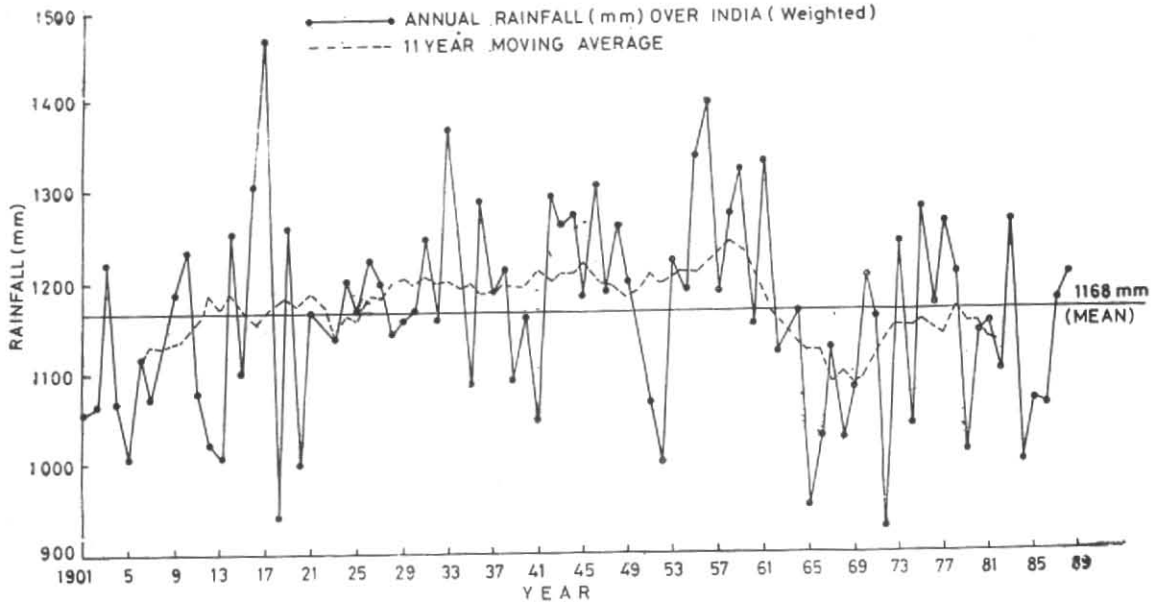


Fig. 2. Rainfall series and moving averages

TABLE 1

**Decadal mean of annual rainfall and the percentage variations**

| Decade | Decadal mean rainfall (mm) | Decadal percentage rise/fall | Percentage rise/fall |
|---|---|---|---|
| | **Annual** | | |
| 1901-1910 | 1120 | | |
| | | +4.0 | |
| 1911-1920 | 1165 | | |
| | | +0.8 | +9.64 (1901-1950) |
| 1921-1930 | 1174 | | |
| | | +2.3 | |
| 1931-1940 | 1201 | | |
| | | +2.3 | |
| 1941-1950 | 1228 | | |
| | | —1.3 | |
| 1951-1960 | 1212 | | |
| | | —7.4 | |
| 1961-1970 | 1122 | | |
| | | +2.5 | |
| 1971-1980 | 1150 | | |
| | | —3.5 | —9.60 (1951-1988) |
| 1981-1988 | 1110 | | |

TABLE 2

**Decadal mean of monsoon rainfall and the percentage variations**

| Decade | Decadal mean rainfall (mm) | Decadal percentage rise/fall | Percentage rise/fall |
|---|---|---|---|
| | **Monsoon** | | |
| 1901-1910 | 843 | | |
| | | +1.3 | +8.54 (1901-1950) |
| 1911-1920 | 854 | | |
| | | +2.7 | |
| 1921-1930 | 877 | | |
| | | +3.4 | |
| 1931-1940 | 907 | | |
| | | +0.9 | |
| 1941-1950 | 915 | | |
| | | —1.3 | |
| 1951-1960 | 903 | | |
| | | —3.9 | |
| 1961-1970 | 866 | | |
| | | —1.4 | —7.2 (1951-1988) |
| 1971-1980 | 854 | | |
| | | 0.5 | |
| 1981-1988 | 849 | | |

area weighted means have been computed by the formula :

$$R_I = \frac{\sum_{i=1}^{35} A_i r_i}{\sum_{i=1}^{35} A_i}$$

where,

$R_I$ = Mean annual/monsoon rainfall,

$r_i$ = Average annual/monsoon rainfall in $i$th meteorological sub-division,

$A_i$ = Area of the $i$th sub-division,

$I$ = No. of years ranging from 1901 to 1988,

$i$ = No. of meteorological sub-divisions ranging from 1 to 35.

