# Trends in indian rainfall

<u>Science</u>



National Climate Centre Research Report No: 2/2006 Trends in the rainfall pattern over India P. Guhathakurta and M. Rajeevan National Climate Centre India Meteorological Department PUNE. INDIA 411005[email protected]gov. in 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 1. Introduction In the context ofclimate 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.

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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 sub- 2 divisions viz. Punjab, Konkan & Goa, West Madhya Pradesh and Telangana are having increasing trends. Using the network of 306 stations and for the period 18711984, 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 raingauge 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. (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 raingauge 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. % 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. 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. mm and 9.6% and the same for the present time series are 71. 0 mm, 8. 1% respectively. Coefficient of variation of the https://assignbuster.com/trends-in-indian-rainfall/

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present time series is similar compared to infinitine series. An Epochal patterns of 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 4 requency behavior. These epochs of above and below 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 equence 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 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. 5, 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 Subdivisional 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 6 the sub-divisions Marathwada, Vidarbha and Telangana. Fig. 10 shows the trends in southwest https://assignbuster.com/trends-in-indian-rainfall/

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 subdivisions 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 https://assignbuster.com/trends-in-indian-rainfall/ 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 7 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, premonsoon, 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 subdivisions Himachal Pradesh, Jharkhand and Nagaland, Manipur, Mizoram & Tripura during thewinter 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 premonsoon 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 https://assignbuster.com/trends-in-indian-rainfall/

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 subdivisions 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 8 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 (19912000) 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. https://assignbuster.com/trends-in-indian-rainfall/

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. Acknowledgements: The authors are thankful to Dr (Mrs) N. Jayanthi, LACD ADGM(R) and Shri Thakur Prasad, DDGM (C) for providing kind support and encouragements for this research work. We also acknowledge the help provided by the staff of the Hydrology section.

Note : Electronic version of the all India monthly rainfall shown in Table – 1 can be obtained from National Climate Centre ([email protected]pune. gov. in) 9 References Pant, G. B. & Rupa Kumar, K. , 1997, Climates of South Asia. John Wiley & Sons, Chichester, 320 pp. Parthasarathy B, 1984, Inter-annual https://assignbuster.com/trends-in-indian-rainfall/ and long term variability of Indian summer monsoon rainfall', Proc. Indian Acad. Sci. (Earth Planet. Sci.), 93, 371-385. Parthasarathy B, Rupa Kumar K and Munot A 1993 Homogeneous Indian monsoon rainfall: variability and prediction; Proc. Indian Acad. Sci. (Earth PlanetScience) 102 121-155.

