Daily rainfall characteristics from a high density rain gauge network

G. Srinivasan[1,]* and Sushma Nair[2]

[1]Department of Science and Technology, New Delhi 110 016, India
[2]Regional Meteorological Centre, Mumbai 400 005, India

Enhanced observational information on the spatial distribution of rainfall, at a finer resolution, is vital for evaluation of mesoscale models. The present study examines the daily rainfall data from a high-density mesoscale rain gauge network consisting of 25 stations within a hundred sq. km. area, during the south west monsoon season (June–September) for the period 1996–2000. The rainfalls reported are from lake catchments along the Western Ghats, falling in the district of Raigad and other urban locations in and around Mumbai. Using this data-set, an attempt has been made to examine the spatial distribution of heavy rainfall events. Poor correlations between stations indicate that they cannot be pooled together during spatial averaging for representing rainfall over the area. Heavy rainfall events contributed largest rainfall amounts at the foothills of the ghats and the least for sites on the Western ghats at higher altitudes. The results suggest that different controls modulate the synoptic situations to produce a spectrum of spatial and temporal precipitation variability on local scales, which would require further observational and modeling efforts to understand and predict.

PRECIPITATION, the driving force of the hydrological cycle exhibits large spatial and temporal variations. Identifying and understanding the space–time structure of rainfall at regional level is therefore crucial to water management strategies. The high variability of rainfall makes it a difficult parameter to simulate. Models with finer spatial resolution are required to simulate the steep gradients in precipitation that particularly dominate regions with convective rainfall modulated by terrain. Mesoscale models are therefore being increasingly employed for operational forecasting at regional and subregional levels. However, evaluation of the model performance is often inhibited by limited observational data.

In any region with tall orography, rainfall shows great variations from windward side to the summit and the leeward side. Maharashtra experiences extremes in spatial distribution of annual seasonal rainfall from 600 cm on the ghats to 50 cm in Madhya Maharashtra. The Western Ghats which run roughly from north to south separate the coastal districts of Konkan from the rest of Maharashtra. Rainfall governed by enhancement of the southwest monsoon current by the orography of Western Ghats makes Konkan the wettest region of Maharashtra. Though heavy to very heavy rainfall is a feature of weather over the region during the monsoon season, there are occasions when rainfall is heavy over the coast and relatively less over the ghats and vice versa[1]. Previous studies over the region were either for the region as a whole[2] or for isolated stations in the region[3]. Very few studies have attempted to look at sub-regional level. This study is focused on daily rainfall characteristics, with particular emphasis on heavy rainfall events at a sub-regional level (between long. 72.43–73.6 and lat. 17.92–19.1) along the west coast and the windward slopes of the Western Ghats, for a sample period 1996–2000. Extreme precipitation events are known to occur as isolated episodes or extended wet spells during the season. Daily rainfall totals are therefore utilized for characterization of these extreme events.

High density rain gauge network

In addition to the rainguages at the meteorological stations established by the India Meteorological Department, many rain gauges are being operated by other agencies including private sector companies in regional and periods of their interest. Such data become available during the monsoon season for forecasting purposes. Compilation of these data at spatial scales of less than 100 km, would also help in evolving physically based initialization procedures. In connection with their hydroelectric power projects, Tata Electric Power have maintained a high resolution rainfall monitoring network, which reports daily rainfall from catchments of lakes and other locations over the Western Ghats. Most of the stations, which form a part of this network, fall in the district of Raigad on the slopes of the windward side of the Western Ghats. Also included in the study are the rainfall totals at a few urban locations in and around Mumbai, mostly along the west coast. A total of 25 stations with maximum interstation distance of < 100 km are used for this study. With most of the rain over the specified region (i.e. more than 90%) occurring in the monsoon months, the study is restricted to the monsoon months of June–September. Based on 96% data availability, only 18 stations entered the analysis. Figure 1 shows the location of rainguage stations and Table 1 gives the names of the stations and their co-ordinates. Depending on their proximity, stations could be roughly divided into three

*For correspondence. (e-mail: srinidst@alpha.nic.in)

