Observed Rainfall Variability and Changes over Sikkim State

Pulak Guhathakurta, Arti Bandgar, Preetha Menon, Ashwini Kumar Prasad, Neha Sangwan and S C Advani
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<th>Document Title</th>
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<tbody>
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<td>Authors</td>
<td>Pulak Guhathakurta, Arti Bandgar, Preetha Menon, Ashwini Kumar Prasad, Neha Sangwan and S C Advani</td>
</tr>
<tr>
<td>13</td>
<td>Originating Division/ Group</td>
<td>Climate Research Division/ Climate Application &amp; User Interface Group/ Hydrometeorology</td>
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<td>16</td>
<td>Abstract</td>
<td>India is in the tropical monsoon zone and receives plenty of rainfall as most of the annual rainfall during the monsoon season every year. However, the rainfall is having high temporal and spatial variability and due to the impact of climate changes there are significant changes in the mean rainfall pattern and their variability as well as in the intensity and frequencies of extreme rainfall events. The report brings the result of the analysis based on the rent 30 years of data (1989-2018) on the mean spatial rainfall pattern as well as mean spatial pattern of different rainfall events, trends and variability as well as extreme rainfall events during the monsoon months and annual for the state.</td>
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<td>Key Words</td>
<td>Rainfall trend, variability, extreme events, dry days</td>
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1. Introduction

Sikkim is the second smallest state of India. Sikkim state is located in the northeastern part of India and nestled on the lap of Eastern Himalaya between the 27°05’N - 28°08’N latitudes and 88°05’E- 88°55’E longitudes. It shares its boundaries with Nepal to the west, Bhutan to the east, China’s Tibet Autonomous region to the north and east and the state West Bengal to the south. The state of Sikkim covers 7096 square km, the cross-section of the state measures 114 km from north to south and 64 km from east to west. This state has hilly terrain with forest, valleys, lakes and rivers. The state has a large numbers of plants in the southern part. The world's third highest peak, Kanchenjunga is located on the border of Nepal and Sikkim (North Sikkim district). The state has a lot number of mountain peaks, glaciers, lakes and rivers including the famous Teesta, which is also called "lifeline of Sikkim".

The topography of Sikkim in south blends with the plain land of West Bengal and gathers high elevations towards the north, west and east. Altitude of Sikkim ranges from 300 meters to as high as 8586 meters, the top of the mighty Kanchenjunga on the Nepal border. The Singalila range encompasses the western borders of Sikkim. In the east, the Chola range separates Sikkim from its neighboring state. In the north, the Donkia range reaches out to the Tibetan Plateau. The major peaks of Sikkim are 1. Khanchenjunga (8586 m), 2.Jonsang (7444 m), 3.Tent Peak (7365 m), 4.Talung (7351 m), 5.Karbu (7338 m), 6.Pauhunri (7125 m), Siniolchu (6888 m), 7. Simvo (6811m), 8. Pandim (6691m), 9.Koktang (6147m), 10. Rathong (6087 m). The extreme northern and western parts of Sikkim state are mostly covered by snow throughout the year. The permanent snow-covered areas are found at 5000m or above. The climate within the state varies from place to place due to significant variation in elevation and topography.

Many studies available on the observed trends and variability of rainfall and also extreme rainfall events over India, but all the studies are based on past 100 years or more data and also the recent years are not included (Guhathakurta et al, 2015; Guhathakurta et al, 2011; Guhathakurta & Rajeevan, 2008 etc). Also, there are limited studies on district rainfall trends and variability of Sikkim state. In the present report all the analysis of observed rainfall patterns, trends and variability have been done based on recent past 30 years (1989-2018) that will help to have idea of the recent changes for climate change adaptation and management by the state authorities.
2. **Data and Methodology**

Daily Rainfall data from 1989 to 2018 is considered for analysis of trend variability and mean rainfall patterns. From the daily rainfall data monthly rainfall series of each stations are computed and then monthly district rainfall series has been constructed by considering arithmetic average of all the station rainfall values within the district. The monthly rainfall series of the state has been computed by using area weighted rainfall values of all the districts within the state. Fig.1 gives the location of the districts of the state. The objective of the analysis is to:

1. Identify the spatial pattern of the mean rainfall
2. Understand district wise observed rainfall trend and variability in annual and SW monsoon season (June, July, August and September).