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Table-1 All India monthly, seasonal and annual rainfall Rainfall in mm YEAR 1901 1902 1903 1904 1905 1906 1907 1908 1909 1910 1911 1912 1913 1914 1915 1916 1917 1918 1919 1920 1921 1922 1923 1924 1925 1926 1927 1928 1929 1930 1931 1932 1933 1934 1935 1936 1937 1938 1939 1940 1941 1942 1943 1944 1945 1946 1947 1948 1949 1950 1951 JAN 34. 1 11. 4 18. 7 17. 5 24. 9 23. 0 15. 8 22. 2 25. 7 16. 2 41. 1 23. 4 8. 9 6. 4 22. 1 5. 8 9. 6 14. 1 50. 6 24. 9 39. 9 29. 4 26. 0 21. 3 14. 6 29. 4 14. 3 23. 2 28. 0 23. 6 13. 8 10. 0 17. 8 24. 8 30. 0 11. 8 7. 8 30. 8 14. 1 16. 0 25. 7 25. 0 54. 9 28. 5 34. 8 6. 9 23. 2 25. 6 13. 2 30. 2 15. FEB 40. 2 12. 4 14. 0 15. 6 26. 3 49. 2 48. 6 23. 0 21. 4 15. 2 11. 1 23. 7 41. 7 32. 8 42. 1 22. 3 35. 7 7. 1 24. 4 23. 6 10. 8 12. 5 42. 2 25. 7 13. 4 13. 2 34. 2 42. 5 22. 4 22. 2 33. 2 25. 1 32. 9 11. 4 21. 3 41. 5 53. 6 32. 6 33. 4 27. 9 17. 4 45. 1 12. 2 43. 0 10. 8 21. 5 21. 0 29. 0 29. 7 25. 0 15. 3 MAR 29. 6 28. 6 35. 8 38. 5 45. 1 39. 1 46. 7 21. 5 19. 3 22. 5 52. 9 27. 5 31. 0 33. 2 51. 8 17. 8 29. 7 39. 6 27. 6 49. 4 20. 0 18. 4 29. 0 20. 7 20. 9 59. 0 27. 6 25. 6 18. 4 27. 1 22. 2 26. 7 31. 0 22. 2 22. 7 41. 1 24. 6 28. 2 36. 5 45. 1 21. 2 19. 3 26. 7 59. 7 23. 2 26. 0 29. 1 42. 4 24. 4 37. 4 43. 1 APR 41. 9 48. 28. 8 38. 5 39. 5 25. 5 66. 8 38. 2 69. 4 35. 8 32. 4 43. 9 33. 4 50. 6 42. 8 36. 0 43. 2 41. 1 34. 9 36. 8 41. 1 32. 7 32. 4 35. 1 42. 3 42. 9 33. 5 39. 8 50. 4 47. 2 33. 6 32. 6 48. 7 36. 5 46. 9 32. 1 57. 9 31. 1 38. 3 32. 9 30. 7 45. 5 48. 6 37. 6 48. 0 48. 5 35. 4 40. 2 48. 0 26. 9 46. 2 MAY 59. 1 57. 3 66. 3 77. 2 62. 3 45. 6 41. 8 52. 5 59. 9 50. 6 52. 5 49. 7 77. 1 72. 5 62. 0 57. 6 80. 0 89. 4 60. 0 57. 5 40. 1 47. 4 55. 3 59. 7 86. 2 59. 6 54. 5 48. 6 55. 0 59. 8 56. 4 72. 1 98. 8 41. 5 36. 2 79. 4 53. 8 69. 4 39. 4 76. 0 69. 4 56. 1 86. 0 47. 6 50. 4 63. 5 47. 2 75. 2 78. 1 50. 2 58. 4 JUN 129. 4 123. 8 131. 169. 2 112. 1 185. 3 160. 9 135. 7 208. 1 213. 2 196. 8 115. 3 218. 8 166. 9 161. 8 215. 0 221. 3 181. 2 185. 7 151. 4 172. 5 184. 4 98. 6 121. 3 199. 2 95. 1 164. 5 158. 8 179. 0 172. 2 114. 5 125. 0 206. 9 197. 5 141. 9 241. 9 160. 2 245. 5 153. 7 170. 4 162. 2 172. 3 154. 6 138. 1 155. 7 201. 1 124. 0 153. 9 146. 7 142. 7 150. 3 JUL 252. 7 285. 6 298. 9 271. 9 263. 5 290. 7 236. 3 327. 0 314. 9 251. 3 174. 0 329. 3 278. 5 348. 6 232. 9 269. 8 267. 4 160. 9 294. 3 294. 2 274. 6 304. 1 321. 1 315. 0 297. 7 301. 8 333. 6 291. 3 292. 6 289. 1 294. 7 326. 7 275. 7 273. 5 312. 3 276. 2 329. 3 283. 5 262. 5 296. 0 234. 0 339. 305. 5 343. 4 315. 2 297. 4 294. 7 308. 3 298. 9 335. 5 251. 6 AUG 268. 6 209. 8 269. 3 216. 4 211. 3 252. 2 310, 9 308, 5 229, 0 285, 5 214, 6 262, 2 198, 3 239, 8 225, 8 302, 6 287, 3 231. 0 288. 6 177. 9 259. 9 214. 4 272. 2 249. 4 232. 2 326. 6 251. 9 216. 4 240. 9 196. 7 305. 5 227. 8 301. 9 290. 6 228. 1 228. 4 194. 9 239. 6 235. 6 282, 9 223, 4 286, 0 228, 3 288, 4 232, 9 286, 5 287, 4 275, 2 236, 8 235, 6 223. 9 SEP 137. 3 201. 1 195. 3 141. 6 175. 6 182. 5 104. 0 158. 8 165. 9 https://assignbuster.com/trends-in-indian-rainfall/

