Diurnal variations in rainfall over Indian region using self recording raingauge data

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Diurnal variation of rainfall of different intensities using self-recording raingauge data of about 150 stations spread across India is presented here. Analysis of annual average number of rainfall hours revealed that the highest number (>900) is realized over northeast India, followed by west coast (700–800). Lowest incidence (<100) was found over west Rajasthan. Distribution was nearly similar for hours with rainfall >10, >20 and >30 mm. A zone of less number of hours with different intensities extended from west Rajasthan to west Uttar Pradesh; and another one to south Tamil Nadu through Gujarat, west Madhya Pradesh and the rain shadow zones of Maharashtra, Karnataka and Andhra Pradesh. The percentage of contribution to total annual rainfall by intense rainfall of >20 mm and >30 mm, however, was found to be higher in the low rainfall zones and northwest India. Diurnal variation of rainfall showed prominent maxima in the early morning over northeast India; and in the afternoon/evening over northwest India and interior Peninsula. Coastal areas on east and west coast, however, did not exhibit any significant diurnal variations, but a tendency of higher frequency in the early morning was noticed.

Keywords: Diurnal variation, Katabatic–anabatic winds, self-recording raingauge.

OVER the past few years extreme precipitation events have received considerable attention, due to their damage potential. Most of the studies have used daily precipitation totals for extreme rainfall analysis, but the precipitation events concentrated over a shorter time period are important as they lead to flash floods, mudslides, etc. and thus cause unprecedented damages, particularly in highly populated urban areas. Studies based on hourly rainfall data are very few over Indian region. Using hourly data from self-recording raingauge stations (SRRG), diurnal variation of rainfall in Brahmaputra valley was studied in the early seventies and the results showed a well-marked diurnal variation in the rainfall, with a maximum in the early morning hours and minimum in the afternoon hours for NE India[1,2]. Haldar *et al.*[3] analysed spatial and temporal diurnal variation of rainfall and the effect of mesoscale system on the diurnal cycle of rainfall over central India. Studies have also been done using satellite derived estimates of rainfall for short periods to study the effect of mesoscale circulations like land-sea breezes, Katabatic–anabatic winds, and mountain valley winds on the rainfall patterns[4]. Diurnal analysis during active and break phases of monsoon along the west coast[5] indicated peak rainfall in the morning hours during both phases. SenRoy[6] used station level hourly precipitation data across Indian subcontinent to study trends in extreme heavy precipitation events. The results indicated rising trends in extreme heavy precipitation events, mostly in the high elevation regions of NW Himalayas as well as along foothills of the Himalayas extending south into the Indo-Gangetic basin. Diurnal variation of precipitation over India has been studied[7,8] using data from a few raingauge stations over a particular region while others have used remotely sensed observations[9]. Diurnal variation in rainfall during northeast monsoon period[10] over southern peninsula was also studied and the results indicated an early morning peak along the east coast of India and afternoon/evening peaking over the inland regions. The harmonic analysis also revealed that over south peninsula, more than 70% of the variance was explained by the diurnal mode.

Most of the above studies were carried out region-wise for few stations or during a particular period of the year. To explain the mean diurnal variations of hourly rainfall for the entire year, thus ignoring the synoptic situation for that particular hour of the day, this study was undertaken for the period 1980–2000 using data of 150 SRRG stations.

Hourly rainfall data of around 250 SRRG stations was collected for the period 1970–2010. Each station was checked for spuriousness and continuity in data distribution during the study period. Based on the continuity of data, 150 SRRG data for the period 1980–2000 was utilized for the analysis. The data utilized was for stations having more than 15 years of data, except for Bihar and Jharkhand, where continuous data was available for 11 and 5 years respectively (Figure 1).

Rain occurring within any chronological hour was called a rain event. The following analysis was performed for various SRRG stations during the period mentioned in Figure 1. (a) Diurnal variations in the frequency of rain events >0, >5, >10, >20 and >30 mm; (b) distribution of annual average frequency of rainfall events greater than 0 mm; (c) distribution of annual frequency of rain event >10, > 20 and >30 mm; (d) percentage contribution of rain events >10, >20 and >30 mm to the total rain events; (e) all-India distribution of time period of highest frequency rainfall events; (f) all-India distribution of time period of lowest frequency rainfall events; and (g) difference in the frequency of highest and lowest frequency of rain event.

