

SOME CHARACTERISTICS OF RAINFALL OVER MAJOR URBAN CENTRES OF GUJARAT

1. Gujarat state is located in the extreme western part of India with Thar Desert in the north-east, Rann of Kutch in the west and the mighty Arabian Sea which envelops the state towards the south and south-west. As a result, Gujarat state is marked by large scale variation in land characteristics, vegetation and rapidly growing urbanisation. All these features result in complex mesoscale and microscale circulations embedded in large scale monsoon flow. Consequently, the rainfall extremes during monsoon season leads to unusual floods and droughts over Gujarat. The permanent and semi-permanent synoptic features over Indian region in the large scale monsoon circulation produce variability in the rainfall distribution both spatially and temporally. The land surface processes predominantly influence the distribution and intensity of rainfall through mesoscale processes in smaller regions like cities.

The total annual rainfall in the Gujarat state varies from less than 40 cm over the extreme northwestern parts

to more than 225 cm over the extreme southeastern parts of the state. The southwest monsoon is the principal rainy season, when the state receives almost 95 to 96% of its annual rain. The south west monsoon advances into Gujarat state during the second week of June and extends over the entire state by end of June. July and August are the rainiest month and account individually to 38% and 24% of annual rain. The bulk of the rainfall activity over Gujarat occurs during the months of July and August under the influence of synoptic scale systems like the monsoon lows/depressions or the mid - tropospheric cyclonic circulations. In each of these months there are 14 to 16 rainy days in Gujarat region. The monsoon withdraws from the state during the second half of the September. The rainfall variability over the state is quite high. The coefficient of variation of seasonal monsoon rainfall increases from 30% over the southeastern parts of Gujarat state to more than 60% over northwestern parts (Kutch).

During monsoon season, Gujarat state gets heavy, very heavy, extremely heavy rains in association with the combined effect of passage of synoptic systems such as low/depression/deep depression formed over Bay of Bengal towards west, west-northwest or along the

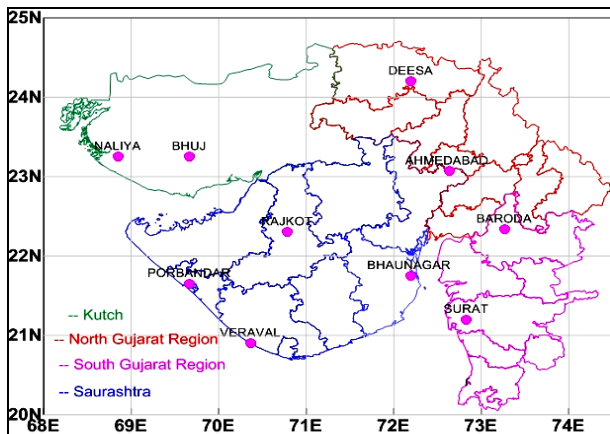


Fig. 1. Locations of urban centres of Gujarat state used for the study

monsoon trough, the persistence of cyclonic circulation extending up to mid - tropospheric level, an off-shore trough from Gujarat coast to Kerala coast and western disturbances that lie over north Pakistan and its adjoining area. The state also gets heavy rainfall in association with the mid- tropospheric circulation formed over Arabian Sea adjoining the state.

Against the backdrop of rising global surface temperature, the stability of the Indian monsoon rainfall over the past century has been a puzzle. By using a daily rainfall data set, Goswami *et al.* (2006) have shown (i) significant rising trends in the frequency and the magnitude of extreme rainfall events and (ii) a significant decreasing trend in the frequency of moderate events over central India during the monsoon seasons from 1951 to 2000. The seasonal mean rainfall does not show a significant trend, because the contribution from increasing heavy events is offset by decreasing moderate events. According to them, a substantial increase in hazards related to heavy rain is expected over central India in the future. A study by Rajeevan *et al.* (2006) also endorsed the above findings. Another case study showed that the increasing trend of extreme rainfall events over central India could be associated with the increasing trend of sea surface temperature and surface latent heat flux over tropical Indian Ocean (Rajeevan *et al.*, 2008). However, the trends in heavy rainfall events are not uniform over central India. For example, Mohapatra & Mohanty (2005) have found that there is no significant trend in frequency of very heavy rainfall in recent years (1980-1999) over Odisha.

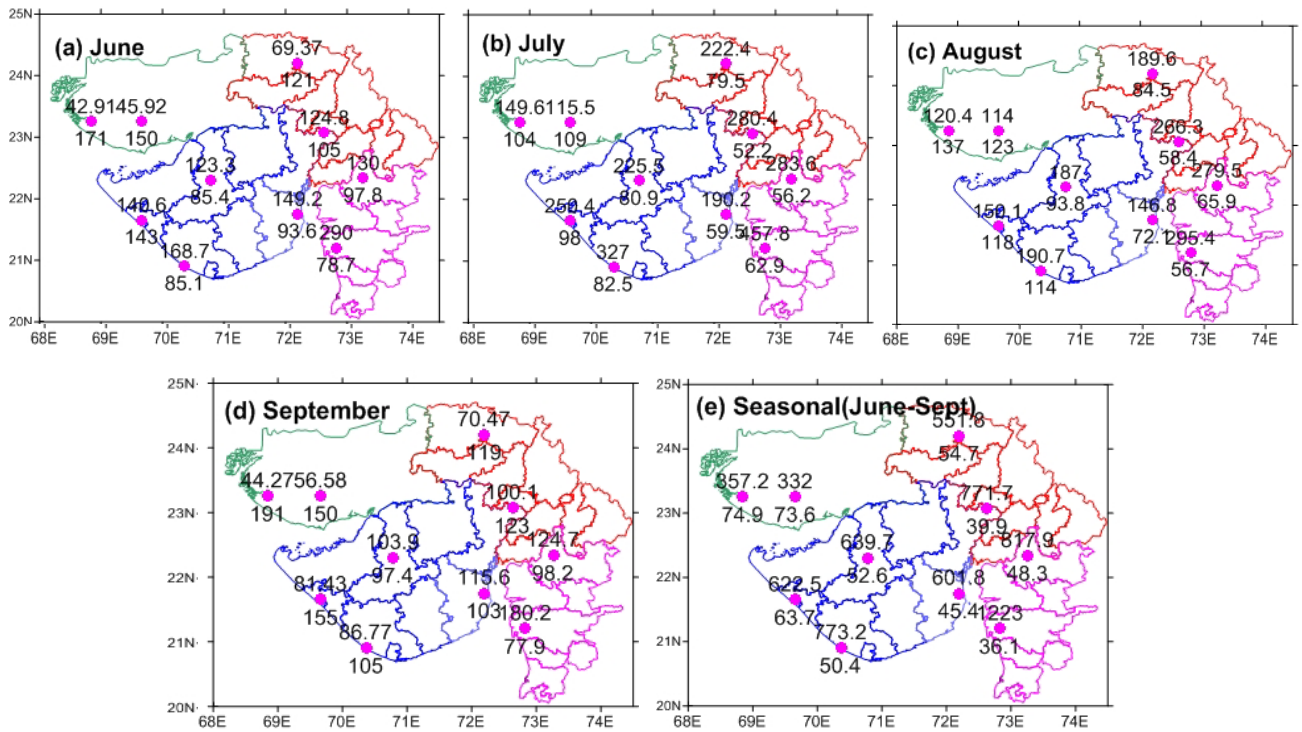
However, there are a very few studies on the study of rainfall characteristics of rapidly growing urban centers of Gujarat. There are 10 major urban centers in the state. Considering all these, a climatological study of rainfall