These area weighted means are found to be different from the actual means. For instance, in the year 1988, the mean annual rainfall of all the meteorological sub-divisions is 1618 mm whereas the area weighted mean annual rainfall is 1208 mm only. The value 1168 mm (Fig. 2) is the mean annual rainfall for all meteorological sub-divisions for the entire period from 1901 to 1988.

The eighty eight period has been divided into three sub-periods of 30, 30 and 28 years. The area weighted means and variances for monsoon period for each sub-division and for each sub-period have been calculated and given in Table 3.

### 3. Analysis

The area weighted annual rainfall over India and the eleven-year moving averages are shown in Fig. 2. The peak annual rainfall occurred in 1917 followed by another peak in 1956. The least rainfall occurred in 1972. The eleven-year moving average indicates increasing trend up to 1958 and decreasing trend thereafter.

The decadal mean of annual rainfall and the percentage departures are given in Table 1. It can be seen that there is a steady increase of rainfall till the middle of the century. From 1901 to 1950, the rainfall has increased by 9.64 per cent. The rainfall gradually decreased from 1951. The amount of decrease from 1951 to 1988 is 9.6 per cent. The decadal means for area weighted monsoon rainfall with percentage departures is given in Table 2. Similar trend is observed in this case also. The percentage increase from 1901 to 1950 is 8.54 and decrease from 1951 to 1988 is 7.2.