The results were displayed for India as a whole, by filling gap areas using Ordinary Kriging method of interpolation in ArcGIS-10.1 (ref. 11). Since the data locations

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are fairly dense and uniformly distributed throughout the study area, fairly good estimates could be obtained using any method of interpolation.

Annual average frequency of rain events at each hour of the day was greater than 900 in sub-Himalayan Gangetic planes, Assam and Meghalaya and less than 100 in extreme western parts of the country (Figure 2 *a*). The frequency of hourly rain increases from west to east and exceeds 1000 annually in the wind-ward side of Khasi and Jayantia Hills.

Incidences of extreme precipitation events can lead to widespread damage in the form of floods and associated destruction, particularly in vulnerable areas. In view of the presence of significant positive trends in the occurrence of heavy precipitation[6,12], the distribution of frequency of rainfall events more than 5, 10, 20 and 30 mm was also calculated for the period 1981–2000. The annual frequency of all rain intensities was highest in Northeast India and Sub-Himalayan West Bengal. The next highest frequencies were over East India, Uttarakhand, Punjab, Himachal Pradesh and along west coast. The frequency of rain events greater than 30 mm was less along the west coast despite the wind-ward slopes of Western Ghats receiving seasonal total rainfall only slightly less than that of Northeast India (Figure 2 *b*). The annual percentages of rainfall events contributing more than 5 mm of rainfall were highest in Northeast India and sub-Himalayan West Bengal (18–20%) (Figure 3 *a*). Cherrapunji had more than 20% of the events with greater than 5 mm rainfall. As the rainfall intensity increased, there was a decrease in number of rain events. In order to account for very high intensity precipitation, the percentage contribution of rainfall events >30 mm was also analysed

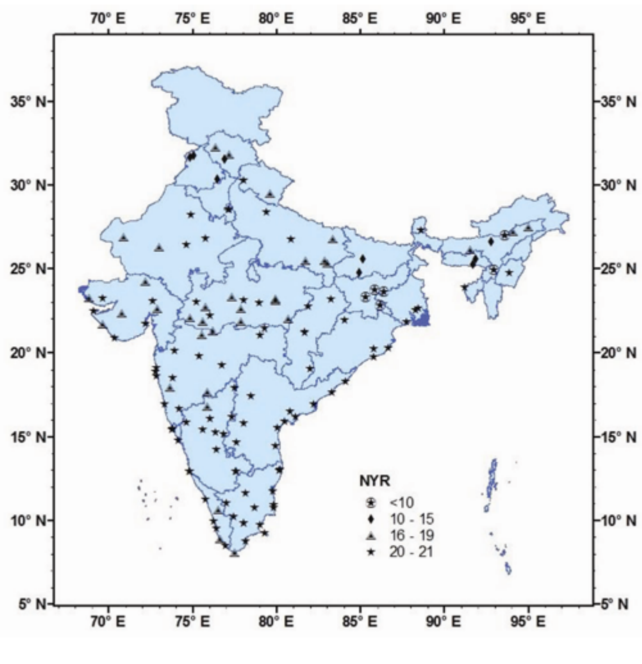

Figure 1. Location and years of SRRG data utilized in the analysis.

(Figure 3 *b*). Assam, Meghalaya, Sub-Himalayan West Bengal, parts of west Rajasthan, coastal Gujarat, Uttar Pradesh, Uttarakhand, Himachal Pradesh and Coastal Tamil Nadu had 1% contribution of high intensity rainfall events. The percentage of events was lowest (0.4–0.6) along west coast and central India.