over 10 cities of Gujarat (Fig. 1) over a period of 42 years has been carried out for the monsoon season (Jun-Sep).

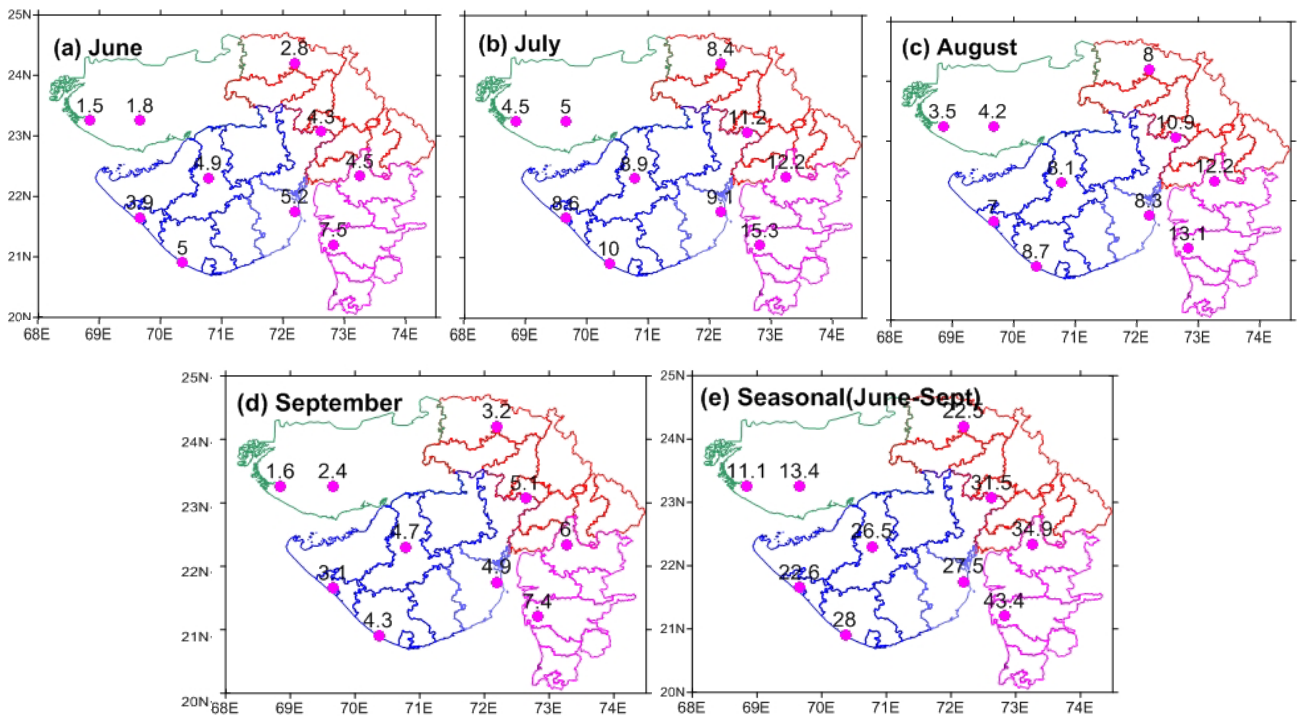
The study will be helpful in planning of economic development of Gujarat, especially the urban local bodies, as most of the socio-economic activities are linked with climate of the place. Further, typical synoptic situations that affect the weather over Gujarat in conjunction with its unique geography and topography makes numerical weather prediction (NWP) a multi-scale problem that involves synoptic scale features along with a variety of physics and parameterization schemes. It is due to these complexities that the use of an advanced meso - scale model in a nested configuration is a major requirement for simulating and forecasting the rainfall occurrences over this region. However, these models have not yet succeeded to simulate the heavy rainfall events over urban regions, like, Ahmedabad (Deb *et al.*, 2008). Hence, in the absence of a reliable NWP model, the climatological information still carries its importance in prediction of such heavy rainfall events.

2. To find out the characteristic features of annual monsoon rains over major urban centres of Gujarat, daily rainfall data of 10 such centres for the period of 42 years (1969-2010) have been considered for the study. These rainfall data have been collected from National Data Centre (NDC), Pune, India. Gujarat state (Fig. 1) has two meteorological sub divisions, *viz.*, Gujarat region and Saurashtra & Kutch as defined by India Meteorological Department (IMD), 2009. Further, Gujarat region is subdivided into North Gujarat region and South Gujarat region for rainfall analysis in state level. The stations considered for the study are Ahmedabad (23.04° N/ 72.38° E) and Deesa (24.2° N/ 72.2° E) situated in the north Gujarat region, Surat (21.2° N/ 72.8° E) and Baroda (22.3° N/ 73.3° E) situated in south Gujarat region, Bhuj (23.3° N/ 69.7° E) and Naliya (23.3° N/ 68.8° E) situated in Kutch, Porbandar (21.6° N/ 69.6° E), Bhavnagar (21.75° N/ 72.2° E), Veraval (20.9° N/ 70.36° E) and Rajkot (22.3° N/ 70.78° E) situated in Saurashtra.