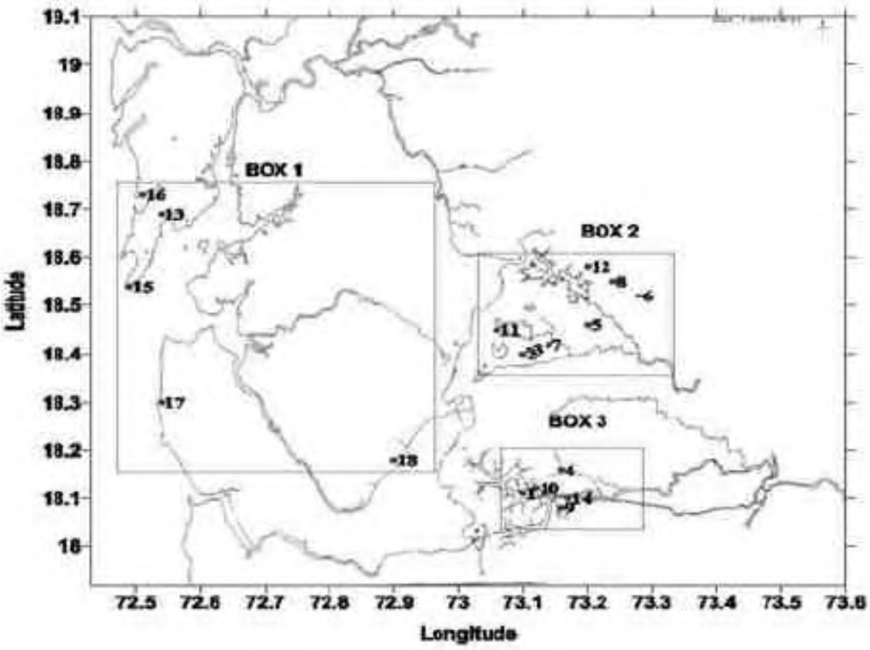


Figure 1. Location of stations in the Mumbai urban and lake catchments in the Raigad region of the Western Ghats.

Table 1. Stations in the high-density rainfall network

Station name	Latitude	Longitude	Percentage data
Bhira	18.11	73.10	98.03
Lonavala_T	18.40	73.10	98.85
Lonavala_O	18.41	73.11	98.69
Shirgaon	18.16	73.16	97.21
Shirota	18.46	73.20	98.52
Thakurwadi	18.52	73.28	96.72
Walvan	18.42	73.14	97.70
Wangaon	18.55	73.24	96.56
Dawdi	18.08	73.16	97.87
Dungerwadi	18.12	73.12	98.03
Khopoli	18.45	73.06	97.54
Khand	18.58	73.20	98.36
Dharavi	18.69	72.54	98.03
Tamini	18.10	73.17	97.05
Colaba	18.54	72.49	100.00
Santacruz	18.73	72.51	100.00
Alibag	18.30	72.54	99.34
Sudhagad Pali	18.18	72.90	96.89

groups. Box 1 includes urban location stations, stations located at higher elevations on the ghats are in box 2 and stations located at the foothills of the windward side of the ghats are grouped together in box 3.

As a preliminary, a basic statistical analysis was carried out on the data for which, the small percentage of data missing were linearly interpolated from the respective station time series. Correlations between the observed rainfall amounts at each station and the interstation distance showed that correlations fell from 0.98 to < 0.3 for interstation distances greater than 75 km (Figure 2).

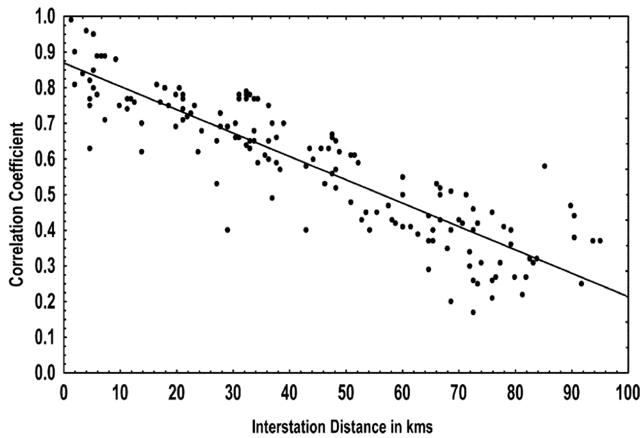


Figure 2. Scatter plot of inter-station correlations and distances.

An extreme precipitation event is normally defined as a daily amount exceeding a certain specified threshold. Daily rainfall amounts exceeding threshold values of 200, 100 and 70 mm were examined. The sample size was found to be too less for any meaningful statistical interpretation for thresholds of 200 and 100 mm. So a threshold of 70 mm was chosen to define heavy rainfall days. The percentage contributions derived from heavy rainfall events to the total annual precipitation were also calculated. For a better understanding of the temporal characteristics of the data set, the individual time series for each station were examined for continuous wet and dry spells. Days with rainfall amounts exceeding a threshold of 2.5 mm were defined as a wet day. Days with nil rainfall or rainfall amounts less than 2.5 mm were categorized as dry days.