Mean annual frequency of rainfall at each hour of the day was analysed to find the diurnal variation. Many stations showed a distinct maximum and minimum during the day (Figure 4 *a* and *b*), while for some of the stations the variations were random (Figure 4 *c*). The behaviour was distinct, with well-defined maximum and minimum for stations in northeast and northwest India and over interior peninsula, whereas it was not prominent over coastal stations, both on east and west coasts. The annual average number of hours with rainfall events of different intensities is given in Figure 4. The behaviour was more or less similar for rainfall events of different intensities. The difference in the annual average frequency of maximum and minimum rainfall event frequency was plotted in an all-India map using Kriging method and the results indicated a very high difference in frequency over the east southern peninsula and NE India (Figure 5). This indicated a well-defined diurnal behaviour of rainfall in these regions. There was a difference of more than 40 rainfall events in the two peaks over Assam, Meghalaya, sub-Himalayan Gangetic Bengal, southern Kerala and adjoining Tamil Nadu. In other places like Gujarat, west Rajasthan and central Uttar Pradesh, the maximum and minimum were not well defined and thus the difference in two peaks was 2–3 rainfall events. The presence of one maximum and one minimum suggested a strong diurnal cycle. The diurnal peaks of maximum and minimum frequency also varied across different regions. Figure 6 *a* shows a plot of time period of maximum frequency and Figure 6 *b* minimum frequency. It was seen that most of the coastal stations had maximum frequency of rainfall hours from 2 to 6 h (early hours) and most of the inland stations had maxima in the evening, i.e. from 16 to 18 h and few in the late evening from 18 to 20 h. The lowest frequency hours were also seen in the range 08–12 h for majority of inland stations and 13–14 h for coastal stations. In NW India the lowest frequency in some hilly station was found from 21 to 24 h, particularly in Dehradun, Patiala, Jammu, Gorakhpur, etc. Rapid rise to maximum in 4–6 h but slow decline to minimum in 16–18 h indicated significant contributions from other high frequency cycles too.

If we consider defining diurnal variations at any time of the year ignoring synoptic situation for that particular hour of the day, the diurnal variation of the rainfall will depend upon the diurnal variation of instability, moisture content, low level convergence and radiation cooling of the top of the cloud[8].

A major portion of Indian region has most rainfall from tall clouds (Cumulonimbus or Cumulus) formed by

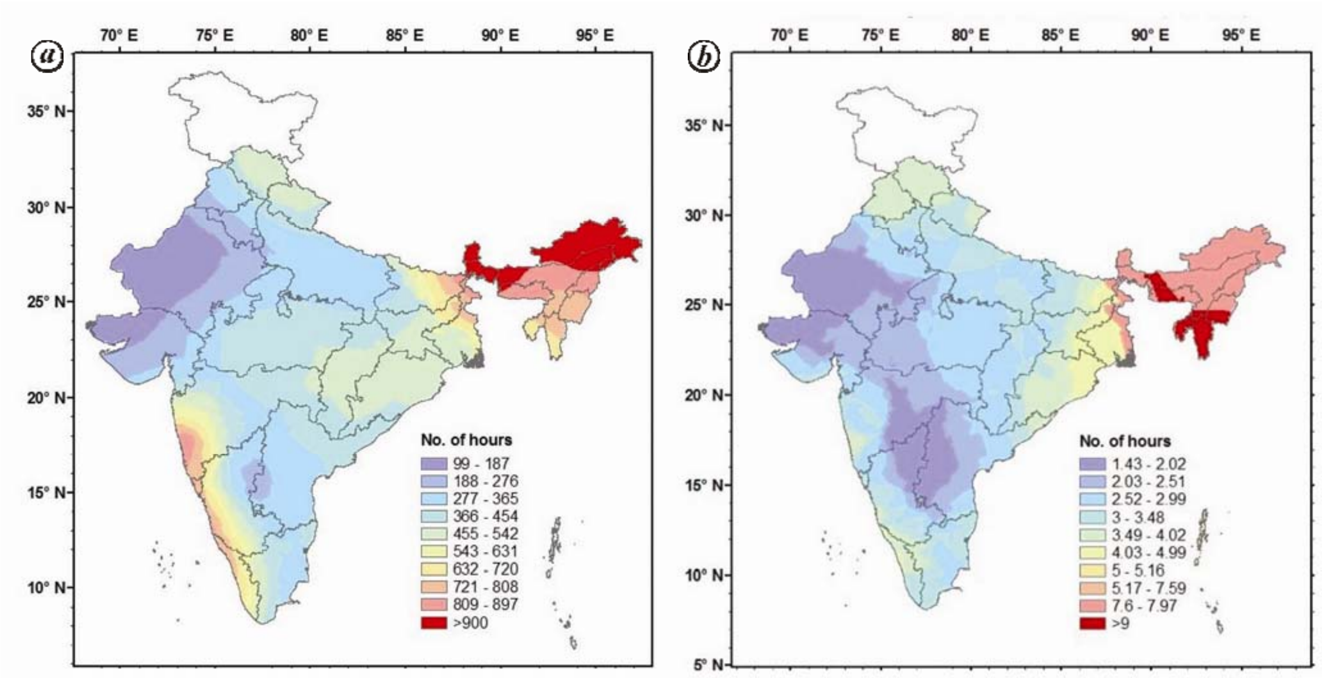

Figure 2. Annual average frequency of rain events with (***a***) rainfall >0 mm and (***b***) rainfall >30 mm.

