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Trends in the rainfall pattern over India

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Abstract

Monthly, seasonal and annual rainfall time series of 36 meteorological sub-divisions of India were constructed using a fixed but a large network of about 1476 rain-gauge stations. These rainfall series are thus temporally as well as spatially homogenous. Trend analysis was carried out to examine the long-term trends in rainfall over different sub divisions. Also monthly contributions of each of the monsoon months to annual rainfall in each year were computed and the trend analysis was performed. It has been found that the contribution of June, July and September rainfall to annual rainfall is decreasing for few sub-divisions while contribution of August rainfall is increasing in few other subdivisions.

1. Introduction

In the context of climate change, it is pertinent to ascertain whether the characteristics of Indian summer monsoon also is changing. The Indian summer monsoon (June to September) rainfall is very crucial for the economic development, disaster management, hydrological planning for the country. Earlier, Mooley and Parthasarathy (1984), Parthasarathy et al. (1993), Parthasarathy et al. (1994), constructed all India rainfall series based on 306 uniformly distributed stations. They have also used area weighted method to calculate all India rainfall using rainfall data of the 306 districts outside the hilly regions like Jammu and Kashmir, Himachal Pradesh, Hills of west Uttar Pradesh, Sikkim and Arunachal Pradesh, Bay Islands and Arabian Sea Island. Presently this time series is updated by the Indian Institute of Tropical Meteorology, Pune (www.tropmet.res.in) and this rainfall time series was extensively used by many researchers.

At present there are more than 500 districts in the country. Using only 306 raingauge stations, it may not be possible to represent all the districts and prepare district-wise rainfall climatology. All the districts are having geographical area more than 100 square km (except Andaman and Nicobar Islands). Only one station in the district may not produce reliable district rainfall climatology as rainfall is highly variable (WMO, 1983). Spatial homogeneity cannot be achieved with one or two stations in a district.

Long term trends of Indian monsoon rainfall for the country as a whole as well as for smaller regions have been studied by several researchers. Most of the studies are based on the rainfall series constructed by Parthasarathy et al. (1994). They have found that the monsoon rainfall is without any trend and mainly random in nature over a long period of time, particularly on the all India time scale (Mooley and Parthasarathy, 1984). But on the spatial scale, existence of trends was noticed by Parthasarathy (1984) and Rupa Kumar et al. (1992). Parthasarathy (1984) found that the monsoon rainfall for the two subdivisions viz. sub-Himalayan West Bengal & Sikkim and the Bihar Plains are having decreasing trends while for the four subdivisions viz. Punjab, Konkan & Goa, West Madhya Pradesh and Telangana are having increasing trends. Using the network of 306 stations and for the period 1871-1984, Rupa Kumar et al. (1992) identified the areas having decreasing and increasing trends of monsoon rainfall.

The past performances of the monsoon rainfall may give an indication of the future scenario. But in order to do so we should also understand the climatology in a better way. The construction of a homogeneous rainfall data series (spatially as well as temporally) was the first step in this study. India Meteorological Department (IMD) has a good network of rain gauge stations. From the vast data set archived at the National Data Centre, IMD, Pune, a network of 1476 rain-gauge stations was selected which have only 10% or less missing years of data. To construct a homogeneous data series for the complete data period of 1901-2003 missing period of the observatory data are replaced by the neighboring state rain-gauge data and vice versa. Fig. 1 (a) shows the plot of the 1476 stations used for the study while Fig. 1 (b) show the plot of 306 stations used by the Indian Institute of Tropical Meteorology for construction of homogeneous rainfall data (Parthasarathy 1984). Clearly, the network considered in this study is more uniformly spaced and temporally homogeneous, which can be used for analyzing the spatial and temporal variability in a better way.

2. Construction of homogeneous data series

To prepare a homogenous rainfall time series, we have selected 1476 rain-gauge stations having maximum data availability during the period 1901-2003. Data for these stations are available for at least 90% of the years considered for this study (1901-2003). However, if some data was found missing for a particular station, the data gap was filled up by the rainfall data of a neighboring rain-gauge station. We have considered 458 districts for the present analysis. Each of these 458 districts of the country has two or more representing stations. First of all, the district rainfall is calculated as the arithmetic average of rainfall data of stations in the district. Thus, the rainfall data series was constructed as spatially and temporally homogeneous.

Rainfall for the meteorological subdivisions (36) was calculated as the area weighted rainfall of the districts within the meteorological sub divisions.

3. Rainfall Over the country as a whole

All India monthly, seasonal and annual rainfall series were constructed based on the area weighted rainfall of all the 36 meteorological subdivisions of the country. The results are given in Table 1. The mean, standard deviation and coefficient of variation are also given in the same Table. Mean **(1901-2003)** rainfall of July is 286.5 mm, which is the highest and contributes 24.2 % of annual rainfall (1182.8 mm). The August rainfall is slightly lower and it contributes 21.2% of annual rainfall. June and September rainfall are almost similar and they contributes 13.8 % and 14.2 % of annual rainfall respectively. The mean south-west monsoon rainfall (877.2 mm) contributes 74.2 % of annual rainfall (1182.8 mm). Contribution of pre-monsoon rainfall and post-monsoon rainfall in annual rainfall is mostly the same (11%). Coefficient of variation is higher during the months of November, December, January and February. Fig.3 shows the comparison of the IITM southwest monsoon season (June-September) rainfall series with the rainfall series constructed in this study. The correlation coefficient between these two series is found to be very large, 0.97. The mean seasonal rainfall of IITM series is 844.5 mm whereas the men value of this time series is 877.2 mm. The high mean value of the present series is because of the consideration all the 36 meteorological subdivisions, including hilly regions. The standard deviation and coefficient of variability for the IITM series are 81.0 mm and 9.6% and the same for the present time series are 71.0 mm, 8.1% respectively. Coefficient of variation of the present time series is smaller compared to IITM time series.

4. Epochal patterns of Indian summer monsoon rainfall

It is well known that Indian summer monsoon rainfall displays multi-decadal variations in which there is a clustering of wet or dry anomalies (Pant and Kumar, 1997). To examine the epochs of above and below normal rainfall, 31-year running means of Indian summer monsoon rainfall (ISMR) was calculated to isolate low frequency behavior. These epochs of above and below normal rainfall are shown in Figure 4. Rainfall was above normal for nearly forty years from 1930s to 1960s. To understand the epochal behavior of rainfall series for different monsoon months, we have also calculated 31-year running means of each of the monsoon months (Figure 5). It is seen that epochal behavior of July and September rainfall is almost similar to that of monsoon seasonal rainfall. In August, the above normal or positive phases started from the middle of 1950s and continued till to the end. Both June and August rainfall are in positive phase in the recent decades while July and September rainfall are in the negative phase. Fig. 6 shows the decadal means of all India summer monsoon rainfall anomalies. The alternating sequence of multi-decadal periods having frequent droughts and flood years are clearly noticed in Fig. 6. We can delineate (i) 1901-1930 dry period (ii) 1931-60 wet period (iii) 1961-90 Dry period (iv) 1991-2020 (possibly) Wet period. Earlier studies by Pant and Kumar(1997) using the data series of Parthasarathy et al.(1994) also found the similar results of 30 years of alternating sequences of dry and wet period. The Table 2 shows the decadal mean, frequencies of drought and flood years. The deficient or excess monsoon years are defined for those years where monsoon rainfall percentage departures from the mean rainfall are less or more than the standard deviation (8.1% of mean). In the decade 1911-20, there were four deficient and three excess years. During the dry period of 1901-30, we had eight deficient years and three excess years. During the next three decades of wet period, we had three deficient years and five excess years. In the dry period of 1961-90, there were seven deficient years and four excess years. Also during the period of 1901-2003, number of deficient years (19) is more than the number of excess years (13).

Fig. 7 shows a similar picture for each of the four monsoon months. Except for the decade 1921-30, behavior of July rainfall was almost similar to that of monsoon seasonal rainfall. During the decade 1921-30, in spite of high contribution from July, seasonal rainfall became negative because of high negative contribution of June and August rainfall. Decadal variability is more in June where alternating sequence of wet and dry periods are seen on almost every decade. Coefficient of variability of July (12.3%) and August (12.0%) rainfall are also less compared to June (18.1%) and September (19.1%) rainfall.

5. Trends in All India monsoon rainfall

Fig. 8 shows the All India monsoon seasonal rainfall series as percentage departure from long period average. The series was subjected to a 'low- pass filter' in order to suppress the high frequency oscillations. The weights used were nine point Gaussian probability curve (0.01, 0.05, 0.12, 0.20, 0.24, 0.20, 0.12, 0.05, 0.01). It is clearly seen that no linear trend exists in this series. We have also used linear regression technique and the 'Students t' test for testing if there is any significance in the trend. All India summer monsoon rainfall as well the rainfall during the four monsoon months do not show any significant trend.