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269. 0 209. 8 278. 9 256. 1 283. 4 270. 5 253. 3 251. 0 240. 2 229. 8 244. 0 250. 1 255. 3 30. 6 12. 0 121. 9 169. 8 244. 5 217. 7 169. 0 130. 3 215. 0 219. 1 168. 6 228. 0 207. 0 163. 2 198. 4 145. 5 151. 7 176. 8 144. 3 179. 6 203. 3 159. 2 138. 9 182. 7 155. 8 224. 1 150. 2 152. 2 160. 4 146. 4 144. 8 193. 5 135. 5 224. 4 149. 7 157. 6 142. 0 152. 0 214. 0 170. 2 195. 2 135. 6 169. 2 200. 6 153. 3 183. 8 147. 0 163. 0 195. 5 191. 5 154. 3 138. 3 173. 0 181. 171. 8 32. 8 19. 1 76. 7 88. 5 81. 6 145. 9 149. 7 66. 4 103. 9 118. 6 75. 3 116, 7 80, 8 93, 0 68, 5 45, 3 62, 1 52, 0 73, 2 63, 5 75, 2 95, 5 70, 8 106, 2 101. 1 109. 8 39. 0 88. 7 62. 7 63. 5 56. 3 53. 8 60. 3 85. 1 69. 1 115. 0 72. 0 88. 4 57. 1 54. 2 99. 9 63. 9 69. 0 87. 8 87. 6 76. 3 98. 8 68. 1 102. 1 106. 5 60. 7 95. 0 69. 8 93. 8 78. 4 24. 8 31. 6 9. 4 14. 1 5. 6 28. 4 42. 8 27. 2 35. 4 25. 4 34. 8 22. 9 19. 9 25. 9 26. 4 18. 7 49. 4 14. 8 23. 4 35. 5 20. 0 16. 1 31. 3 17. 8 14. 4 23. 8 53. 5 61. 8 44. 5 71. 8 26. 0 29. 1 43. 9 14. 0 18. 2 20. 9 43. 9 45. 2 17. 9 20. 6 32. 2 33. 7 42. 3 29. 0 26. 8 35. 7 16. 5 56. 38. 9 23. 2 20. 6 26. 7 27. 0 26. 0 30. 7 15. 1 49. 3 24. 5 9. 8 16. 9 12. 9 15. 8 16. 3 18. 7 11. 6 12. 6 13. 6 31. 5 19. 1 14. 8 25. 4 18. 4 46. 1 14. 6 17. 5 10. 0 18. 1 23. 8 19. 3 11. 9 9. 8 13. 0 15. 1 24. 6 16. 4 23. 4 16. 8 15. 0 24. 1 16. 9 22. 5 25. 9 21. 3 17. 0 18. 1 25. 2 22. 0 7. 6 18. 6 19. 1 10. 6 18. 6 45. 1 12. 5 8. 5 11. 5 11. 8 12. 0 20. 7 17. 9 7. 9 44. 0 33. 6 40. 1 67. 0 34. 6 34. 1 51. 0 35. 6 53. 8 25. 5 58. 8 39. 0 29. 7 32. 2 36. 2 39. 5 27. 0 45. 7 29. 1 50. 6 40. 5 37. 7 34. 4 26. 1 38. 6 34. 9 36. 3 43. 4 54. 7 36. 5 47. 2 51. 0 41. 7 52. 2 37, 4 52, 3 38, 1 35, 9 33, 6 59, 3 40, 3 42, 7 45, 49, 8 56, 5 45, 1 29, 2 50, 6 33. 9 48. 8 25. 4 40. 5 46. 4 44. 9 12. 3 27. 3 142. 8 115. 9 114. 4 146. 8 159. 9 139. 0 136. 5 132. 6 132. 1 134. 5 137. 2 143. 0 119. 5 126. 7 119. 5 136. 6 113. 1 135. 4 136. 8 149. 0 122. 6 120. 7 127. 0 118. 5 122. 3 167. 5 137. 7 117. 9 121. 1 142. 3 154. 4 151. 9 129. 9 121. 6 130. 9 132. 4 157. 7 https://assignbuster.com/trends-in-indian-rainfall/