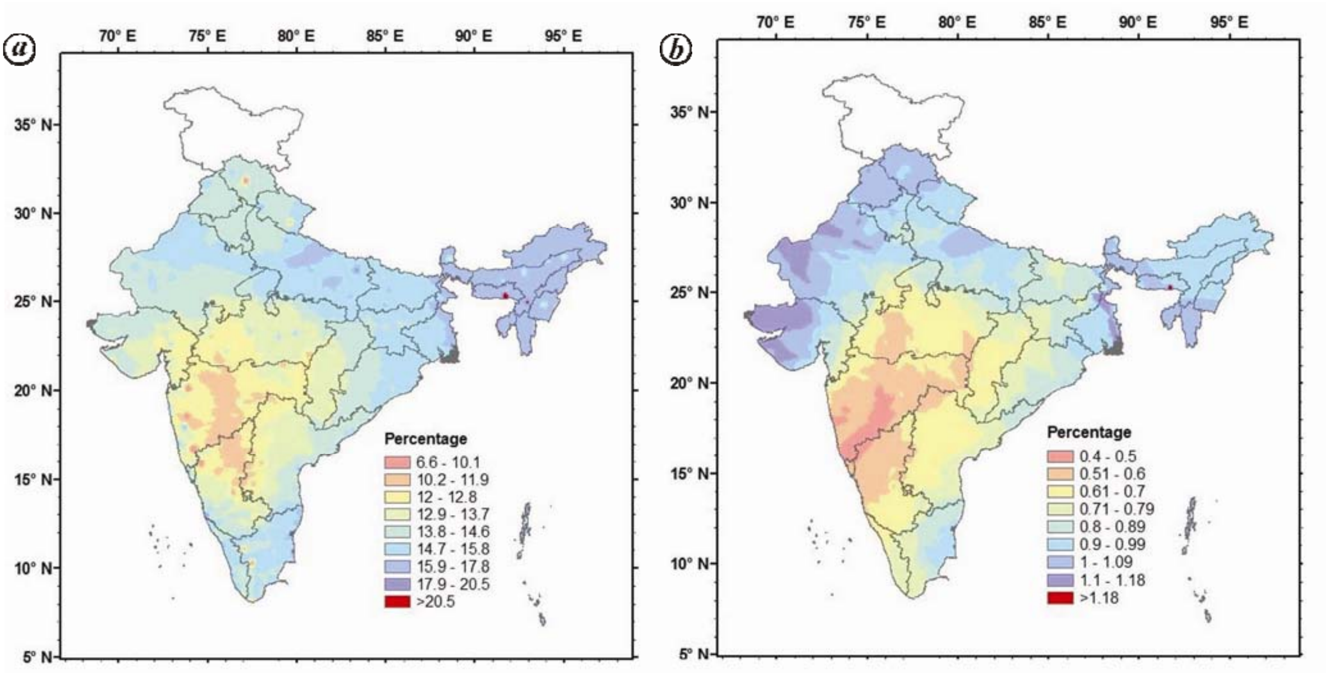

Figure 3. Annual percent of rain events with (***a***) rainfall >5 mm and (***b***) rainfall >30 mm.

convection within a deep layer of the atmosphere. The usual force for such clouds to form is the heating from below by the solar radiation, absorbed by the ground during the day[4]. Thus the observed distribution of the hour of maximum rainfall events over most of India is similar to that expected from diurnal variation of the force by solar radiation. In NE India the Katabatic winds lead to enhanced convection and the maximum precipitation is in the early hours. So, a well marked maximum in the diurnal variation of rainfall in the valley is the effect of low level convergence, leading to higher frequency of rainfall activity in early morning. The maximum rainfall intensity over central parts of India and northern peninsula corresponds to intense solar radiation during afternoon hours[3].