6. Trends in Sub-divisional rainfall

It is interesting to see that for the country as a whole, the all India monsoon rainfall and monthly rainfall for the monsoon months do not show any significant trend. But there can be large variations in the regional scale. In order to study the secular variations of regional rainfall we have then carried out the trend analysis for the monthly rainfall series of June, July, August, and September and also for the season as a whole for all the 36 subdivisions. The results are shown in Fig 9, which shows significant and remarkable variations on the regional scale. We have analyzed July and August rainfall, which contributes major portion of monsoon seasonal rainfall. We find in July, six subdivisions have shown decreasing trends and eight subdivisions have increasing trends. In August, four (ten) subdivisions have decreasing (increasing) trends for August rainfall. We have considered all the cases of 99%, 95% and 90% levels of statistical significance. June rainfall has shown increasing trend for the western and southwestern parts of the country whereas decreasing trends are observed for the central and eastern parts of the country. But July rainfall has decreased for most parts of the central and peninsular India but increased significantly in the northeastern parts of the country. August rainfall has increased significantly (at 95% significance level) for the subdivisions Konkan & Goa, Marathwada, Madhya Maharashtra, Vidarbha, West M.P., Telangana and west U.P. September rainfall is increasing significantly (at 95% level of significance) in Gangetic West Bengal and decreasing significantly (at 90% level of significance) for the sub-divisions Marathwada, Vidarbha and Telangana. Fig. 10 shows the trends in southwest monsoon rainfall (in mm in 100 year) for each of the 36 subdivisions. Different levels of significance are shaded with colours. During the season, three subdivisions viz. Jharkhand (95%), Chattisgarh (99%), Kerala (90%) show significant decreasing trends and eight subdivisions viz. Gangetic WB (90%), West UP (90%), Jammu & Kashmir (90%), Konkan & Goa (95%), Madhya Maharashtra (90%), Rayalseema (90%), Coastal A P (90%) and North Interior Karnataka (95%) show significant increasing trends.

In order to examine further, whether the contribution of each month's rainfall in the annual rainfall shows any significant trend, we have prepared a time series of contribution of rainfall for each month towards the annual total rainfall for each year in percentages. Trend analyses are carried out for each month and for all the 36 subdivisions. Results suggest that contribution of June and August rainfall exhibited significant increasing trends, while contribution of July rainfall exhibited decreasing trends. Fig.11 shows some very interesting results. June rainfall is getting importance as its contribution to annual rainfall is increasing in almost 19 sub-divisions while decreasing in the remaining 17 subdivisions. Contribution of July rainfall is decreasing in central and west peninsular India (significantly in South interior Karnataka (95%), East M.P.(90%) Vidarbha (90%), Madhya Maharashtra (90%), Marathwada (90%), Konkan & Goa (90%), and North interior Karnataka (90%)). Interestingly, contribution of August rainfall is increasing in all these subdivisions. Therefore, we see a major shift in rainfall pattern spatially and temperally during the recent years.

7. Trends in sub-divisional rainfall during other seasons

Though south-west monsoon is the major rain producing season over the country, other seasons have also significant contribution in some specific areas. The rainfall during the winter and pre-monsoon seasons are mostly predominant by western disturbances and convective activities whereas during northeast monsoon is predominant over southern states during the October-December period. Therefore, trends analysis was also carried out on sub-divisional rainfall series for the winter season (January – February), pre-monsoon season (March-May), post-monsoon season (October-December) and also for the annual rainfall. Fig.12 shows the increase/decrease in mm in 100 year in each of 36 subdivisions for the winter, pre-monsoon, post-monsoon seasons and annual. Different levels of significance are shaded with different colours. Rainfall is decreasing in almost all the sub-divisions except for the sub-divisions Himachal Pradesh, Jharkhand and Nagaland, Manipur, Mizoram & Tripura during the winter season. The rainfall for the subdivisions viz. east Uttar Pradesh, Bihar, east Madhya Pradesh where winter rainfall is mostly due to western disturbances is also decreasing significantly. Rainfall is decreasing significantly for the eighteen sub-divisions of the country during the winter season. During the pre-monsoon season, rainfall is decreasing over most parts of the central India. This may indirectly suggests that the convective activity which is the main cause for the rainfall activities during the pre-monsoon season is decreasing over the central parts of the country. Rainfall is decreasing significantly for the six subdivisions viz. Gujarat Region, west M.P., east M.P., Vidarbha, Chattisgarh and Jharkhand. However during the post-monsoon season, rainfall is increasing for almost all the sub-divisions except for the nine sub-divisions. It is increasing significantly for the sub-divisions viz. Saurashtra & Kutch, Marathwada and Rayalseema. For the sub-divisions Chattisgarh, Jharkhand and Kerala significant decrease in rainfall is even observed in annual scale. Significant increasing trend is observed in the annual scale for the sub-divisions Konkan & Goa, Madhya Maharashtra, North Interior Karnataka, Rayalseema, coastal Andhra Pradesh, Gangetic West Bengal, Assam & Meghalaya and Jammu & Kashmir.

8. Conclusions

There was a need for development of a homogeneous (spatially and temporally) rainfall series for all the 36 meteorological subdivisions as well as for the country as a whole. The newly constructed rainfall series is uniformly distributed through out the country and it represents all the existing districts. Though Indian monsoon rainfall as a whole does not show any significant trend, significant rainfall trends are observed over some specific areas. Present study brings out some of the interesting and also significant changes in the rainfall pattern of the country. The alternating sequence of multi-decadal periods of thirty years having frequent droughts and flood years are observed in the all India monsoon rainfall data. The decades 1961-70, 1971-80 and 1981-90 were dry periods. The first decade (1991-2000) in the next 30 years period already experienced wet period (Fig. 6). Therefore, there is a chance of wet period for the subsequent two decades viz. 2001-2010 and 2011-2020. Decadal variability is more for the June and September months while decadal variability of July rainfall is almost similar to that of monsoon rainfall. July rainfall is decreasing for most parts of central India while it is decreasing for the north eastern parts of the country. However June and August rainfall is increasing for the central and south western parts of the country. During the southwest monsoon season, three subdivisions viz. Jharkhand, Chattisgarh, Kerala show significant decreasing trend and eight subdivisions viz. Gangetic WB, West UP, Jammu & Kashmir , Konkan & Goa , Madhya Maharashtra, Rayalseema , Coastal A P and North Interior Karnataka show significant increasing trends. For the first time, we have also studied contribution of each of major rain producing month's (i.e. June, July, August and September) in annual rainfall and examine whether there is any significant change in their contribution. June rainfall is getting importance as its contribution to annual rainfall is increasing in almost 19 sub-divisions while decreasing in the remaining 17 subdivisions. Contribution of July rainfall is decreasing in central and west peninsular India. But contribution of August rainfall is increasing in all these areas. Significant increasing trend is also observed in the annual rainfall for the sub-divisions Konkan & Goa, Madhya Maharashtra, North Interior Karnataka, Rayalseema, coastal Andhra Pradesh, Gangetic West Bengal, Assam & Meghalaya and Jammu & Kashmir.

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Note : Electronic version of the all India monthly rainfall shown in Table – 1 can be obtained from National Climate Centre (ncc@imd.pune.gov.in)