Table 2. A synoptic overview of the major rainfall events

Heavy rainfall episodes	No. of stations reporting heavy rainfall from the high density network	Accompanying synoptic feature
27 July 1997	14	A well marked low which formed over Bay on 22 July and moved westwards and lay over East Madhya Pradesh and Vidharbha on 24 July, moved further westwards and lay over North Rajasthan as a cyclonic circulation on 27 July before merging with the seasonal trough on 29 July.
31 July 1997	13	A low, which formed over north Bay and neighbourhood concentrated into a depression and moved in a westerly direction and crossed Orissa coast as a deep depression on 30 July evening. Moved in west northwesterly direction and weakened into a depression in the evening of 31 July.
23–25 August 1997	14	Deep depression over Orissa moved in a west northwesterly direction from 21–24 August and then in a north northwesterly direction from 25 to 27 August. A cyclonic circulation in LTL over Gujarat and neighbourhood merged with deep depression on 23 August.
1–3 July 1998	12	A cyclonic circulation in LTL lay over West Madhya Pradesh on 29 June and lay over adjoining Gujarat on 30 June. A well marked low pressure area formed in Gulf of Cambay on 1 July and stayed over Saurashtra and neighbourhood before moving away westwards by 4 July evening.
8 July 1998	12	A cyclonic circulation over Gujarat region and adjoining North Konkan from 7 to 9 July in MTL.
23 June 1999	17	A low pressure which formed in Bay off Orissa coast on 16 June intensified into a dd and moved in a westerly direction weakened into a low after crossing land and lay over east UP and west MP on 21 June. A cyclonic circulation in LTL lay over east Bihar and nieghbourhood on 23 June.

As rainfall variations over a particular region are controlled by synoptic systems a compilation of synoptic situations that prevailed during heavy rainfall events was also made from the weekly weather reports issued by Regional Meteorological Centre, Mumbai.

Rainfall variability

Results of the daily rainfall analysis showed considerable spatial variability. Distribution of the seasonal rainfall averaged for the period considered is shown in Figure 3. Precipitation distribution shows a maxima at the foothills of the ghats, where the rainfall amounts received were of the order of 450–625 cm. Precipitation decreased steeply at higher elevations on the ghats. The average seasonal rainfall amounts at some of the stations like Thakurwadi on the ghats (approx. at 660 mts asl) was only 150 cm. Urban location stations, which are mostly located along the coast had means of 197 cm. The average daily values were of the order of 12 mm at Thakurwadi on the ghats to 53 mm at Dungerwadi at the foothills.

The inter-station correlations (Figure 2) indicate the presence of considerable spatial variation within the small region (~ <100 km^2) considered. The correlations also indicate the possibility of demarcating aerial domains for averaging rainfall in the region and for examining coherent climatic changes at local levels.

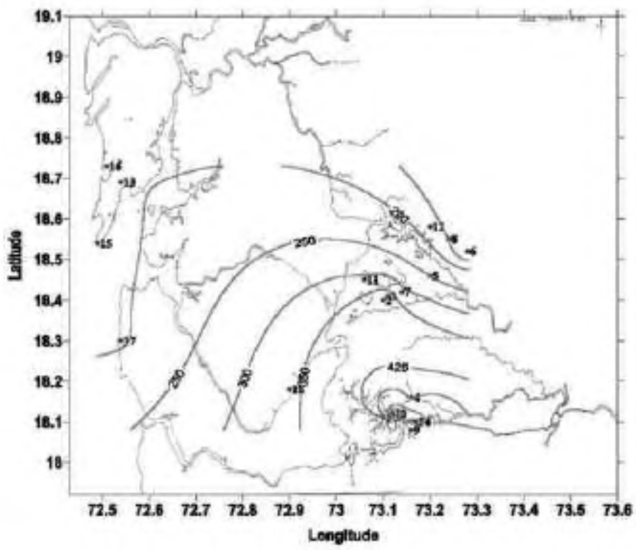


Figure 3. Spatial distribution of average seasonal (JJAS) rainfall (cm).

Percentage contribution of rainfall amounts derived from days with heavy precipitation (exceeding 70 mm) to the total seasonal rainfall was examined (Figure 4). Percentages were largest, exceeding 60% for gauge sites located at the foothills of the ghats. Percentage contributions reduced progressively at higher elevations. The percentages were the least for sites on the ghats (for e.g. station nos. 6 and 8). They were moderately high for stations along the coast.