The annual average rain during the months of monsoon and season as a whole with their standard deviation are calculated. The coefficient of variation (CV) of rainfall for different months of monsoon and the season as a whole have been estimated. Average rainy days for different months of monsoon and for the season as a whole have also been found out and analyzed. It is found that the monthly and seasonal rainfall over different stations is highly convective and heavy rainfall events have large contribution to monthly and seasonal rainfall. The frequency of heavy, very heavy and extremely heavy rainfall events have been found out based on the data of 42 years (1969-2010). For this study heavy rainfall event



Figs. 2(a-e). Average rainfall (mm) and coefficient of variation during different monsoon months and the season based on the data of 42 years (1969-2012). The rainfall and CV are mentioned above and below the station



Figs. 3(a-e). Average of rainy days over all the stations during different monsoon months and the season (1969-2012)

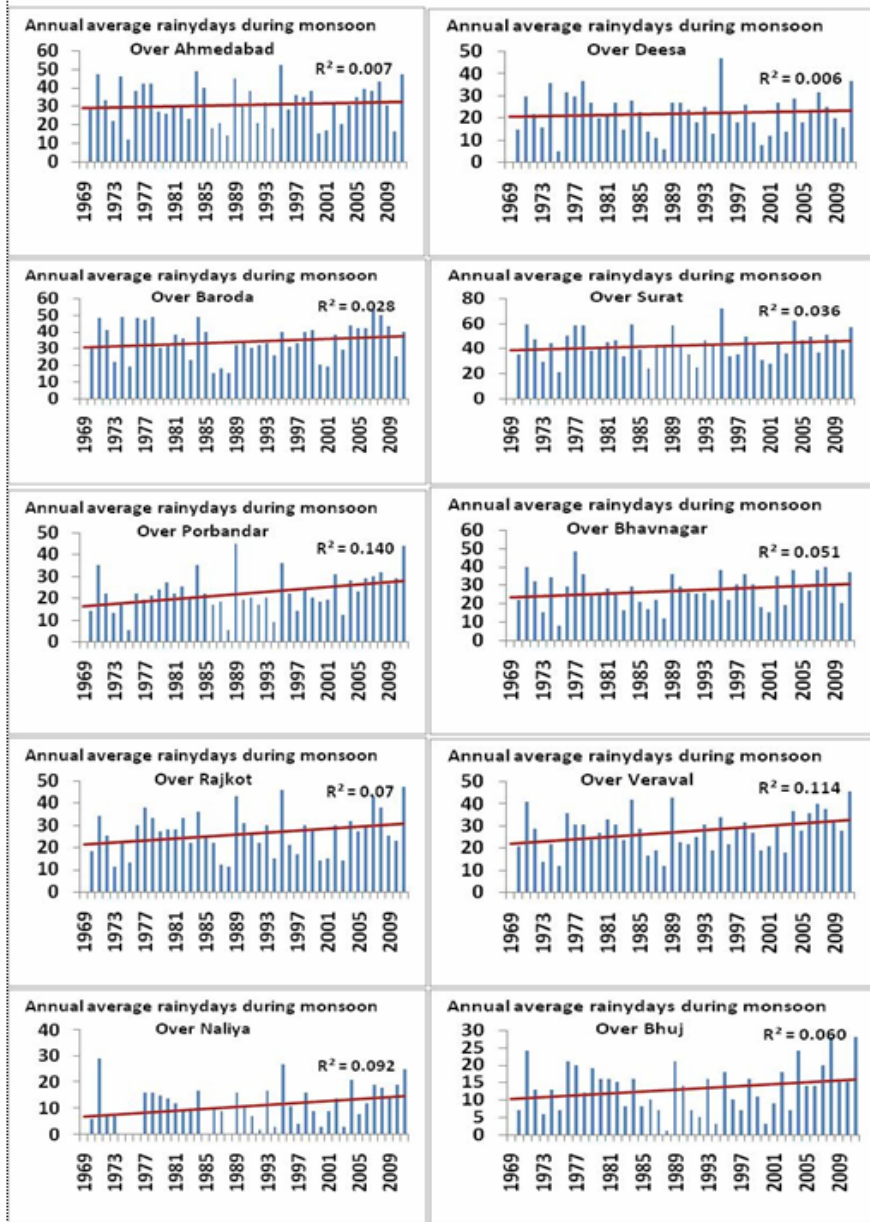


Fig. 4. The time series of seasonal average rainy days of the stations during the monsoon season from June to September with their trends

with daily 24 hour cumulative rainfall recorded at 0830 hrs IST amounting to 65 mm to 124 mm, very heavy rainfall amounting to 125 mm to 199 mm and extremely heavy rainfall amounting to 200 mm or more are considered. The month-wise comparison of the above events over different stations has been made and inter-annual variation of such events has been analyzed. The linear trend coefficients of rainfall have been calculated

based on the data of 1969-2010 and the significance of the trend coefficients has been analyzed by calculating the squared correlation coefficients and applying Student's 't' test.

3. The average rainfall and rainy days over 10 stations of Gujarat state is presented in Sec. 3.1. The trends in monthly and seasonal rainfall over different

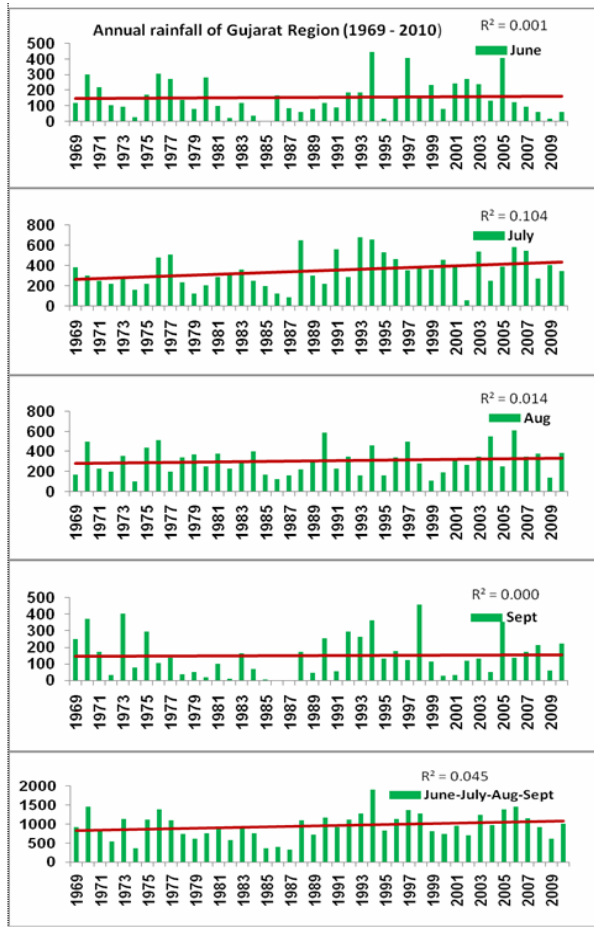


Fig. 5(a). The time series of monthly seasonal rainfall during the monsoon season from June to September of met subdivision Gujarat region for the period 1969-2010