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Table-1

All India monthly, seasonal and annual rainfall
Rainfall in mm

YEAR	JAN	FEB	MAR	APR	MAY	JUN	JUL	AUG	SEP	OCT	NOV	DEC	J-F	MAM	J-S	O-D	ANNUAL
1901	34.1	40.2	29.6	41.9	59.1	129.4	252.7	268.6	137.3	59.5	37.1	14.0	74.3	130.6	788.0	110.6	1103.5
1902	11.4	12.4	28.6	48.1	57.3	123.8	285.6	209.8	201.1	69.9	29.3	27.3	23.8	134.0	820.3	126.5	1104.6
1903	18.7	14.0	35.8	28.8	66.3	131.4	298.9	269.3	195.3	116.1	39.3	22.6	32.7	130.9	894.9	178.0	1236.5
1904	17.5	15.6	38.5	38.5	77.2	169.2	271.9	216.4	141.6	73.7	13.4	19.7	33.1	154.2	799.1	106.8	1093.2
1905	24.9	26.3	45.1	39.5	62.3	112.1	263.5	211.3	175.6	60.2	12.9	14.2	51.2	146.9	762.5	87.3	1047.9
1906	23.0	49.2	39.1	25.5	45.6	185.3	290.7	252.2	182.5	55.7	19.2	29.8	72.2	110.2	910.7	104.7	1197.8
1907	15.8	48.6	46.7	66.8	41.8	160.9	236.3	310.9	104.0	31.8	24.5	16.6	64.4	155.3	812.1	72.9	1104.7
1908	22.2	23.0	21.5	38.2	52.5	135.7	327.0	308.5	158.8	46.8	8.9	12.6	45.2	112.2	930.0	68.3	1155.7
1909	25.7	21.4	19.3	69.4	59.9	208.1	314.9	229.0	165.9	45.2	12.6	31.4	47.1	148.6	917.9	89.2	1202.8
1910	16.2	15.2	22.5	35.8	50.6	213.2	251.3	285.5	191.6	111.8	36.1	9.5	31.4	108.9	941.6	157.4	1239.3
1911	41.1	11.1	52.9	32.4	52.5	196.8	174.0	214.6	181.3	71.0	43.8	14.8	52.2	137.8	766.7	129.6	1086.3
1912	23.4	23.7	27.5	43.9	49.7	115.3	329.3	262.2	128.8	61.3	50.3	8.5	47.1	121.1	835.6	120.1	1123.9
1913	8.9	41.7	31.0	33.4	77.1	218.8	278.5	198.3	117.9	69.6	18.7	25.1	50.6	141.5	813.5	113.4	1119.0
1914	6.4	32.8	33.2	50.6	72.5	166.9	348.6	239.8	198.2	52.6	22.3	23.2	39.2	156.3	953.5	98.1	1247.1
1915	22.1	42.1	51.8	42.8	62.0	161.8	232.9	225.8	175.8	93.8	47.6	11.2	64.2	156.6	796.3	152.6	1169.7
1916	5.8	22.3	17.8	36.0	57.6	215.0	269.8	302.6	197.4	140.4	45.5	5.8	28.1	111.4	984.8	191.7	1316.0
1917	9.6	35.7	29.7	43.2	80.0	221.3	267.4	287.3	277.6	157.1	27.4	13.4	45.3	152.9	1053.6	197.9	1449.7
1918	14.1	7.1	39.6	41.1	89.4	181.2	160.9	231.0	105.2	23.5	44.7	18.7	21.2	170.1	678.3	86.9	956.5
1919	50.6	24.4	27.6	34.9	60.0	185.7	294.3	288.6	152.6	77.1	50.4	22.5	75.0	122.5	921.2	150.0	1268.7
1920	24.9	23.6	49.4	36.8	57.5	151.4	294.2	177.9	122.3	47.0	26.5	6.2	48.5	143.7	745.8	79.7	1017.7
1921	39.9	10.8	20.0	41.1	40.1	172.5	274.6	259.9	193.5	69.3	16.8	19.3	50.7	101.2	900.5	105.4	1157.8
1922	29.4	12.5	18.4	32.7	47.4	184.4	304.1	214.4	200.6	56.5	55.2	16.5	41.9	98.5	903.5	128.2	1172.1
1923	26.0	42.2	29.0	32.4	55.3	98.6	321.1	272.2	167.9	63.0	17.7	18.3	68.2	116.7	859.8	99.0	1143.7
1924	21.3	25.7	20.7	35.1	59.7	121.3	315.0	249.4	232.9	63.3	54.6	18.7	47.0	115.5	918.6	136.6	1217.7
1925	14.6	13.4	20.9	42.3	86.2	199.2	297.7	232.2	123.4	72.2	42.4	18.4	28.0	149.4	852.5	133.0	1162.9
1926	29.4	13.2	59.0	42.9	59.6	95.1	301.8	326.6	205.5	54.9	11.8	11.7	42.6	161.5	929.0	78.4	1211.5
1927	14.3	34.2	27.6	33.5	54.5	164.5	333.6	251.9	152.6	62.8	56.9	13.7	48.5	115.6	902.6	133.4	1200.1
1928	23.2	42.5	25.6	39.8	48.6	158.8	291.3	216.4	139.1	115.3	23.4	29.1	65.7	114.0	805.6	167.8	1153.1
1929	28.0	22.4	18.4	50.4	55.0	179.0	292.6	240.9	122.9	95.8	19.6	39.7	50.4	123.8	835.4	155.1	1164.7
1930	23.6	22.2	27.1	47.2	59.8	172.2	289.1	196.7	173.5	93.1	47.7	12.6	45.8	134.1	831.5	153.4	1164.8
1931	13.8	33.2	22.2	33.6	56.4	114.5	294.7	305.5	186.3	121.7	41.2	23.8	47.0	112.2	901.0	186.7	1246.9
1932	10.0	25.1	26.7	32.6	72.1	125.0	326.7	227.8	173.8	68.9	55.7	17.2	35.1	131.4	853.3	141.8	1161.6
1933	17.8	32.9	31.0	48.7	98.8	206.9	275.7	301.9	211.1	95.9	21.3	19.1	50.7	178.5	995.6	136.3	1361.1
1934	24.8	11.4	22.2	36.5	41.5	197.5	273.5	290.6	164.4	62.2	29.5	14.7	36.2	100.2	926.0	106.4	1168.8
1935	30.0	21.3	22.7	46.9	36.2	141.9	312.3	228.1	178.1	57.1	17.3	12.9	51.3	105.8	860.4	87.3	1104.8
1936	11.8	41.5	41.1	32.1	79.4	241.9	276.2	228.4	185.4	64.3	56.2	22.6	53.3	152.6	931.9	143.1	1280.9
1937	7.8	53.6	24.6	57.9	53.8	160.2	329.3	194.9	174.0	94.5	21.9	21.0	61.4	136.3	858.4	137.4	1193.5
1938	30.8	32.6	28.2	31.1	69.4	245.5	283.5	239.6	156.2	75.0	16.1	7.9	63.4	128.7	924.8	99.0	1215.9
1939	14.1	33.4	36.5	38.3	39.4	153.7	262.5	235.6	150.3	88.9	29.7	4.5	47.5	114.2	802.1	123.1	1086.9
1940	16.0	27.9	45.1	32.9	76.0	170.4	296.0	282.9	115.1	62.4	41.4	18.0	43.9	154.0	864.4	121.8	1184.1
1941	25.7	17.4	21.2	30.7	69.4	162.2	234.0	223.4	148.0	62.9	27.6	21.5	43.1	121.3	767.6	112.0	1044.0
1942	25.0	45.1	19.3	45.5	56.1	172.3	339.5	286.0	180.4	44.0	18.2	29.2	70.1	120.9	978.2	91.4	1260.6
1943	54.9	12.2	26.7	48.6	86.0	154.6	305.5	228.3	203.0	90.5	18.1	8.5	67.1	161.3	891.4	117.1	1236.9
1944	28.5	43.0	59.7	37.6	47.6	138.1	343.4	288.4	148.1	90.4	30.3	17.9	71.5	144.9	918.0	138.6	1273.0
1945	34.8	10.8	23.2	48.0	50.4	155.7	315.2	232.9	210.6	82.4	21.2	7.8	45.6	121.6	914.4	111.4	1193.0
1946	6.9	21.5	26.0	48.5	63.5	201.1	297.4	286.5	141.6	79.6	76.9	39.4	28.4	138.0	926.6	195.9	1288.9
1947	23.2	21.0	29.1	35.4	47.2	124.0	294.7	287.4	234.3	66.9	9.8	26.4	44.2	111.7	940.4	103.1	1199.4
1948	25.6	29.0	42.4	40.2	75.2	153.9	308.3	275.2	176.5	63.4	70.0	12.6	54.6	157.8	913.9	146.0	1272.3
1949	13.2	29.7	24.4	48.0	78.1	146.7	298.9	236.8	217.2	93.2	12.6	5.7	42.9	150.5	899.6	111.5	1204.5
1950	30.2	25.0	37.4	26.9	50.2	142.7	335.5	235.6	196.7	56.6	25.4	10.6	55.2	114.5	910.5	92.6	1172.8
1951	15.9	15.3	43.1	46.2	58.4	150.3	251.6	223.9	130.5	75.4	31.7	8.7	31.2	147.7	756.3	115.8	1051.0