122. 7 194. 6 154. 2 120. 3 138. 3 125. 4 140. 9 132. 9 127. 7 142. 5 124. 3 136. 5 128. 8 130. 5 127. 5 133. 7 17. 7 13. 2 821. 1 932. 0 928. 3 953. 1 988. 3 836. 4 938. 8 982. 7 855. 8 1020. 1 861. 0 861. 3 944. 5 756. 0 803. 4 885. 8 808. 0 877. 2 948. 4 883. 1 736. 4 909. 1 793. 4 980. 894. 1 897. 1 916. 9 777. 0 910. 7 895. 3 792. 6 948. 9 856. 8 820. 2 817. 0 756. 8 1012. 5 899. 8 947. 7 854. 8 838. 0 890. 2 968. 3 878. 6 878. 1 885. 0 904. 3 884. 6 847. 1 829. 1 742. 2 905. 7 877. 2 71. 0 8. 1 110. 6 112. 4 104. 1 187. 2 208. 3 109. 9 158. 0 155. 6 122. 7 153. 2 132. 2 138. 0 109. 7 89. 4 129. 9 112. 9 111. 2 116. 5 105. 2 129. 7 125. 9 143. 3 127. 4 143. 4 105. 5 165. 6 131. 8 151. 7 105. 7 99. 7 119. 2 123. 2 104. 2 158. 4 141. 8 154. 9 92. 0 92. 9 157. 3 119. 6 118. 9 135. 4 133. 5 122. 6 133. 9 169. 9 153. 5 138. 2 92. 8 133. 5 108. 8 140. 5 126. 9 28. 8 22. 7 1108. 1 1200. 4 1213. 8 1321. 7 1390. 1136. 3 1268, 9 1324, 7 1136, 1 1366, 6 1169, 4 1172, 0 1205, 9 1008, 3 1092, 3 1162. 3 1078. 0 1158. 2 1241. 0 1202. 3 1022. 6 1207. 5 1073. 9 1280. 8 1156. 8 1266. 5 1229. 8 1101. 3 1174. 0 1184. 5 1117. 2 1265. 7 1143. 1 1137. 6 1142. 0 1082. 2 1298. 1 1149. 0 1358. 9 1168. 9 1119. 9 1209. 4 1277. 0 1198. 6 1190. 0 1211. 8 1250. 9 1181. 0 1125. 2 1116. 8 1022. 0 1220. 1 1182. 8 87. 0 7. 4 12 Table-2 Decadal mean (% departure from normal), frequency of drought and flood years Decadal mean DECADE Per cent departure from normal 1901-10 1911-20 1921-30 1931-40 1941-50 1951-60 1961-70 1971-80 1981-90 1991-2000 2001-2003 -2. -2. 5 -0. 4 1. 7 3. 3 2. 5 -0. 1 -0. 8 -0. 3 0. 6 -5. 9 3 4 1 1 1 1 2 3 2 0 1 0 3 0 1 1 3 1 1 2 1 0 Freq. of Deficient year Freq. of Excess year 13 Fig. 1 Location of raingauge stations considered for the study 14 Fig. 2. Location of raingauge stations used by IITM (Parthasarathy et al. 1994) 15 R/F IN MM 0. 5 1. 5 2. 5 3. 5 -1 0 1 2 3 -0. 5 -1. 5 1000 1100 -2 500 600 700 800 900 1901 1904 1901 1904 https://assignbuster.com/trends-in-indian-rainfall/

1907 1910 1913 1916 1919 1922 1925 1928 1931 1934 1937 1940 1943 1946 1949 1952 1955 1958 1961 1964 1967 1970 1973 1976 1979 1982 1985 1988 1991 1994 1997 2000 2003 YEAR 1907 1910 1913 1916 1919 1922 1925 928 1931 1934 1937 1940 1943 1946 1949 IITM(Parthosarothy Series) series and the new IMD series Fig. 3. Comparison between IITM South-West monsoon seasonal rainfall Fig. 4. The 31 year moving averages of all India south-west monsoon seasonal rainfall 16 1952 1955 1958 1961 1964 1967 1970 1973 1976 1979 1982 1985 IMD series 1988 1991 1994 1997 2000 2003 PERCENTAGE DEPARTURE -4 0 1 2 3 4 1901 -6 -4 -2 0 2 4 PERCENTAGE DEPARTURE 6 8 1901 1904 1907 1910 1913 1916 1919 1922 1925 1928 1931 1934 1937 1940 1943 1946 1949 1952 1955 1958 1961 1964 1967 1970 1973 1976 1979 1982 1985 1988 1991 1994 1997 2000 2003 3 -2 -1 1991-2000 1904 1907 1910 1913 1916 1919 1922 1925 1928 1931 1934 1937 1940 1943 1946 1949 1952 1955 YEAR 2001-03 1901-10 -8. 0 31 YEAR MOVING AVERAGE ALL INDIA AUGUST RAINFALL 1981-90 -6. 0 YEAR 1958 1961 1964 1967 1970 1973 1976 1979 1982 1985 1988 1991 1994 1997 2000 2003 1971-80 -4. 0 -2. 0 1961-70 1951-60 1941-50 1931-40 1921-30 1911-20 31 YEAR MOVING AVERAGE ALL INDIA JUNE RAINFAL DECADAL MEANS OF ALL INDIA SUMMER MONSOON RAINFALL (% DEPARTURE FROM MEAN) (June, July, August, September) Fig. 5. 31 year moving average of all India rainfall for the four monsoon months Fig 6.