TABLE 3

**Mean and standard deviations for monsoon rainfall during the three sub-periods**

| S. No. | Met. sub-division | 1901-1930 | | 1931-1960 | | 1961-1988 | |
|---|---|---|---|---|---|---|---|
| | | $X_1$ | $S_1$ | $X_2$ | $S_2$ | $X_3$ | $S_3$ |
| 1 | Andaman & Nicobar | 1694.4 | 285.4 | 1836.8 | 319.8 | 1591.2 | 184.4 |
| 2 | Arunachal Pradesh | 3117.0 | 603.5 | 2692.2 | 607.8 | 2483.4 | 664.3 |
| 3 | Assam & Meghalaya | 1628.8 | 135.9 | 1607.3 | 110.8 | 1563.0 | 216.4 |
| 4 | Naga., Mani., Mizo. & Tripura | 1463.4 | 236.6 | 1638.1 | 179.3 | 1300.0 | 382.0 |
| 5 | Sub-Himalayan W. B. & Sikkim | 2212.7 | 344.7 | 2199.0 | 259.9 | 2104.8 | 436.0 |
| 6 | Gangetic W.B. | 1078.1 | 149.2 | 1063.2 | 163.5 | 1150.2 | 191.6 |
| 7 | Orissa | 1112.6 | 133.3 | 1128.3 | 168.0 | 1102.0 | 147.3 |
| 8 | Bihar Plateau | 1116.6 | 139.5 | 1117.1 | 133.1 | 1068.2 | 197.2 |
| 9 | Bihar Plains | 1028.3 | 175.2 | 1015.6 | 149.6 | 968.6 | 258.1 |
| 10 | East UP | 881.6 | 178.0 | 9909.7 | 178.4 | 882.1 | 205.1 |
| 11 | Plains of west UP | 699.4 | 184.5 | 760.5 | 150.2 | 781.6 | 182.1 |
| 12 | Hills of west UP | 1433.9 | 325.4 | 1428.4 | 209.1 | 1279.7 | 251.6 |
| 13 | Haryana, Chandigarh & Delhi | 452.7 | 139.9 | 455.9 | 131.6 | 541.5 | 178.6 |
| 14 | Punjab | 425.0 | 143.2 | 484.2 | 139.3 | 486.4 | 174.3 |
| 15 | Himachal Pradesh | 1377.7 | 386.3 | 1435.2 | 274.3 | 1056.2 | 327.4 |
| 16 | Jammu & Kashmir | 529.5 | 142.1 | 527.6 | 163.6 | 496.8 | 220.3 |
| 17 | West Rajasthan | 275.5 | 134.2 | 269.0 | 73.8 | 268.4 | 111.9 |
| 18 | East Rajasthan | 590.7 | 194.7 | 654.9 | 150.0 | 608.6 | 161.0 |
| 19 | West MP | 865.0 | 154.3 | 1006.4 | 149.2 | 929.7 | 182.6 |
| 20 | East MP | 1177.1 | 147.5 | 1231.4 | 145.8 | 1120.4 | 223.5 |
| 21 | Gujarat Region, Daman, Dadar | 888.1 | 274.1 | 970.7 | 265.3 | 870.1 | 269.2 |
| 22 | Saurashtra, Kutch & Diu | 479.2 | 187.4 | 490.1 | 163.6 | 507.6 | 214.5 |
| 23 | Konkan & Goa | 2543.4 | 428.5 | 2931.0 | 425.6 | 2661.6 | 491.6 |
| 24 | Madhya Maharashtra | 738.0 | 140.9 | 853.6 | 093.8 | 671.2 | 165.4 |
| 25 | Marathwada | 633.4 | 175.5 | 730.2 | 146.7 | 695.7 | 202.5 |
| 26 | Vidarbha | 871.9 | 159.7 | 1009.0 | 165.7 | 904.4 | 188.0 |
| 27 | Coastal Andhra Pradesh | 566.0 | 113.1 | 596.5 | 102.4 | 571.9 | 141.7 |
| 28 | Telangana | 691.0 | 155.4 | 796.7 | 149.6 | 776.0 | 202.1 |
| 29 | Rayalaseema | 387.2 | 118.9 | 367.5 | 80.8 | 401.2 | 110.3 |
| 30 | Tamil Nadu & Pondicherry | 348.7 | 71.7 | 342.4 | 56.1 | 326.4 | 61.7 |
| 31 | Coastal Karnataka | 2808.0 | 431.9 | 2946.7 | 382.3 | 3064.0 | 576.9 |
| 32 | North Interior Karnataka | 437.6 | 94. | 470.4 | 70.1 | 546.8 | 118.3 |
| 33 | South Interior Karnataka | 706.6 | 137.6 | 866.0 | 140.3 | 630.5 | 223.6 |
| 34 | Kerala | 2062.1 | 403.7 | 1895.9 | 325.6 | 1800.1 | 393.3 |
| 35 | Lakshadweep | 986.6 | 256.1 | 938.9 | 203.9 | 1021.5 | 205.3 |

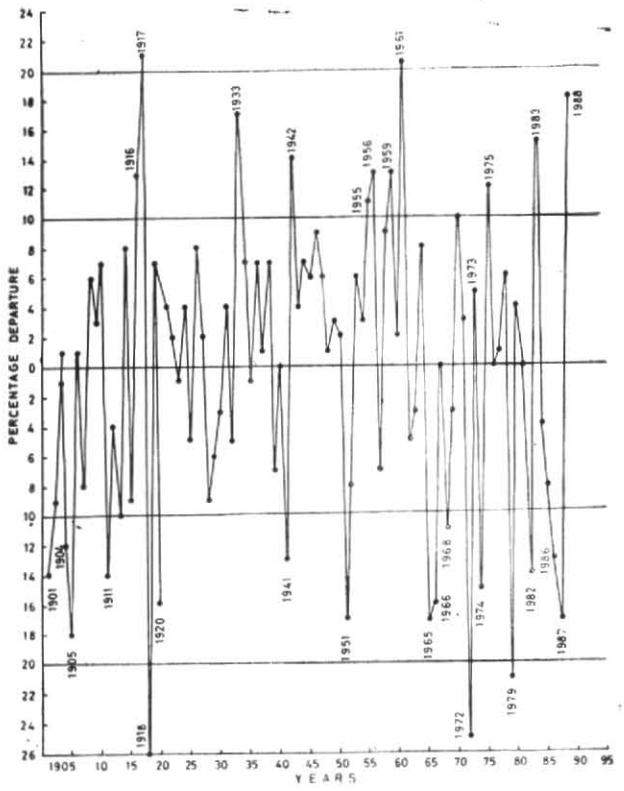


Fig. 3. Percentage departure of monsoon rainfall (weighted)