1952	11.0	22.6	35.1	37.8	69.9	168.4	281.8	249.0	121.9	76.7	9.4	24.5	33.6	142.8	821.1	110.6	1108.1
1953	26.2	13.9	24.8	42.4	48.7	163.3	312.9	286.0	169.8	88.5	14.1	9.8	40.1	115.9	932.0	112.4	1200.4
1954	30.4	36.6	27.9	30.2	56.3	148.6	297.7	237.5	244.5	81.6	5.6	16.9	67.0	114.4	928.3	104.1	1213.8
1955	23.5	11.1	29.9	39.5	77.4	180.3	241.2	313.9	217.7	145.9	28.4	12.9	34.6	146.8	953.1	187.2	1321.7
1956	17.5	16.6	36.7	37.4	85.8	208.4	351.3	259.6	169.0	149.7	42.8	15.8	34.1	159.9	988.3	208.3	1390.6
1957	32.2	18.8	41.3	35.3	62.4	152.3	288.9	264.9	130.3	66.4	27.2	16.3	51.0	139.0	836.4	109.9	1136.3
1958	15.1	20.5	29.8	39.8	66.9	123.9	314.5	285.4	215.0	103.9	35.4	18.7	35.6	136.5	938.8	158.0	1268.9
1959	28.7	25.1	30.0	34.1	68.5	162.6	345.5	255.5	219.1	118.6	25.4	11.6	53.8	132.6	982.7	155.6	1324.7
1960	16.3	9.2	39.7	28.1	64.3	152.0	290.6	244.6	168.6	75.3	34.8	12.6	25.5	132.1	855.8	122.7	1136.1
1961	24.9	33.9	27.8	33.5	73.2	185.8	329.0	277.3	228.0	116.7	22.9	13.6	58.8	134.5	1020.1	153.2	1366.6
1962	14.9	24.1	26.3	47.3	63.6	123.5	272.9	257.6	207.0	80.8	19.9	31.5	39.0	137.2	861.0	132.2	1169.4
1963	13.5	16.2	38.7	45.6	58.7	148.8	254.4	294.9	163.2	93.0	25.9	19.1	29.7	143.0	861.3	138.0	1172.0
1964	13.2	19.0	27.9	38.0	53.6	152.3	320.6	273.2	198.4	68.5	26.4	14.8	32.2	119.5	944.5	109.7	1205.9
1965	13.3	22.9	34.2	41.6	50.9	121.0	279.4	210.1	145.5	45.3	18.7	25.4	36.2	126.7	756.0	89.4	1008.3
1966	15.7	23.8	24.8	34.9	59.8	169.1	253.1	229.5	151.7	62.1	49.4	18.4	39.5	119.5	803.4	129.9	1092.3
1967	12.9	14.1	55.0	33.1	48.5	146.3	296.4	266.3	176.8	52.0	14.8	46.1	27.0	136.6	885.8	112.9	1162.3
1968	24.3	21.4	30.5	37.0	45.6	146.5	302.4	214.8	144.3	73.2	23.4	14.6	45.7	113.1	808.0	111.2	1078.0
1969	12.7	16.4	26.9	42.5	66.0	131.8	305.2	260.6	179.6	63.5	35.5	17.5	29.1	135.4	877.2	116.5	1158.2
1970	23.2	27.4	33.3	37.4	66.1	195.5	248.8	300.8	203.3	75.2	20.0	10.0	50.6	136.8	948.4	105.2	1241.0
1971	17.4	23.1	26.3	49.0	73.7	203.3	260.3	260.3	159.2	95.5	16.1	18.1	40.5	149.0	883.1	129.7	1202.3
1972	12.4	25.3	24.8	37.4	60.4	137.1	226.3	234.1	138.9	70.8	31.3	23.8	37.7	122.6	736.4	125.9	1022.6
1973	15.0	19.4	27.5	31.9	61.3	148.5	284.5	293.4	182.7	106.2	17.8	19.3	34.4	120.7	909.1	143.3	1207.5
1974	11.7	14.4	25.0	35.8	66.2	126.0	271.6	240.0	155.8	101.1	14.4	11.9	26.1	127.0	793.4	127.4	1073.9
1975	17.3	21.3	32.5	31.5	54.5	176.1	295.3	284.8	224.1	109.8	23.8	9.8	38.6	118.5	980.3	143.4	1280.8
1976	12.7	22.2	32.3	39.6	50.4	157.7	294.1	292.1	150.2	39.0	53.5	13.0	34.9	122.3	894.1	105.5	1156.8
1977	17.9	18.4	27.9	58.3	81.3	184.3	305.7	254.9	152.2	88.7	61.8	15.1	36.3	167.5	897.1	165.6	1266.5
1978	14.8	28.6	40.7	32.9	64.1	187.2	291.4	277.9	160.4	62.7	44.5	24.6	43.4	137.7	916.9	131.8	1229.8
1979	20.0	34.7	34.1	26.9	56.9	151.1	244.4	235.1	146.4	63.5	71.8	16.4	54.7	117.9	777.0	151.7	1101.3
1980	15.0	21.5	31.7	38.8	50.6	212.2	290.4	263.3	144.8	56.3	26.0	23.4	36.5	121.1	910.7	105.7	1174.0
1981	26.9	20.3	45.3	36.1	60.9	158.9	303.6	239.3	193.5	53.8	29.1	16.8	47.2	142.3	895.3	99.7	1184.5
1982	25.9	25.1	41.1	50.0	63.3	139.9	242.7	274.5	135.5	60.3	43.9	15.0	51.0	154.4	792.6	119.2	1117.2
1983	18.2	23.5	38.4	49.7	63.8	150.3	279.8	294.4	224.4	85.1	14.0	24.1	41.7	151.9	948.9	123.2	1265.7
1984	20.4	31.8	31.0	42.6	56.3	164.3	282.1	260.7	149.7	69.1	18.2	16.9	52.2	129.9	856.8	104.2	1143.1
1985	23.0	14.4	30.8	36.6	54.2	153.0	270.9	238.7	157.6	115.0	20.9	22.5	37.4	121.6	820.2	158.4	1137.6
1986	17.8	34.5	28.5	48.5	53.9	174.1	265.7	235.2	142.0	72.0	43.9	25.9	52.3	130.9	817.0	141.8	1142.0
1987	17.7	20.4	29.0	39.4	64.0	130.1	237.6	237.1	152.0	88.4	45.2	21.3	38.1	132.4	756.8	154.9	1082.2
1988	11.0	24.9	43.8	45.6	68.3	159.9	353.4	285.2	214.0	57.1	17.9	17.0	35.9	157.7	1012.5	92.0	1298.1
1989	15.8	17.8	32.2	34.4	56.1	183.3	308.2	238.1	170.2	54.2	20.6	18.1	33.6	122.7	899.8	92.9	1149.0
1990	16.8	42.5	49.5	43.4	101.7	180.8	279.0	292.7	195.2	99.9	32.2	25.2	59.3	194.6	947.7	157.3	1358.9
1991	14.6	25.7	29.8	50.9	73.5	181.8	281.4	256.0	135.6	63.9	33.7	22.0	40.3	154.2	854.8	119.6	1168.9
1992	19.2	23.5	33.9	32.5	53.9	141.9	257.9	269.0	169.2	69.0	42.3	7.6	42.7	120.3	838.0	118.9	1119.9
1993	18.6	26.9	40.0	30.7	67.6	165.7	314.1	209.8	200.6	87.8	29.0	18.6	45.5	138.3	890.2	135.4	1209.4
1994	23.9	25.9	27.3	47.2	50.9	199.8	336.3	278.9	153.3	87.6	26.8	19.1	49.8	125.4	968.3	133.5	1277.0
1995	27.5	29.0	28.7	34.5	77.7	137.4	301.3	256.1	183.8	76.3	35.7	10.6	56.5	140.9	878.6	122.6	1198.6
1996	22.3	22.8	36.5	35.5	60.9	170.7	277.0	283.4	147.0	98.8	16.5	18.6	45.1	132.9	878.1	133.9	1190.0
1997	16.2	13.0	33.8	42.9	51.0	166.7	284.8	270.5	163.0	68.1	56.7	45.1	29.2	127.7	885.0	169.9	1211.8
1998	16.9	33.7	41.9	41.7	58.9	162.4	293.1	253.3	195.5	102.1	38.9	12.5	50.6	142.5	904.3	153.5	1250.9
1999	20.3	13.6	18.2	24.2	81.9	167.3	274.8	251.0	191.5	106.5	23.2	8.5	33.9	124.3	884.6	138.2	1181.0
2000	22.0	26.8	22.9	43.7	69.9	178.1	274.5	240.2	154.3	60.7	20.6	11.5	48.8	136.5	847.1	92.8	1125.2
2001	11.3	14.1	23.2	44.2	61.4	185.6	275.4	229.8	138.3	95.0	26.7	11.8	25.4	128.8	829.1	133.5	1116.8
2002	20.4	20.1	28.5	42.3	59.7	161.2	163.9	244.0	173.0	69.8	27.0	12.0	40.5	130.5	742.2	108.8	1022.0
2003	15.5	30.9	32.8	39.0	55.7	167.8	305.9	250.1	181.9	93.8	26.0	20.7	46.4	127.5	905.7	140.5	1220.1
Mean (1901-2003)	**20.3**	**24.6**	**32.0**	**39.8**	**61.9**	**163.4**	**286.7**	**255.3**	**171.8**	**78.4**	**30.7**	**17.9**	**44.9**	**133.7**	**877.2**	**126.9**	**1182.8**
S.D.	**8.5**	**10.0**	**9.2**	**7.9**	**12.5**	**29.5**	**35.3**	**30.6**	**32.8**	**24.8**	**15.1**	**7.9**	**12.3**	**17.7**	**71.0**	**28.8**	**87.0**
C.V.	**41.8**	**40.4**	**28.8**	**19.9**	**20.2**	**18.1**	**12.3**	**12.0**	**19.1**	**31.6**	**49.3**	**44.0**	**27.3**	**13.2**	**8.1**	**22.7**	**7.4**

Table-2

Decadal mean (% departure from normal), frequency of drought and flood years

DECADE	Decadal mean Per cent departure from normal	Freq. of Deficient year	Freq. of Excess year
1901-10	-2.2	3	0
1911-20	-2.5	4	3
1921-30	-0.4	1	0
1931-40	1.7	1	1
1941-50	3.3	1	1
1951-60	2.5	1	3
1961-70	-0.1	2	1
1971-80	-0.8	3	1
1981-90	-0.3	2	2
1991-2000	0.6	0	1
2001-2003	-5.9	1	0