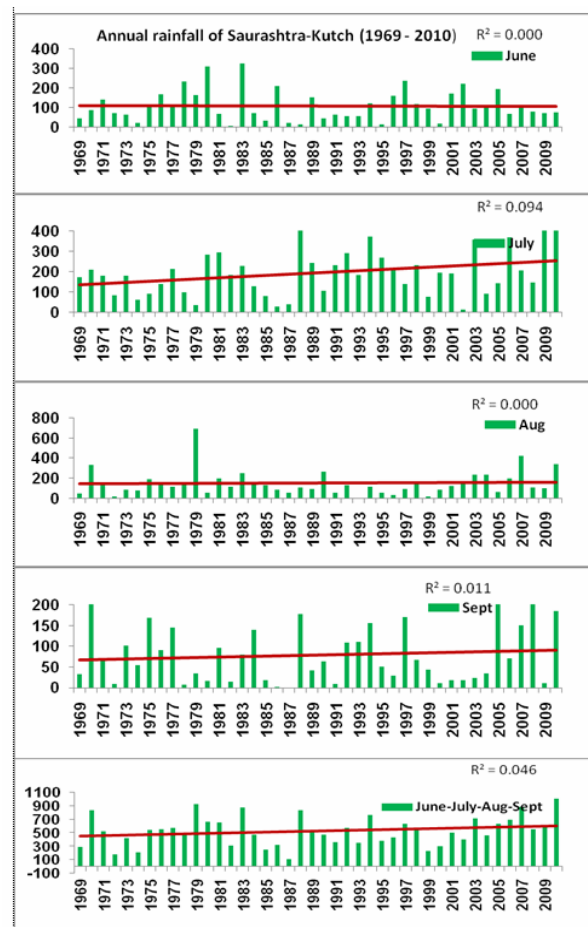


Fig. 5(b). The time series of monthly and seasonal rainfall during the monsoon season from June to September of met subdivision Saurashtra-Kutch for the period 1969-2010

stations are analyzed and presented in Sec. 3.2. The 24 hrs heavy, very heavy and extremely heavy rainfall events over all the stations are analyzed and discussed in Sec.3.3.

3.1 The average monthly and seasonal rainfall and their coefficient of variation (CV) of all the 10 stations of Gujarat [Figs. 2(a-e)] have been analyzed. All the stations have more than 100% of CV indicating that standard deviation (SD) is higher than mean rainfall for all stations. Comparing individual months, the rainfall over all the stations over Gujarat state is highly variable during June and September and more stable in July and August. It may be due to the fact that June and September are the monsoon onset and withdrawal months over Gujarat state, respectively and rainfall is more variable during these phases (Rao, 1976). Further, with the well established monsoon circulation in the country during July and August, the rainfall over all the stations is relatively more stable. The average monthly rainfall is maximum in July

followed by August and minimum in September over most of the stations. However, Deesa, Naliya and Bhuj received minimum monthly rainfall in June.

3.2. The number of rainy days (days with 24 hrs cumulative rainfall recorded at 0830 hr (IST) of 2.5 mm or more) are presented in Fig. 3. It is maximum in July followed by August and minimum in June and September. However, while comparing the average rainfall per rainy day, it is almost same for all the months and is about 20 - 35 mm per day. The higher value of rainfall per day along with lower number of rainy days indicates that the monsoon rainfall is more convective in nature over Gujarat.

3.3. The trend of seasonal average rainy days during monsoon over all the stations of Gujarat have been analyzed (Fig. 4). It is seen that there is increasing trend in seasonal rainy days during monsoon over all the stations.