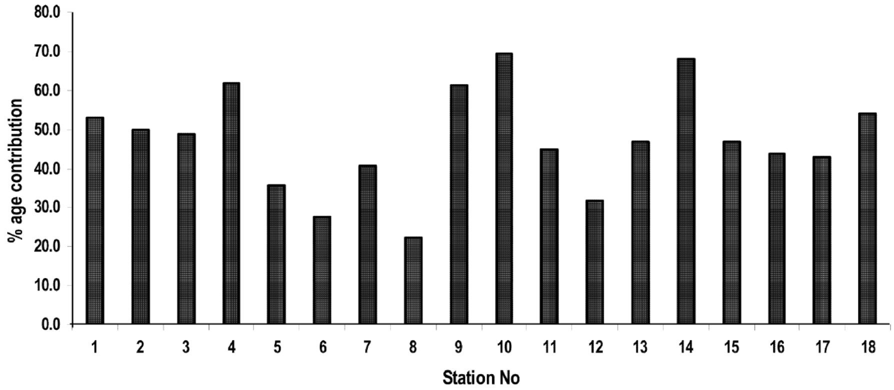
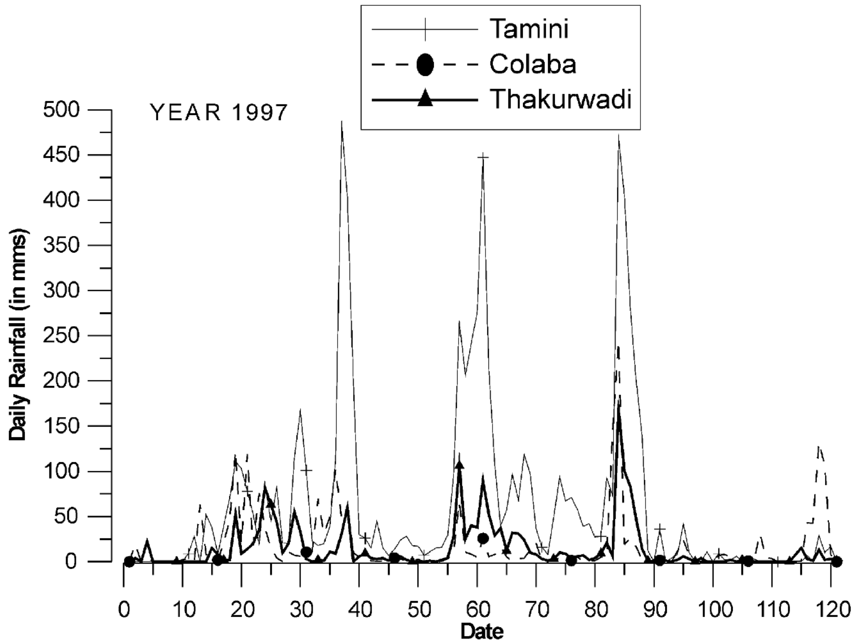


Figure 4. Percentage contribution from heavy rainfall events at each of the 18 stations considered.



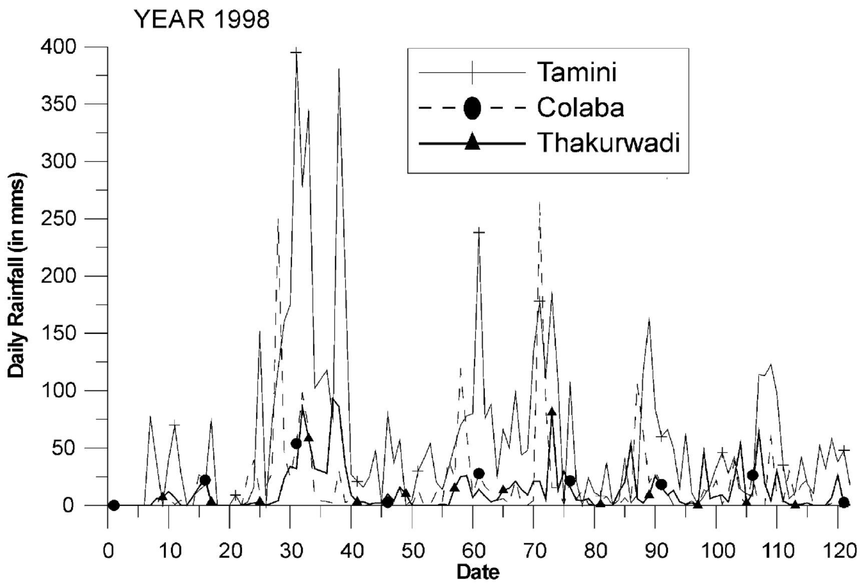


Figure 5. Time series plot for the year 1997 and 1998 for Tamini, Colaba and Thakurvadi stations.