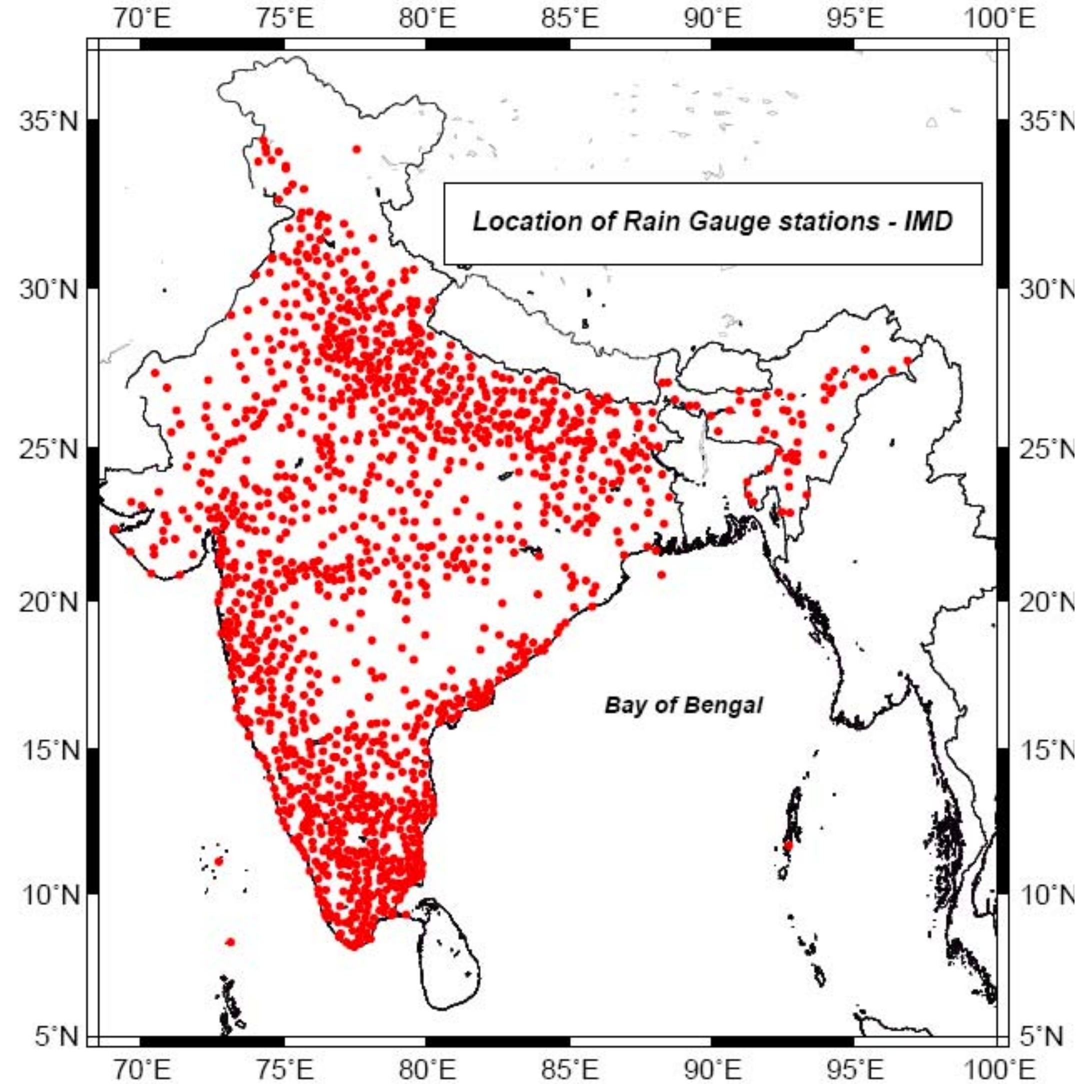

Fig. 1 Location of raingauge stations considered for the study

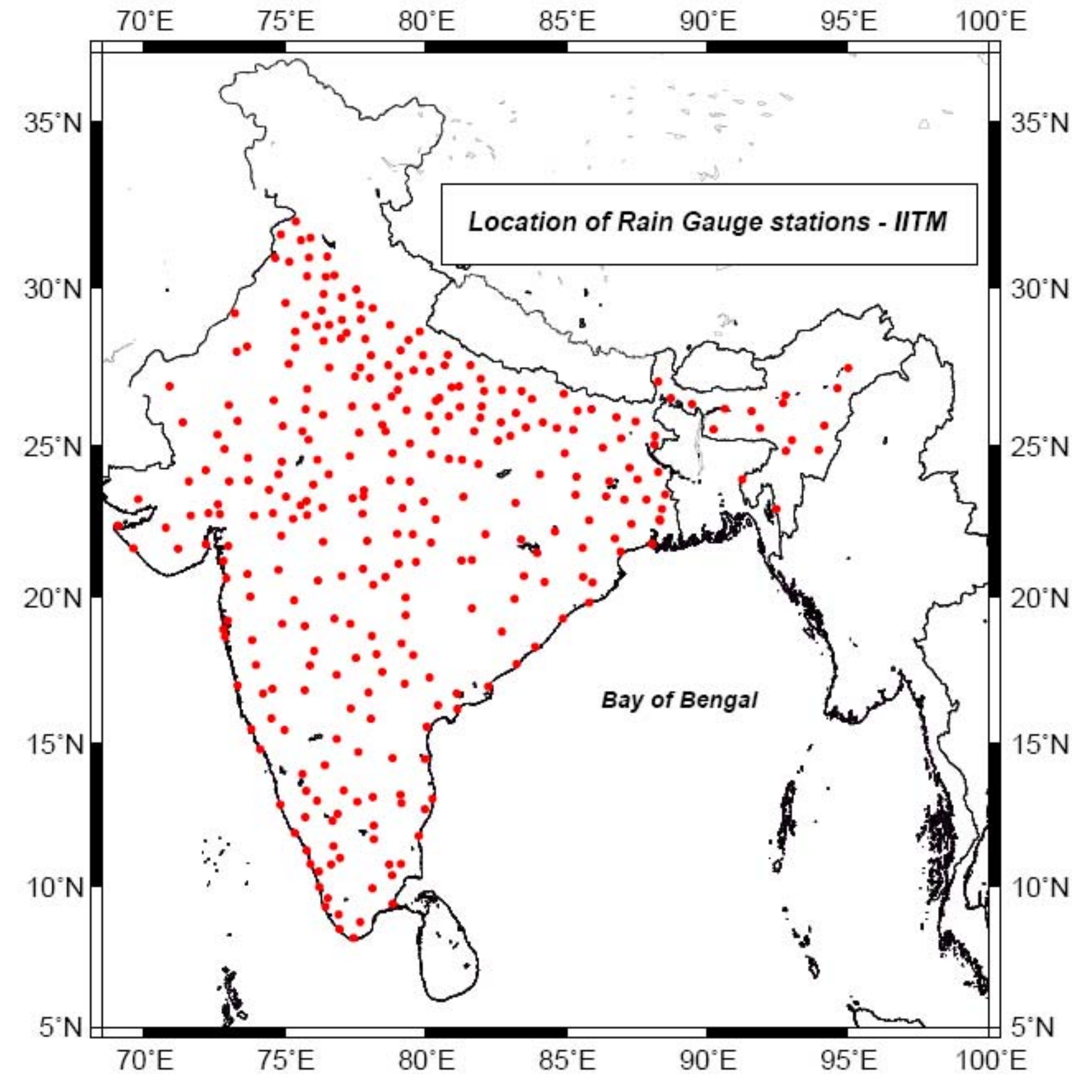

Fig. 2. Location of raingauge stations used by IITM (Parthasarathy et al. 1994)

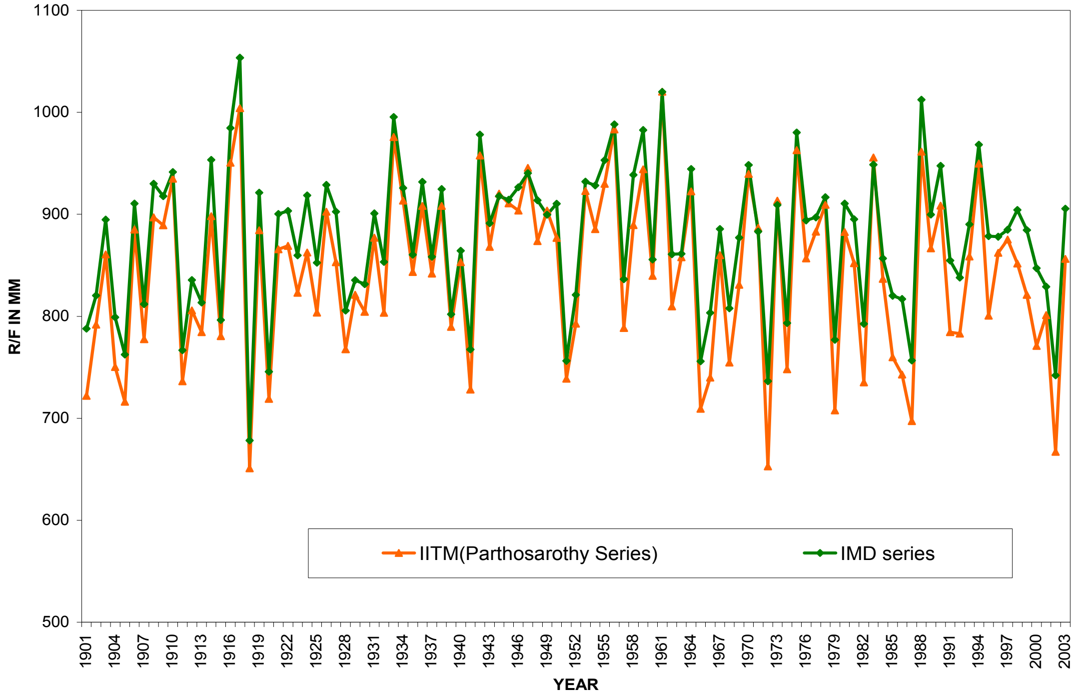

Fig.3. Comparison between IITM South-West monsoon seasonal rainfall series and the new IMD series