Decadal means of all India summer monsoon rainfall (% departure from mean) 17 -4 1901 1904 1907 1910 1913 1916 1919 1922 1925 1928 1931 1934 1937 1940 1943 1946 1949 YEAR 1952 1955 1958 1961 1964 1967 1970 1973 1976 1979 1982 1985 1988 1991 1994 1997 2000 2003 -3 -2 -1 0

PERCENTAGE DEPARTURE PERCENTAG E DEPAR TURE 1 2 3 4 5 6 7 -3 1901 1904 1907 1910 1913 1916 1919 1922 1925 1928 1931 1934 1937 1940 1943 1946 1949 YEAR 1952 1955 1958 1961 1964 1967 1970 1973 1976 1979 1982 1985 1988 1991 1994 1997 2000 2003 -2 -1 0 1 2 3 4 5 6 0. 0 2. 0 4. 0 31 YEAR MOVING AVERAGE ALL INDIA JULY RAINFALL 1 YEAR MOVING AVERAGE ALL INDIA SEPTEMBER RAINFALL June DECADAL MEANS OF ALL INDIA JUNE RAINFALL (% DEPARTURE FROM MEAN) -8. 0 1901-10 1911-20 1911-20 1921-30 1921-30 1931-40 1931-40 DECADE -6. 0 -4. 0 -2. 0 0. 0 2. 0 4. 0 6. 0 8. 0 10. 0 12. 0 -15. 0 1901-10 July DECADAL MEANS OF ALL INDIA JULY RAINFALL (%DEPARTURE FROM MEAN) -10. 0 -5. 0 0. 0 5. 0 10. 0 1941-50 1941-50 Decade DECADE 1951-60 1951-60 1961-70 1961-70 1971-80 1971-80 1981-90 1981-90 1991-2000 1991-2000 2001-03 2001-03 August DECADAL MEANS OF ALL INDIA AUGUST RAINFALL (% DEPARTURER FROM MEAN) -8. 1901-10 -6. 0 -4. 0 -2. 0 0. 0 2. 0 4. 0 6. 0 -10. 0 1901-10 -5. 0 0. 0 Septermber DECADAL MEANS OF ALL INDIA SEPTEMBER RAINFALL (%DEPARTURE FROM MEAN) 5. 0 10. 0 15. 0 20. 0 1911-20 1911-20 1921-30 1921-30 1931-40 DECADE 1931-40 1941-50 1941-50 1951-60 1951-60 1961-70 1961-70 1971-80 1971-80 1981-90 1981-90 1991-2000 1991-2000 2001-03 2001-03 Fig. 7. Decadal means of all India rainfall (% departure from mean) for the month of June, July, August and September 25. 0 20. 0 15. 0 10. 0 5. 0 0. 0 -5. 0 -10. 0 -15. 0 ALL INDIA MONSOON R. F -20. 0 -25. 1901 1904 1907 1910 1913 1916 1919 1922 1925 1928 1931 1934 1937 1940 1943 1946 1949 1952 1955 1958 1961 1964 1967 1970 1973 1976 1979 1982 1985 1988 1991 1994 1997 2000 2003 Nine point gaussian filter PERCENTAGE DEPARTURE YEAR Fig. 8. All India Monsoon rainfall and its nine point Gaussian filter 18 Fig. 9. Increase/Decrease in rainfall in mm in 100 https://assignbuster.com/trends-in-indian-rainfall/

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Different levels of significance are shaded with colors 20 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 21 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 22 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. 23