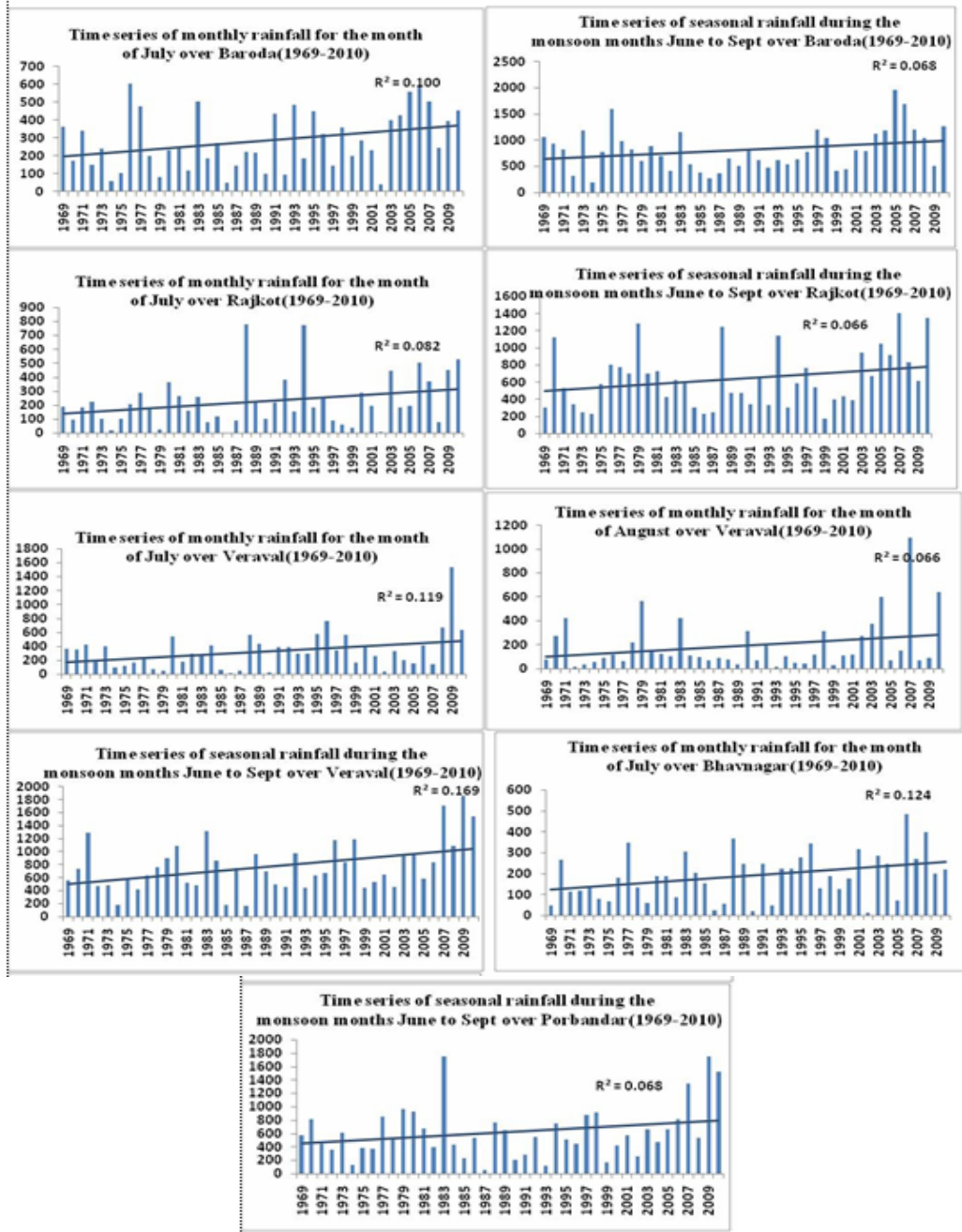
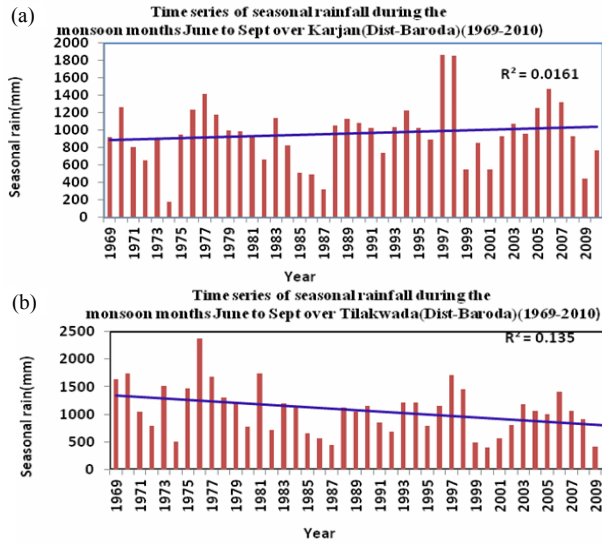


Fig. 6. Time series of monthly and seasonal rainfall of the stations reporting significant increasing trend

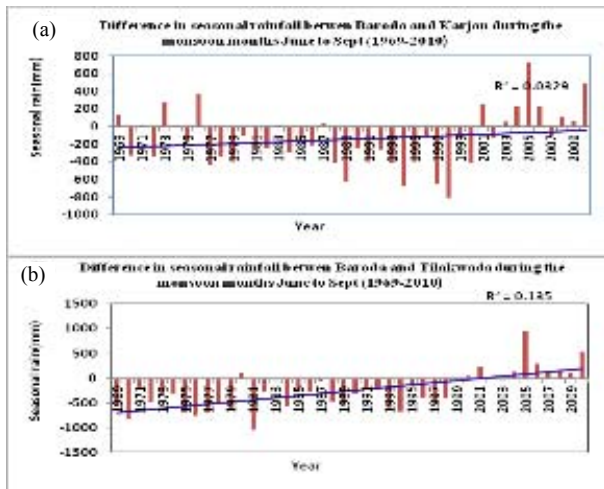
However, the stations reporting significant trend are Veraval (at 95% level of confidence), Porbandar (97% level), Rajkot (90% level) and Naliya (95% level). All these stations lie in the sub-division of Saurashtra & Kutch.

3.4. The time series of monthly and seasonal rainfall during the monsoon season from June to September along

with the linear trend line based on the period of 1969-2010 [Figs. 5(a&b)] have been analysed. It is found that there is insignificant increasing trend in the seasonal monsoon rainfall. However, there is a significant increasing trend in monthly rainfall during the month of July at 95% confidence level. The same analysis is carried out for all the some stations and the rainfall variation for the stations reporting increasing trend in



Figs. 7(a&b). Time series of seasonal rainfall of the stations in the vicinity of Baroda



Figs. 8(a&b). Time series of seasonal rainfall difference between (a) Baroda and Karjan and (b) Baroda and Tilakwada

TABLE 1

Significant level of trend coefficients in rainfall over some urban centres of Gujarat

	Level of confidence				
	June	July	Aug	Sept	Monsoon
Gujarat region	-	95	-	-	-
Saurashtra-Kutch	-	95	-	-	-
Baroda	-	95	-	-	90
Rajkot	-	90	-	-	90
Veraval	-	95	90	-	99
Porbandar	-	-	-	-	90
Bhavnagar	-	95	-	-	-