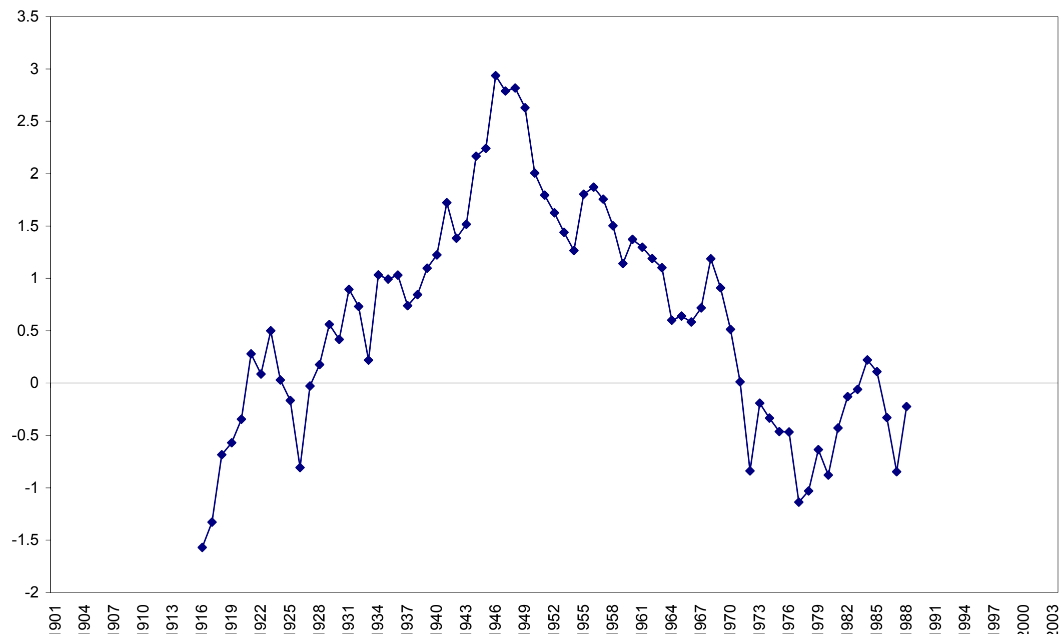

Fig.4. The 31 year moving averages of all India south-west monsoon seasonal rainfall

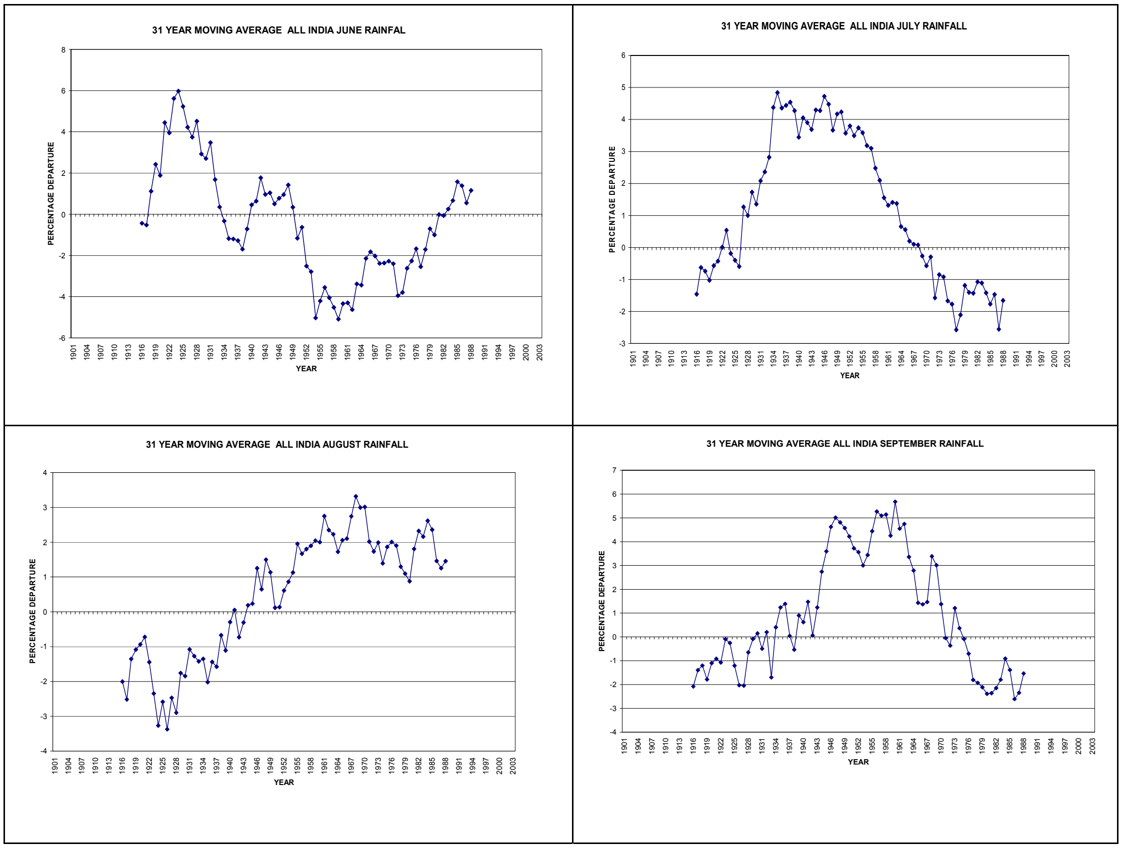

Fig. 5. 31 year moving average of all India rainfall for the four monsoon months (June, July, August, September)

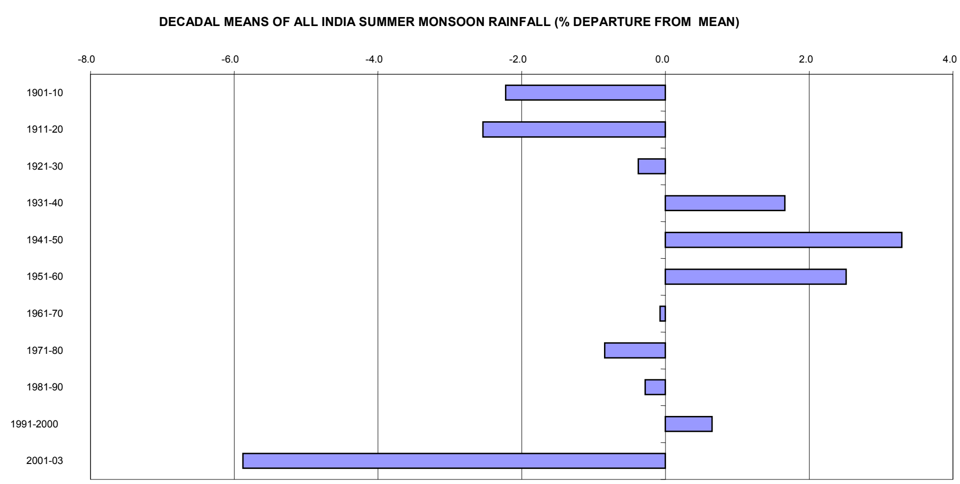

Fig 6. Decadal means of all India summer monsoon rainfall (% departure from mean)