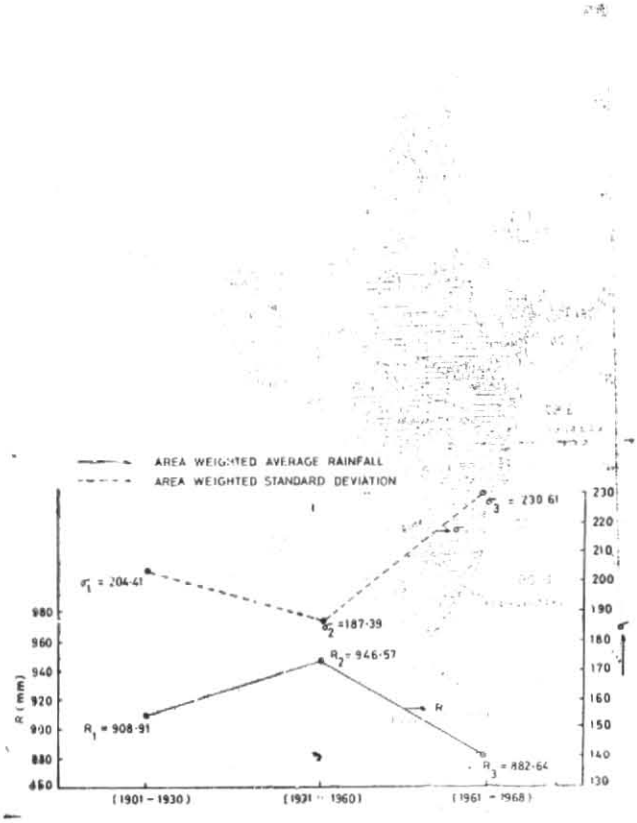


Fig. 4. Area weighted means and standard deviations (Monsoon rainfall)

The percentage increase or decrease of monsoon rainfall for every year with reference to the normal rainfall is shown in Fig. 3. The departures of *minus* ten per cent or less are treated as deficient years and those with *plus* ten per cent or more are treated as excess years. Out of 88 years, there are 12 excess rainfall years and 18 deficient years. The series reveal that there are more frequencies of deficient rainfall during 1901 to 1920, 1965 to 1987 and only two years (1941 and 1951) in a long gap of about 45 years from 1920 to 1965. But it cannot be concluded if there is an excess rainfall in one year, there will be deficient rain in next year and *vice versa*. There are no definite trends or periodicities in the occurrence of rainfall as seen in Fig. 3.

Further study has been made to probe the variability of monsoon rainfall from June to September over India. The entire period from 1901 to 1988 has been divided into three sub-periods, *i.e.*, 1901 to 1930, 1931 to 1960 and 1961 to 1988. In each sub-period, the mean value of rainfall and standard deviation for each sub-division is calculated. The average rainfall of all these sub-divisions in India ($R_1$, $R_2$, $R_3$) are calculated and the standard deviations ($\sigma_1$, $\sigma_2$, $\sigma_3$) computed. We find the average rainfall $R_2$ between 1931 to 1960 is greater than $R_1$ (between 1901 to 1930) by 4.14 per cent and $R_3$ (1961 to 1988) is less than $R_2$ by 6.75 per cent. This also indicates that rainfall has increased from first 30-year period to the second 30-year period and decreased in the third 28-year period. The mean and standard deviation for the three periods are plotted (Fig. 4). It is seen that the mean has increased while the standard deviation has decreased from first sub-period to second sub-period and *vice versa* from second sub-period to third sub-period. The standard deviation and hence the variance is lowest when the rainfall is the highest. The variance of rainfall exhibits an opposite pattern to the mean rainfall.