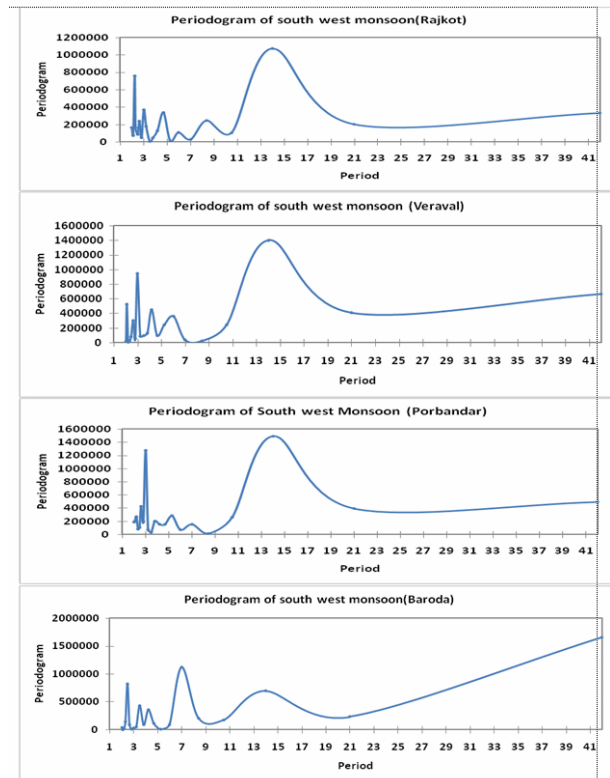
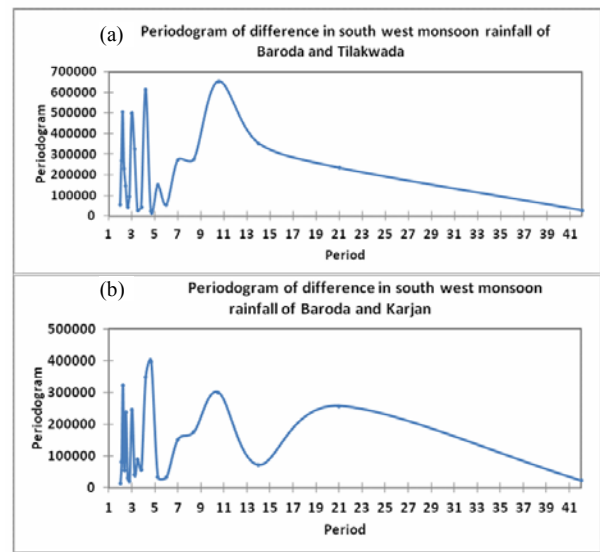
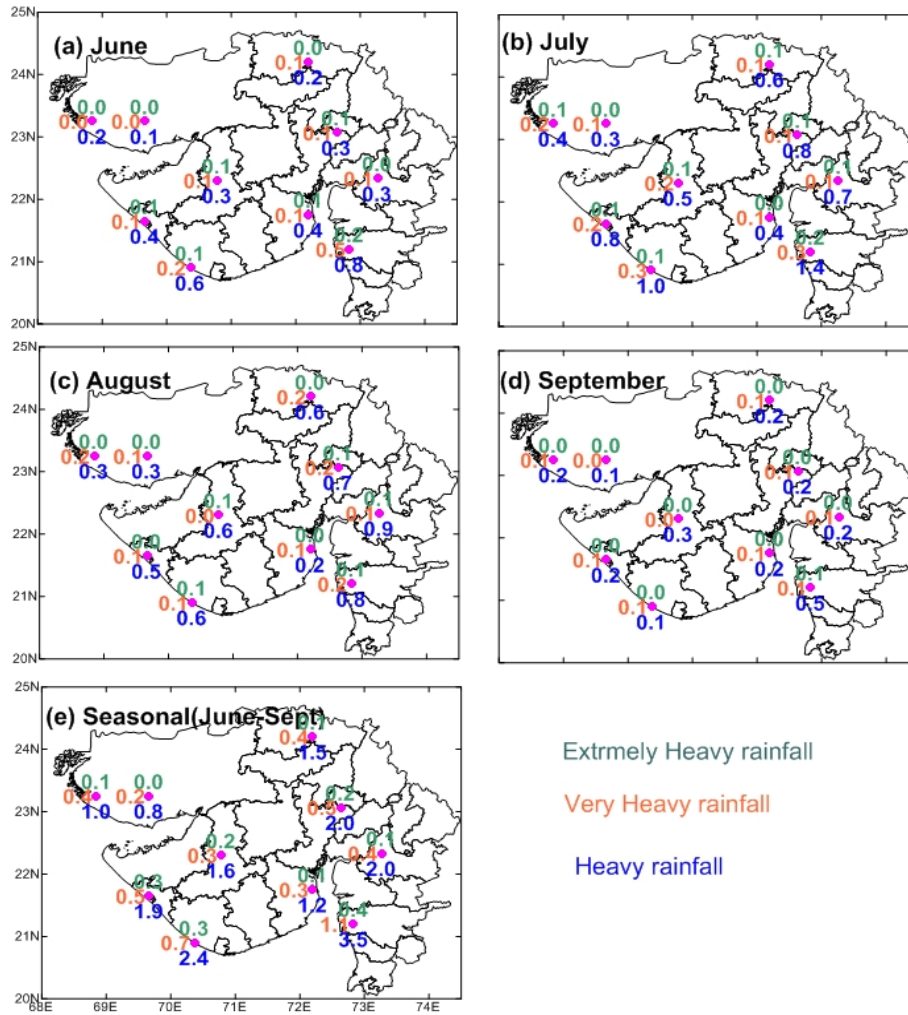


Fig. 9. Periodicity of south west monsoon for the stations reported significant increasing trend



Figs. 10(a&b). Periodicity in difference in seasonal rainfall of (a) Baroda and Tilakwada, (b) Baroda and Karjan

monthly or seasonal rainfall are shown in Fig. 6. There is significant increasing trend in seasonal rainfall as well as monthly rainfall in the month of July over Baroda, Rajkot and Veraval. There is also significant increasing trend in rainfall over Veraval in August and Bhavnagar in July. However, there is significant increasing trend only in the seasonal monsoon rainfall over Porbandar. Table 1 shows



Figs. 11(a-e). Average frequency of heavy (below), very heavy (left) and extremely heavy rainfall above the stations during different monsoon months and the season for the period 1969-2010

the significant level of trend coefficients for the stations. All the above stations lie in the coastal regions of Saurashtra and Kutch. The significant increasing seasonal rainfall may be due to the urbanization. To understand the impact of urbanization, the data of urban centre Barodahas been examined as a case study. Two stations (Karjan, Tilakwada) have been selected in vicinity of Baroda for this purpose. The city of Baroda reported significant increasing trend of monsoon rainfall during 1969 - 2010. The rural stations Karjan and Tilakwada show quite different trends during the same period. The station Karjan reported insignificant increasing trend and Tilakwada reported significant decreasing trend of monsoon rain as shown in the Figs. 7(a&b). To analyse further the impact of urbanization, the difference in rainfall over (i) Baroda and Karjan and (ii) Baroda and Tilakwada are analysed. The results indicate that there has been increasing trend indifference of rainfall [Figs. 8(a&b)]. It suggests that due