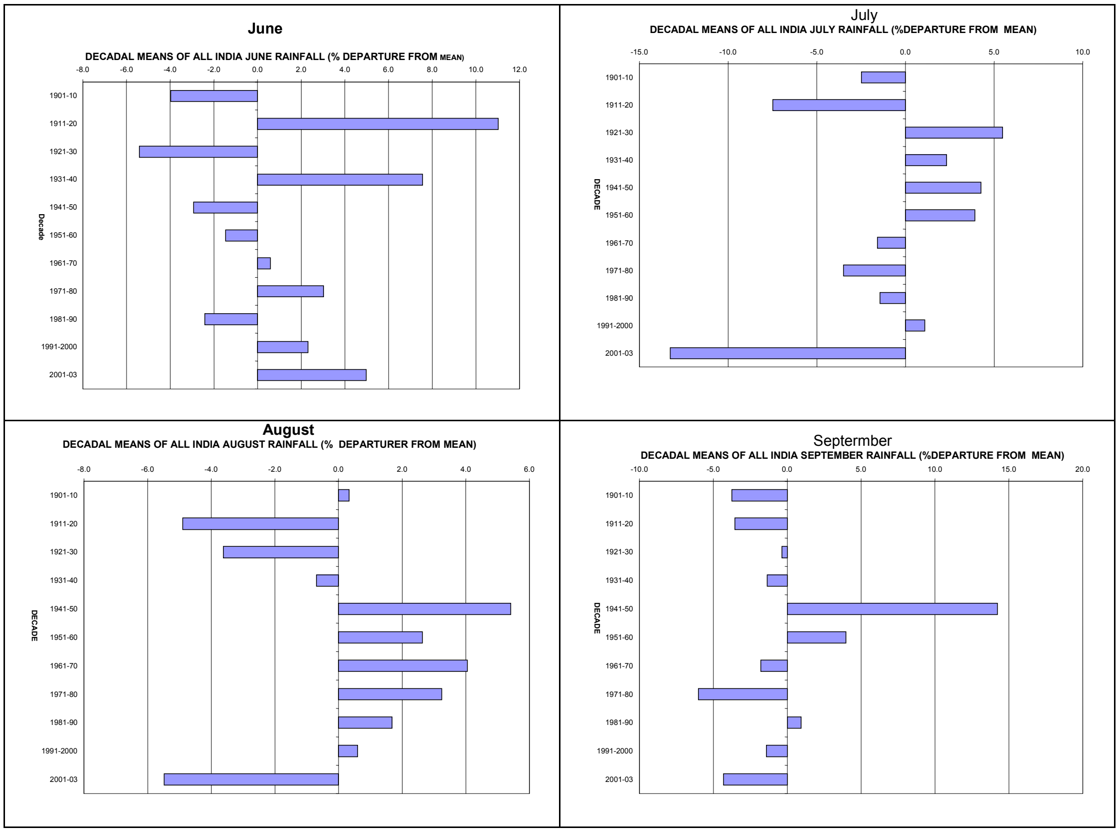

Fig.7. Decadal means of all India rainfall (% departure from mean) for the month of June, July, August and September

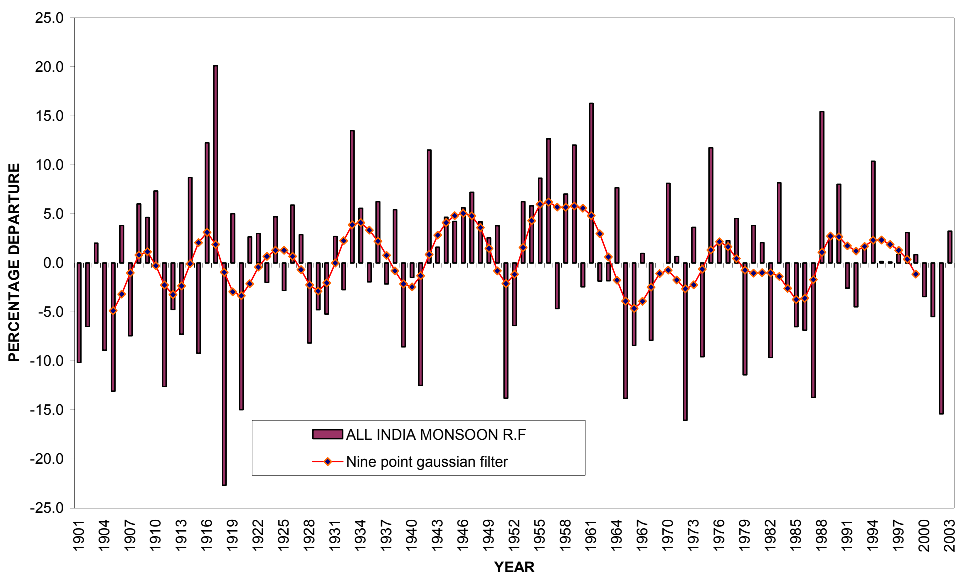

Fig. 8. All India Monsoon rainfall and its nine point Gaussian filter

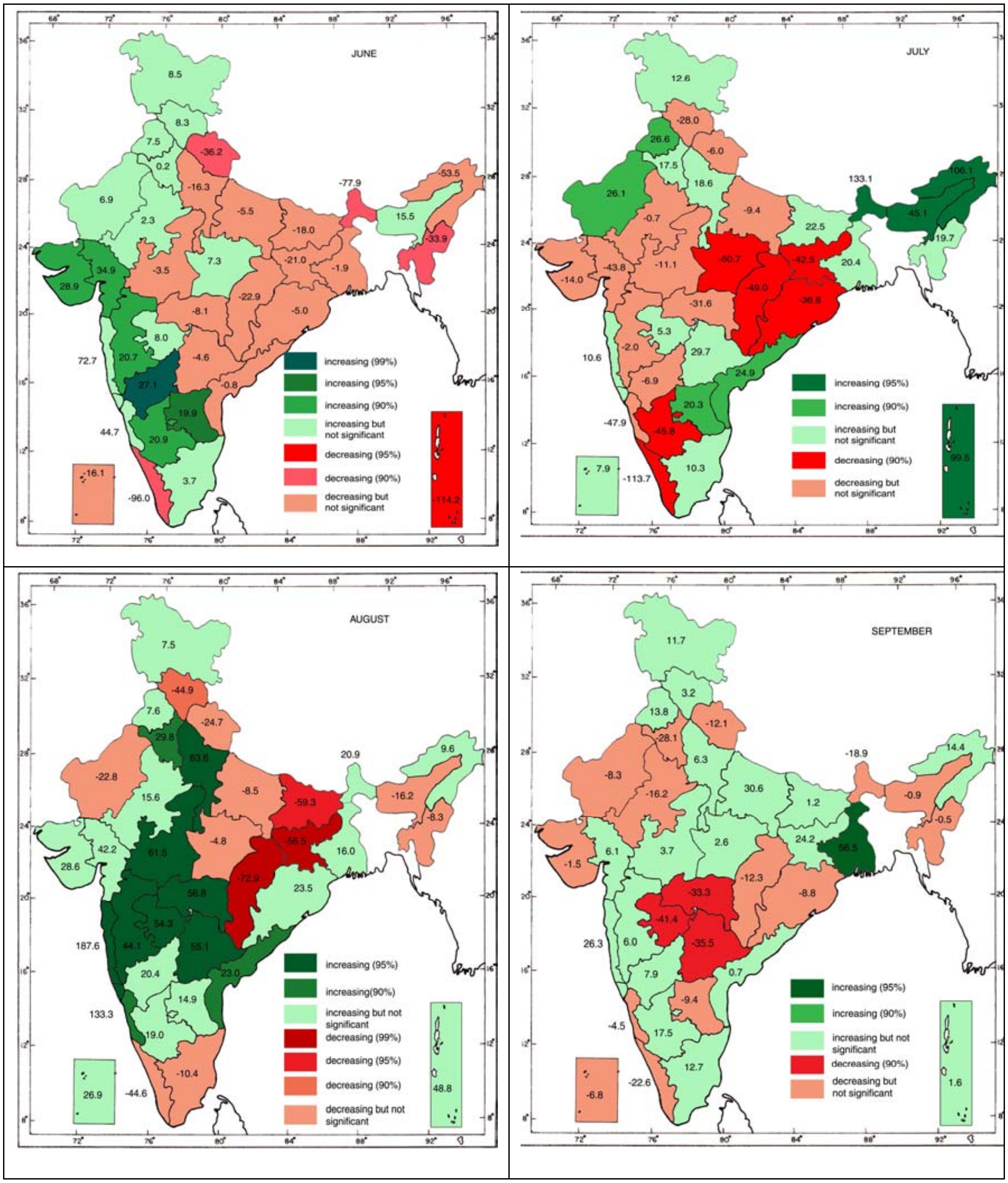

Fig.9. Increase/Decrease in rainfall in mm in 100 year for each of 36 subdivisions for the monsoon months. Different levels of significance are shaded with colors

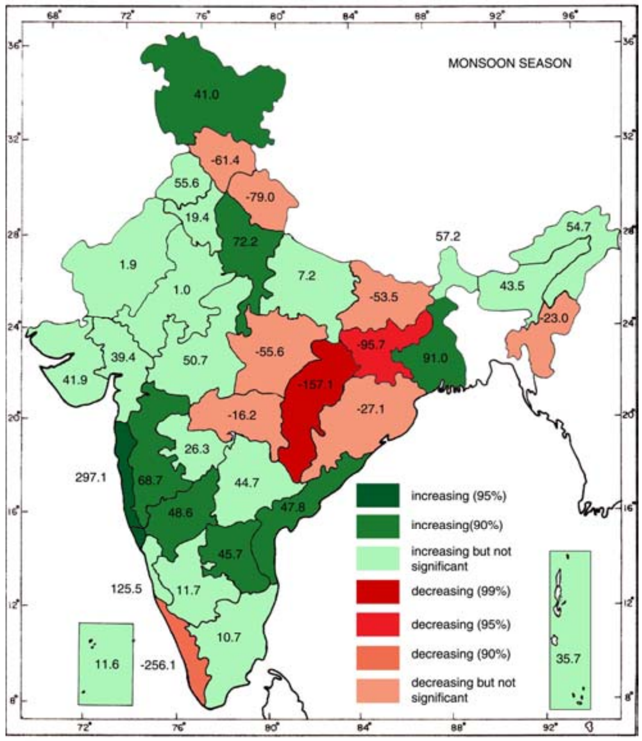

Fig. 10. Increase/Decrease in rainfall in mm in 100 year for each of 36 subdivisions for the south-west monsoon season. Different levels of significance are shaded with colors