In order to study the variability of monsoon rainfall in each meteorological sub-division in the three sub-periods, the variates have been calculated utilizing the mean rainfall and standard deviation of each sub-division in the formulae given below :

$$Z_{1,2} = \frac{|X_1 - X_2|}{\sqrt{\frac{S_1^2}{n_1} + \frac{S_2^2}{n_2}}}, \qquad Z_{2,3} = \frac{|X_2 - X_3|}{\sqrt{\frac{S_2^2}{n_2} + \frac{S_3^2}{n_3}}}$$

where, $Z_{1,2}$ is the variate between sub-period 1 and sub-period 2, $Z_{2,3}$ is the variate between sub-period 2 and 3, $X_1$, $X_2$ and $X_3$ are the mean rainfall in the three sub-periods for each sub-division, $S_1$, $S_2$, $S_3$ are the corresponding standard deviations and $n_1$, $n_2$ and $n_3$ are the number of years that is 30, 30 and 28 years (Table 3).

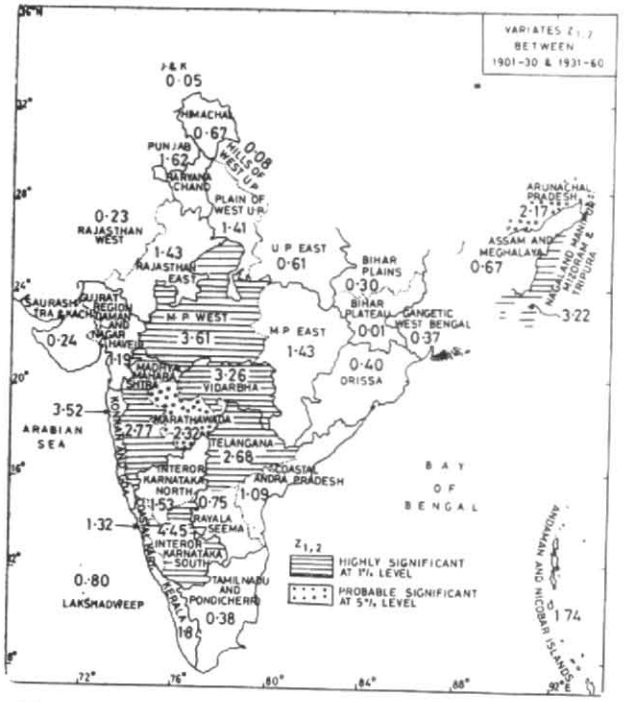


Fig. 5. Variates between periods 1901-1930 and 1931-1960


Fig. 6. Variates between periods 1931-1960 and 1961-1988

These variates are marked on meteorological sub-divisions in Figs. 5 and 6. Statistically, if the computed value of a variate ($Z$) is greater than 1.96, the difference between the means are significant at 5 per cent level. If the variate is greater than 2.58, the difference is significant at one per cent level. From the Figs. 5 and 6 it can be seen that the rainfall variability is more in the south-western and extreme eastern parts of India except for Himachal Pradesh in north. The variability is lowest over Bihar plateau between sub-period one and two and over west Rajasthan between sub-period two and three. It is highest for interior south Karnataka between sub-periods 1 and 2 and for Madhya Maharashtra between sub-periods 2 and 3. There are very few sub-divisions in the entire period which are probably significant at 5 per cent level.

## 4. Conclusions

The analysis of the area weighted monsoon and annual rainfall during the period from 1901 to 1988 enables us to draw the following conclusions :

(*i*) There is a steady increase of rainfall from 1901 to 1950. The annual and monsoon rainfall increased by 9.64 and 8.54 per cent respectively during this period.

(*ii*) There is a gradual fall of rainfall from 1950. The annual and monsoon rainfall decreased by 9.6 and 7.2 per cent during this period.

(*iii*) The highest and lowest area weighted annual rainfall occurred in 1917 (1469 mm) and 1972 (932 mm) respectively. The highest and lowest area weighted monsoon rainfall occurred in 1988 (1107 mm) and 1972 (673 mm) respectively

(*iv*) The eleven-year moving average rainfall over India also indicates a steady increase up to 1958. There is a gradual decrease up to 1969 and slight increase thereafter with minor fluctuations.

(*v*) There are no definite periodicities in the occurrence of rainfall from 1901 to 1988.

(*vi*) The decadal means also show similar trend as variation of annual rainfall.

(*vii*) The variances of rainfall exhibit an opposite pattern to the mean rainfall for three sub-periods from 1901 to 1988.

(*viii*) The variability of the weighted mean rainfall is highest in southwest parts of India. It is lowest in Bihar plateau and west Rajasthan.

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