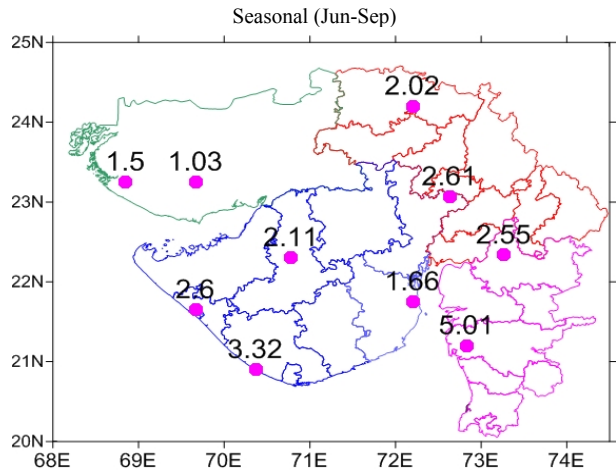
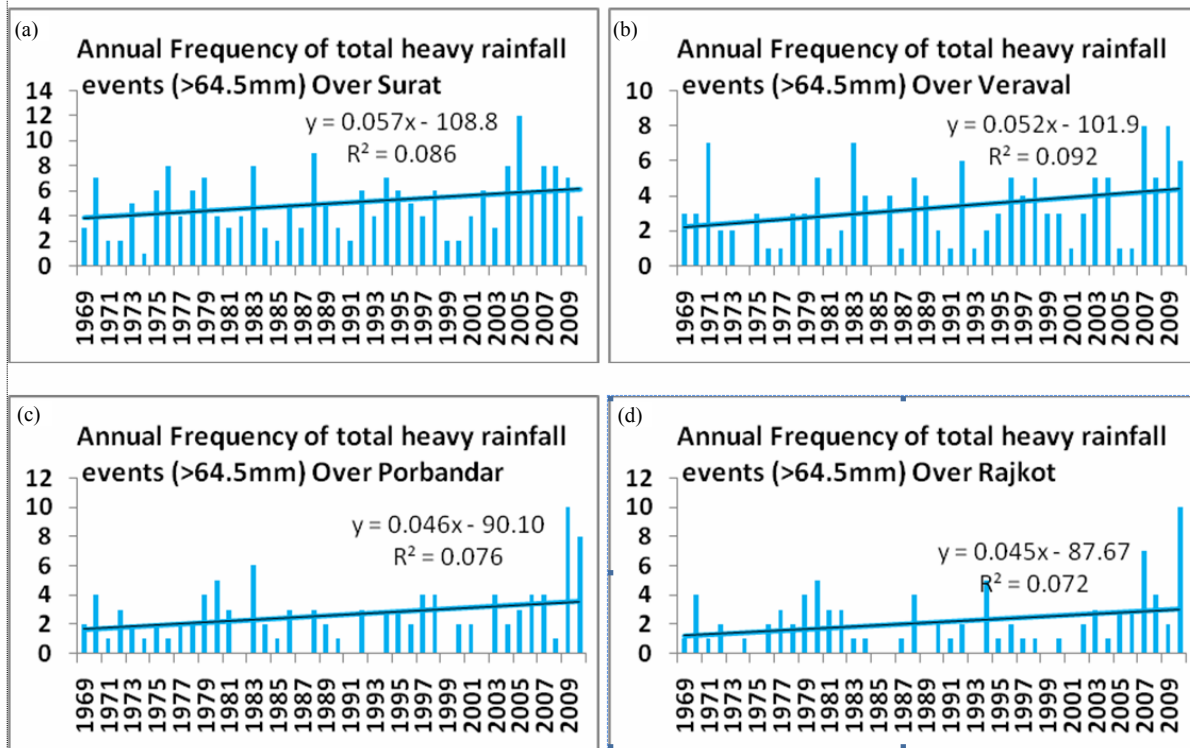


Fig. 12. Average frequency of heavy rainfall (≥ 65 mm) of the stations during the monsoon season for the period 1969-2010



Figs. 13(a-d). Variation in frequency of annual heavy rainfall events (≥ 65 mm) over the stations reporting significant increasing trend

to urbanization, the rainfall over the city centre of Baroda is increasing over the years. To examine whether the increasing trend of the rainfall over city centres of Gujarat are due to increasing of inherent natural periodicity in the rainfall, the power spectrum analysis of the rainfall data during 1969-2010 has been carried out. The results are shown in Fig. 9. It indicates that there are significant periodicities of 14 years and 3 years in case of all the stations. In addition, there is a significant periodicity of 7 years in case of Baroda. Considering the periodicity in difference in rainfall of (i) Baroda and Karjan and (ii) Baroda and Tilakwada [Figs. 10(a&b)] no such periodicity is observed. It indicates that the increase in rainfall over the city centres is not a part of natural variability, but due to the impact of urbanization. However, further study is needed to find out the specific impacts of various components of urbanization. It will be taken up in a separate study.

3.5. The monthly and seasonal frequencies of daily 24 hr cumulative heavy, very heavy and extremely heavy rainfall during past 42 years (1969-2010) over 10 stations of Gujarat state have been analyzed and presented in [Figs. 11(a-e)]. It is observed that the frequency of heavy rainfall events is very high during the month of July followed by August, September and June where as the

frequency of very heavy and extremely heavy rainfall events is high during the month of July followed by August, June and September. The frequency of heavy, very heavy and extremely heavy rainfall events is more during the month of July and August due to the westward/west-northwestward movement of low pressure system, which mostly develops over northwest Bay of Bengal during July and August (Mohapatra and Mohanty, 2004; Mohapatra, 2008). It is also observed that the frequency of heavy and very heavy rainfall events is significantly less and also there is not a single evidence of extremely heavy rainfall event during the month of September and June. It may be due to the fact that low pressure system forms in the lower latitude and move across south peninsula in September and they mostly move northwestwards in June in addition to the fact that the monsoon trough is less marked in these months unlike in July and August (Mohapatra *et al.*, 2009). Also in some occasions, the low pressure system forming over north Bay of Bengal move northwestwards initially and then re-curve northward or north-northeastwards during September.