Daily station rainfall data is utilized for identification of the mean spatial patterns and rainfall intensity trends. From mean and standard deviation (SD), the coefficient of variation (CV) is calculated as follows:

\[
\text{Coefficient of variation (CV)} = \frac{\text{Standard Deviation}}{\text{Mean}} \times 100
\]

![Fig. 1 Location of the districts of Sikkim](image)

3. **State rainfall mean and variability and trend**

Table 1 shows the mean rainfall (mm) and coefficient of variation of the state for the monsoon months, southwest monsoon season and annual during the period 1989-2018. It can be seen that the state gets highest rainfall (29%) of south west monsoon rainfall in July month while June and August months get 26% of the south west monsoon rainfall each. September
month receives 19% of south west monsoon rainfall. About 64% of annual rainfall received during the southwest monsoon season only. The variability of monsoon or annual rainfall is also very less (18% and 14% respectively).

<table>
<thead>
<tr>
<th></th>
<th>June</th>
<th>July</th>
<th>August</th>
<th>September</th>
<th>JJAS</th>
<th>Annual</th>
</tr>
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<tr>
<td><strong>Mean</strong></td>
<td>416.4</td>
<td>476.2</td>
<td>417.4</td>
<td>317.1</td>
<td>1627.0</td>
<td>2554.8</td>
</tr>
<tr>
<td><strong>CV</strong></td>
<td>24.6</td>
<td>23.3</td>
<td>22.2</td>
<td>34.7</td>
<td>17.6</td>
<td>13.5</td>
</tr>
</tbody>
</table>

Table 1 Mean rainfall (mm) and coefficient of variation of the state for the monsoon months, southwest monsoon season and annual

Fig. 2 Time series of rainfall in mm for the months of June, July, August, September and trends
Fig. 3 Time series of rainfall in mm for the southwest monsoon season and annual trends

Fig. 2 and 3 show the time series of rainfall in mm for the months of June, July, August, September and southwest monsoon season, annual respectively. The trend lines are also displayed for each of the series. Neither monthly rainfall nor seasonal or annual rainfall show any significant increasing/decreasing trend. In the monthly rainfall June and September rainfall show increasing trend while July and August rainfall show decreasing trend. Also, Seasonal rainfall shows increasing trend. During the last 30 years highest rainfall of June and July received in the year 2015 and 1990 (670.5mm and 737.6 mm respectively) while highest rainfall of 637.0 in August received in the year 1990 and of 561.0mm in September received in the year 2016. Highest annual rainfall of 3105.3mm received in the year 2018 and highest southwest monsoon rainfall of 2156.7mm received in the year 2009.

4. District rainfall mean, variability and trend

4.1 Mean and coefficient of variation

Table 2 gives the rainfall statistics for the districts of Sikkim for the four monsoon months, southwest monsoon season and annual while Fig. 4-5 show the spatial pattern of these statistics. South Sikkim receives highest rainfall over other districts during all the months and season. Rainfall received over this district is around 480mm in June, 600mm in July, 500mm in August, 400mm in September and around 2000mm during the SW monsoon and annual 3000mm. Lowest rainfall receives during the SW and annual monsoon season over East Sikkim district (1408mm and 2045mm).
Table 2. Rainfall statistics for the districts of Sikkim for the four monsoon months, southwest monsoon season and annual