Results of the investigation revealed that at all the stations more than 70% of the total number of days considered were wet days. Percentage of wet days to the total number of days was a maximum along the foothills of the ghats. Rainfall intensities were also a maximum along the foothills. The daily precipitation totals reported from these stations indicate that these stations receive very heavy rainfall, where on an average on 4–5 occasions in a year one day precipitation totals were observed to be as high as 40–50 cm. Though the percentage number of wet days observed at stations on the ghats and at the urban location stations were almost the same, the rainfall intensities were higher at urban locations. Daily rainfall totals at some of the stations on the ghats rarely exceeded 15 cm. However, urban stations along the coast, report 24-hour precipitation amounts exceeding 20 cm at least 2–3 times in a year.

Distribution climatology of spells of heavy rainfall over the region was also investigated. From the observed data for the reference period, it was seen that 3–4 spells of heavy rain occurred per year in the monsoon months. Multiday spells of heavy rain lasting for at least 7–8 days was observed at the foothills of the ghats. These events occurred as a 1–3 day sequence at stations on the ghats. For stations along the coast they were observed as episodes lasting for 1–2 days.

The distribution of dry days during the monsoon revealed that at stations along the foothills, in a year, not more than 3 consecutive days were dry. The same was observed for stations on the ghats where contributions from non-heavy events are significant. Longer dry spells, sometimes lasting for more than 5 days were noticed at urban location stations along the coast. There could also be significant differences in day-to-day rainfall amounts even among stations located very close by. Figure 5 that presents the time series of selected years (1997 and 1998) for a few selected stations illustrates some of the inter-station variations.

The broad scale synoptic situation prevailing on days with widespread heavy rainfall were also studied. It was observed that in some cases similar synoptic features gave rise to different spatial rainfall distributions. Though all events with precipitation amounts greater than 70 mm were investigated, for brevity in Table 2 we present a synoptic overview of the major rainfall events with thresholds greater than 100 mm reported at 12 or more stations of the 18 considered. Though the presence of an offshore trough along the west coast is a common occurrence during the monsoon months, a well marked low over the Bay region moving westwards or northwestwards, a cyclonic circulation over Gujarat region are also observed during most of the heavy rainfall episodes. However, similar synoptic situations seem to result in significantly different spatial distribution of rainfall at meso-scale.

Conclusions

The results derived from the analysis illustrate the spatial and temporal characteristics of the daily rainfall dataset generated by the high density rainfall network. Datasets from such meso-networks are critical to understand rainfall variability at local scale and evaluate the models used to simulate weather and climate at regional scale. Significant variations are observed even among stations located within about 50 km of each other.

Poor inter-station correlations of heavy rainfall events suggest that a single rainfall index derived from averaging site-specific data cannot be taken as representative of rainfall over the region.

The maximum percentage contribution of heavy precipitation events to the seasonal totals is from sites at the foothills of the ghats, and the least are from stations on the ghats at levels higher than ~ 600 m. Stations along the coasts showed moderate percentage contribution to the heavy rainfall amounts. Extended spells of heavy rainfall of maximum intensity occurred at the foothills of the ghats. The observed intensity of rainfall was greater at urban location stations along the coast.

Analysis of rainfall from longer data sets with more detailed synoptic information are, however, required for a more conclusive confirmation of the spatial and temporal distribution of precipitation over the area. Enhanced understanding of precipitation responses at finer spatial scales can aid in refining the performances of high-resolution mesoscale models.

1. Srinivasan, V., Raman, S., Mukherji, S. and Ramamurthy, K., Southwest monsoon – Typical situations over Konkan and Coastal Mysore, *Forecasting Manual*, 1972, Part III.
2. Shyamala, B. and Shinde, G. M., Study of synoptic systems associated with intraseasonal variability of summer monsoon – A new perspective, *Mausam*, 1999, 31–36.
3. Jayaram, N., A preliminary study of an objective method of forecasting heavy rainfall over Bombay and neighbourhood during the month of July. *Indian J. Meteorol. Geophys.*, 1965, 557–564.

ACKNOWLEDGEMENTS. We thank Shri. Shravan Kumar, Deputy Director General of Meteorology, Regional Met. Centre, Mumbai for the facilities provided and also Shri Thakur Prasad, Director, Regional Met. Centre, Mumbai for extending computing facilities and providing data. The Tata Electric Company is gratefully acknowledged for co-operation in making available their rainfall data and other meta information.