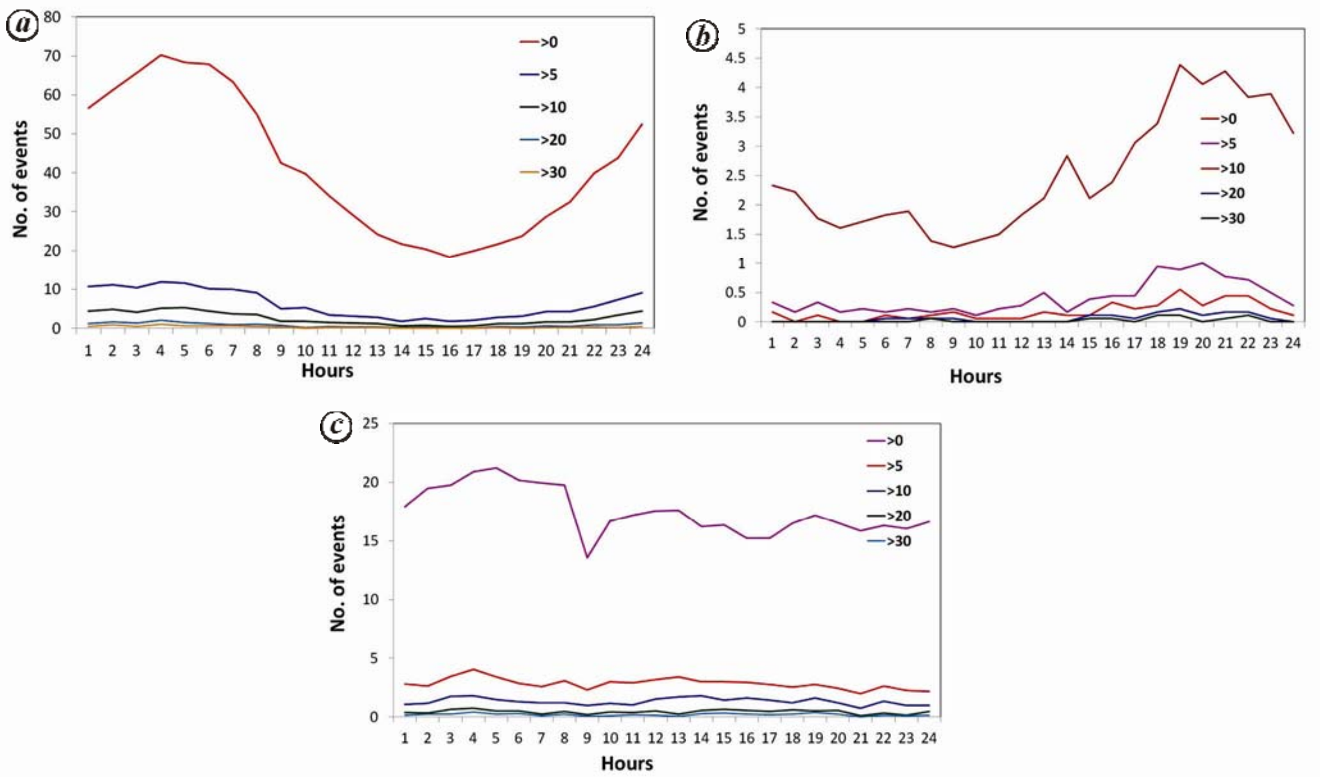

Figure 4. Diurnal variation of annual frequency of rain events (***a***) for North Lakhimpur in Assam and (***b***) for Jaisalmer in Rajasthan for various intensities. ***c***, Diurnal variation of frequency of rain events for Puri in Odisha for various intensities.

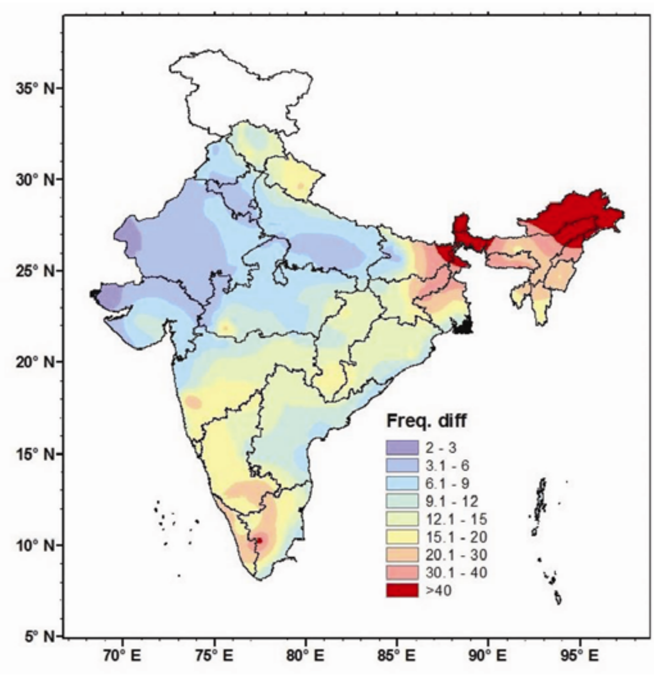

Figure 5. Difference in the highest and lowest annual frequency of rain events.