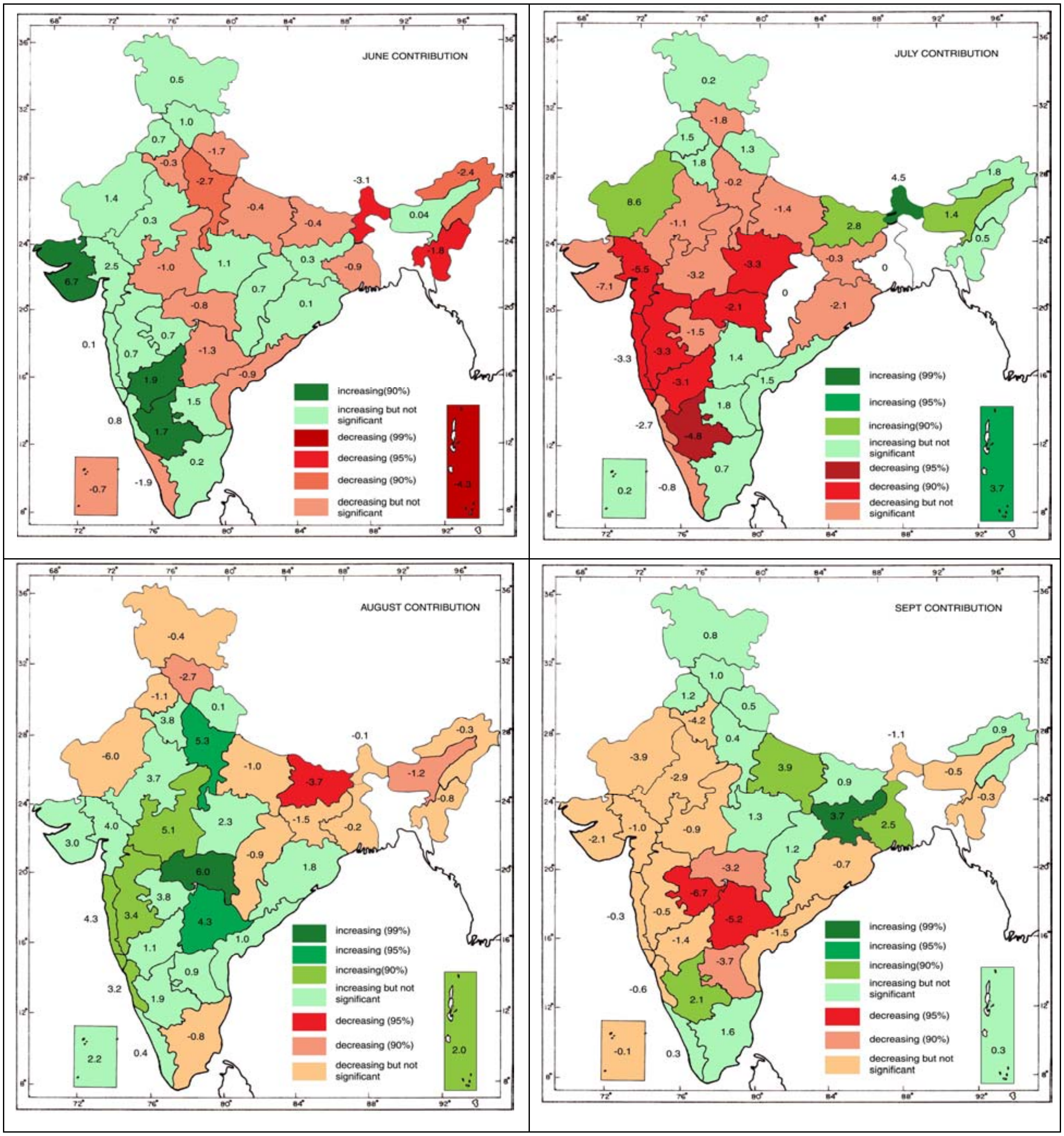

Fig.11. Increase/Decrease in rainfall in percentage in 100 years in monthly contribution of rainfall to annual rainfall for each of the four monsoon months for 36 subdivisions

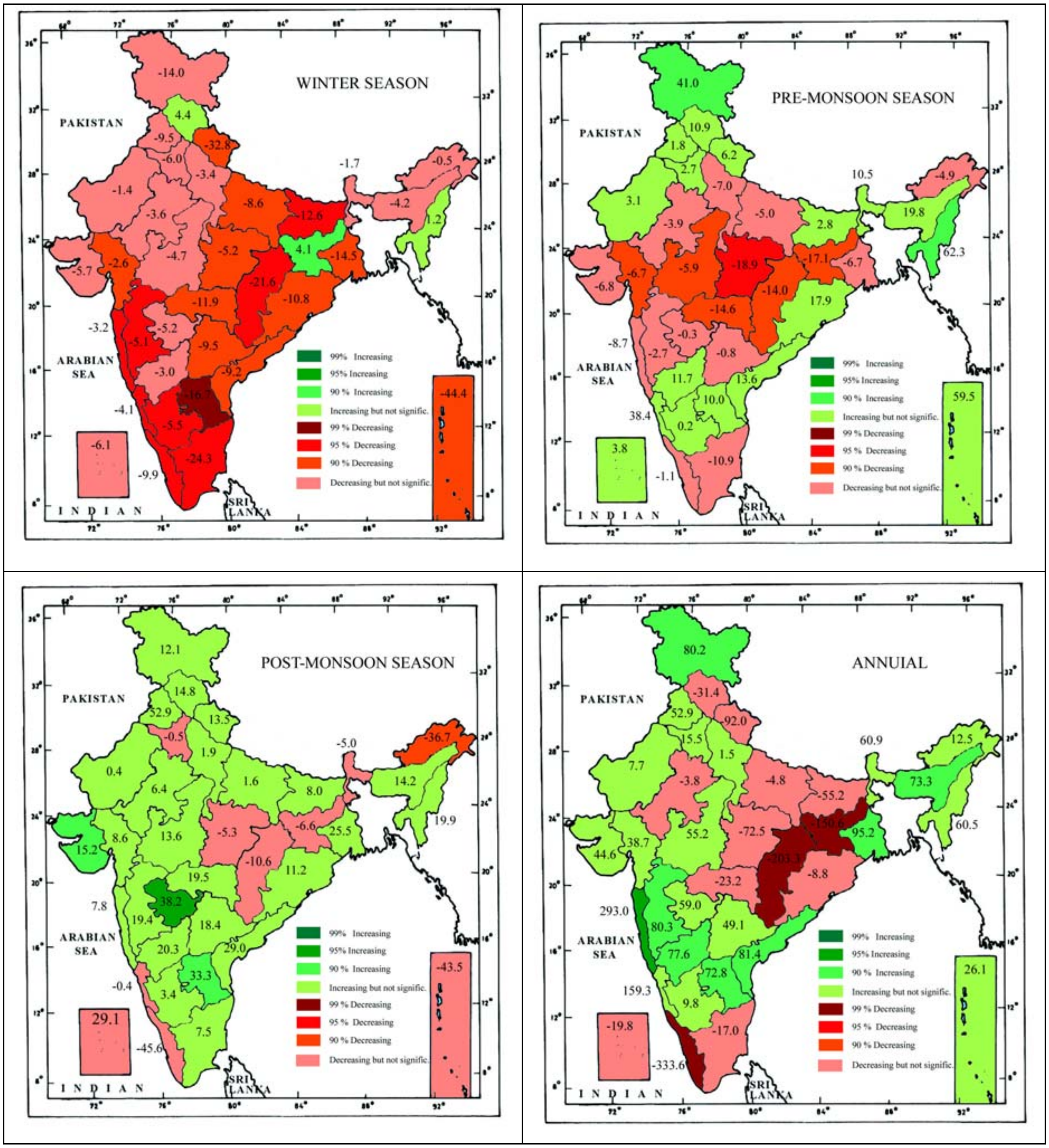

Fig.12. Increase/Decrease in rainfall in mm in 100 year in each of 36 subdivisions for the winter, pre-monsoon, post-monsoon seasons and annual. Different levels of significance are shaded with colors

N C C RESEARCH REPORTS

- New statistical models for long range forecasting of southwest monsoon rainfall over India, M. Rajeevan, D. S. Pai and Anil Kumar Rohilla, Sept. 2005.