The annual frequency of rainfall events greater than 7 cm (heavy rainfall, very heavy rainfall, extremely heavy rainfall) over all the stations of Gujarat state (Fig. 12)

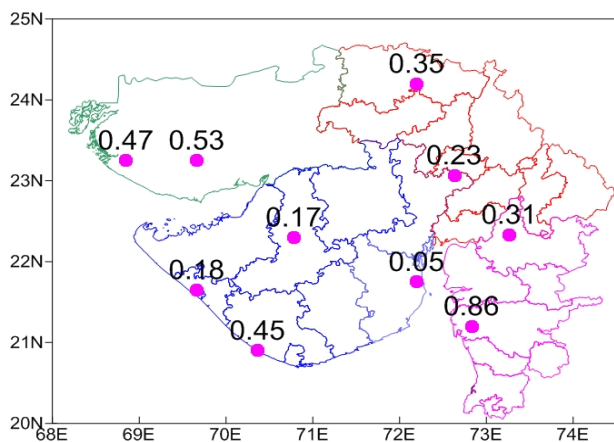


Fig. 14. Linear trend coefficient per 10 years in the frequency of heavy rainfall (≥ 65 mm) events

have been analyzed. It is seen that the frequency of heavy rains is very high in Surat followed by Veraval, Ahmedabad and Porbandar. From the daily rainfall data during monsoon for the periods 1969-2010, it is found that the frequency of extremely heavy rainfall events is more in south Gujarat region and coastal Saurashtra as compared to that over other places of Gujarat state. However, in north Gujarat region, frequency of extremely heavy rainfall events is more in Ahmedabad as compared to that over other places. It may be due to the impact of urbanization as found for other cities, like, Bangalore and Mumbai (Mohapatra *et al.*, 2010).

3.6. The linear trend coefficient of the frequency of heavy, very heavy and extremely heavy rainfall events over 10 stations in Gujarat (Fig. 14) indicates that there is increase in frequency of heavy rainfall events in monsoon season over the urban centres of Gujarat. However, there is a significant increasing trend in the total frequency of these events over Surat, Veraval, Porbandar and Rajkot [Figs. 13(a-d)]. All these are coastal stations. However, it is more significant over Surat, which is the most industrialized city of Gujarat. It endorses the earlier findings that there is increase in heavy rainfall events over central India including Gujarat (Goswami *et al.*, 2006).

4. The analysis of rainfall over 10 cities of Gujarat has been carried out for the monsoon season (June-September) based on data of recent 42 years. The broad conclusions of the study are given below:

The average monthly rainfall is maximum in July followed by August for all the stations. The frequency of heavy rainfall events is very high during the month of July followed by August. The rainfall is highly variable during

June and September and more stable in July and August. Seasonal (June-September) rainfall is significantly related with rainfall during individual months, being most significantly so with rainfall during July.

There is significant increasing trend in seasonal rainfall over Baroda, Rajkot and Veraval. Also, there is significant increase in rainfall during the month of July over these stations. There is significant increasing trend in rainy days over the stations along the coast in Saurashtra & Kutch.

The analysis of the heavy, very heavy and extremely heavy r/f events shows significant increasing trend in total frequency of these events at 90% confidence level over coastal cities in the month of July and season as a whole.

Acknowledgements

The authors are thankful to Director General of Meteorology, India Meteorological Department, New Delhi, Deputy Director General of Meteorology, Regional Meteorological Centre, Mumbai and Director, Met centre, Ahmedabad for providing facilities to carry out the study and also thankful Dr. G. K. Krishna Kumar, NDC Pune, for providing data and valuable suggestions. The authors are also thankful to Shri J. R. Chicholikar and Shri P. I. Patel for their help in making the study successful.

References

- Deb, S. K., Srivastava, T. P. and Kishtawal, C. M., 2008, "The WRF model performance for the simulation of heavy precipitating events over Ahmedabad during August 2006", *J. Earth Syst. Sci.*, **117**, 589-602.
- Goswami, B. N., Venugopal, V., Sengupta, D., Madhusoodanan, M. S. and Xavier, K. Prince, 2006, "Increasing Trend of Extreme Rain Events Over India in a Warming Environment", *Science*, **314** 1442-1445.
- India Meteorological Department, 1999, "Climatological Tables of observatories in India", Published by India Meteorological Department, Shivaji Nagar, Pune.
- Mohapatra, M. and Mohanty, U., C., 2004, "Some characteristics of low pressure systems and summer monsoon rainfall over Orissa", *Curr. Sci.*, **87** 1245-1255.
- Mohapatra, M. and Mohanty, U. C., 2005, "Some characteristics of very heavy rainfall over Orissa during summer monsoon season", *J. Earth syst. Sci.*, **114**, 17-36.
- Mohapatra, M., 2008, "Sub-divisional monsoon rainfall over India in relation to low pressure systems over the Bay of Bengal and adjoining land regions during 1982-1999", *Mausam*, **59**, 3, 327-338.

- Mohapatra, M., Kumar, Naresh and Bandyopadhyay, B. K., 2009, "Role of mesoscale low and urbanisation on exceptionally heavy rainfall event of 26th July, 2005 over Mumbai : Some observational evidence", *Mausam*, **60**, 3, 317-324.
- Mohapatra, M., Kumar, Naresh and Bandyopadhyay, B. K., 2010, "Unprecedented rainfall over Bangalore city during October 2005", *Mausam*, **61**, 1, 105-112.
- Rajeevan, M., Bhate, J. and Jaswal, A. K., 2008, "Analysis of variability and trends of extreme rainfall events over India using 104 years of gridded daily rainfall data", *Geol. Res. Let.*, **35**, 1-6.
- Rajeevan, M. Bhate, J., Kale, K. D. and Lal, B., 2006, "High resolution daily gridded rainfall data for the Indian region : Analysis of break and active monsoon spells", *Curr. Sci.*, **91**, 296-306.
- Rao, Y. P., 1976, "Southwest Monsoon", Meteorological Monograph, Synoptic Meteorology, No. 1/1976, India Meteorological Department, 1-367.

MANORAMA MOHANTY
M. MOHAPATRA*
S. N. A. JAAFFREY**

Meteorological Centre, Ahmadabad, India
**India Meteorological Department, New Delhi, India*
***M. L. Sukhadia University, Udaipur, India*
(Received 23 August 2013, Modified 28 April 2014)
e mail : met_mm@yahoo.co.in