Along the west coast of India, the interaction of the synoptic – scale westerly wind with the opposing land breeze produces low level convergence, enhancing the convection and thus causing maximum rain in the early morning hours[5]. Along the east coast, the maximum rainfall activity occurs in the early morning hours as the synoptic scale westerly is weak over this region and the diurnal variation is dominated by land–sea breeze.

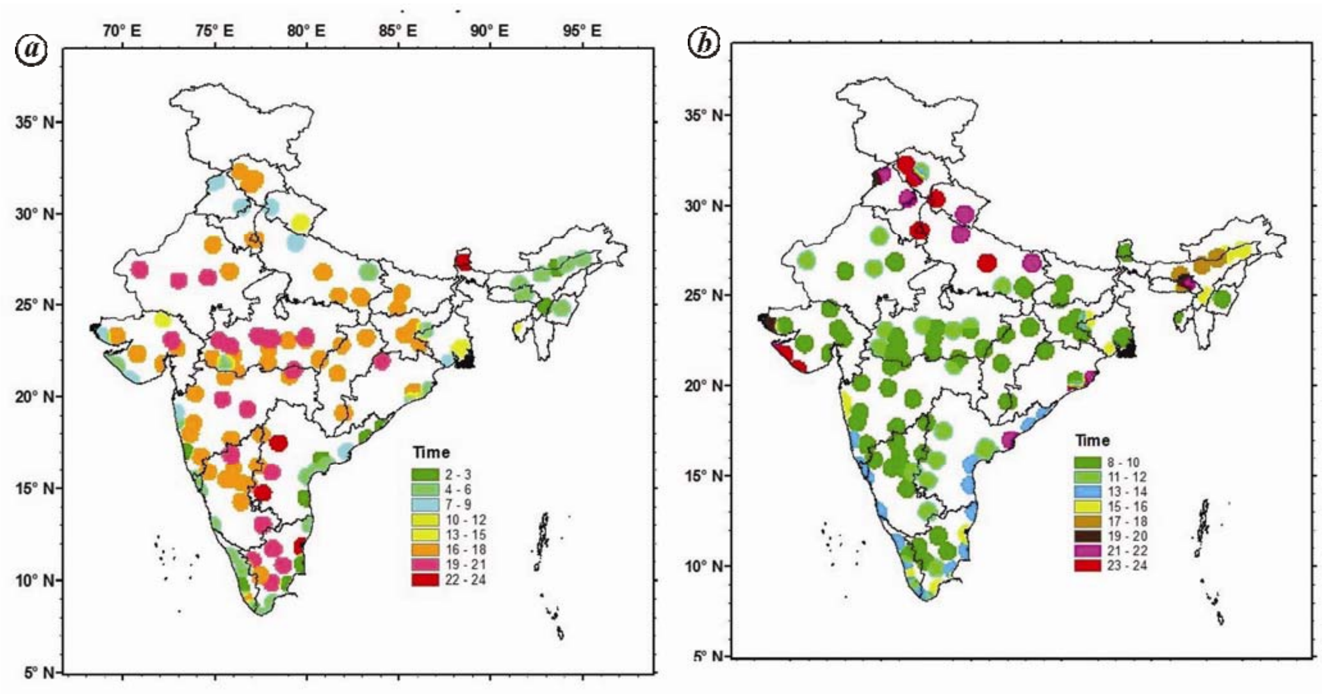

Figure 6. Period of (***a***) maximum and (***b***) minimum frequency of rainfall in various SRRG stations.

The analysis was done for the year as a whole and the results led to establishment of the fact that the diurnal variations in rainfall over a particular region were mostly dependent on the orography and physical characteristics of that place. A station in northeast India will have night or early morning maximum and an inland station will have an afternoon/evening maximum. Stations with prominent diurnal variations (high difference in highest and lowest frequency of rainfall events) in rainfall were strongly guided by the diurnal variation of heating by solar radiation and radiation cooling of cloud tops. Coastal stations along east and west coast had a maximum in the early morning but the diurnal variation along the day was not well marked.

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