<table>
<thead>
<tr>
<th>DISTRICT</th>
<th>JUNE MEAN</th>
<th>CV</th>
<th>JULY MEAN</th>
<th>CV</th>
<th>AUGUST MEAN</th>
<th>CV</th>
<th>SEPTEMBER MEAN</th>
<th>CV</th>
<th>MONSOON MEAN</th>
<th>CV</th>
<th>ANNUAL MEAN</th>
<th>CV</th>
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<tr>
<td>NORTH SIKKIM</td>
<td>414.6</td>
<td>34.0</td>
<td>444.1</td>
<td>31.4</td>
<td>407.0</td>
<td>31.4</td>
<td>313.9</td>
<td>49.2</td>
<td>1579.6</td>
<td>27.5</td>
<td>2661.6</td>
<td>32.5</td>
</tr>
<tr>
<td>WEST SIKKIM</td>
<td>446.0</td>
<td>57.0</td>
<td>585.2</td>
<td>53.7</td>
<td>479.5</td>
<td>52.9</td>
<td>357.3</td>
<td>57.6</td>
<td>1868.0</td>
<td>52.4</td>
<td>2410.4</td>
<td>51.0</td>
</tr>
<tr>
<td>EAST SIKKIM</td>
<td>361.7</td>
<td>32.9</td>
<td>429.1</td>
<td>33.9</td>
<td>349.9</td>
<td>30.5</td>
<td>267.3</td>
<td>37.8</td>
<td>1408.0</td>
<td>22.4</td>
<td>2045.2</td>
<td>28.0</td>
</tr>
<tr>
<td>SOUTH SIKKIM</td>
<td>479.9</td>
<td>34.4</td>
<td>595.6</td>
<td>27.3</td>
<td>513.5</td>
<td>37.3</td>
<td>382.1</td>
<td>31.3</td>
<td>1971.1</td>
<td>34.1</td>
<td>2747.9</td>
<td>38.1</td>
</tr>
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</table>

Fig. 4 Mean rainfall pattern over districts of Sikkim
Fig. 5 Coefficient of Variation (%) over districts of Sikkim

4.2 Trend in district rainfall

Fig. 6 shows the trends in district rainfall for (a) June, (b) July (c) August (d) September (e) JJAS and (f) annual. It can be seen that June rainfall has shown significant decreasing trend in the South Sikkim while no district has shown any significant increasing trend. For the July
and August months, no significant trend has been noticed in any district. September rainfall of North Sikkim district has shown significant increasing trend. During the whole southwest monsoon season West Sikkim and South Sikkim have shown significant decreasing trend. For the annual rainfall also, West Sikkim and South Sikkim show significant decreasing trend while no district showed increasing trend.

Fig. 6 Trends in district rainfall for (a) June, (b) July (c) August (d) September (e) JJAS and (f) annual
5. Analysis of Average frequencies for rainfall events of different intensities

5.1 Average frequency of Rainy days

The average frequency of rainy days is calculated for Sikkim for June, July, August, September, June to September and Annual. Figure 7 shows that in the month of June the maximum number of rainy days lies in the range of 26 to 30 days especially in some parts of East Sikkim while minimum number of rainy days lies in the range of 12 to 16 days especially in some parts of North Sikkim and West Sikkim. Whereas in remaining districts, the number of rainy days lies in the range of 16 to 26 days.

From figure 8, it can be seen that in the month of July the maximum number of rainy days lies in the range of 31 to 36 days especially in some parts of East Sikkim while minimum number of rainy days lies in the range of 17 to 21 days especially in some parts of North Sikkim and West Sikkim districts. Whereas in remaining districts, the number of rainy days lies in the range of 21 to 31 days.

In the month of August (figure 9) the maximum number of rainy days lies in the range of 30 to 35 days especially in some parts of East Sikkim. While minimum number of rainy days lies in the range of 15 to 19 days especially in some parts of North Sikkim and West Sikkim districts. Whereas in remaining districts, the number of rainy days lies in the range of 19 to 30 days.

Fig. 7 Average frequency of rainy days: June
Fig. 8 Average frequency of rainy days: July
As per figure 10, in the month of September the maximum number of rainy days lies in the range of 24 to 27 days especially in some parts of East Sikkim. While minimum number of rainy days lies in the range of 12 to 15 days especially in some parts of North Sikkim and West Sikkim districts. Whereas in remaining districts, the number of rainy days lies in the range of 15 to 24 days.

It can be seen from figure 11, that during June to September the maximum number of rainy days lies in the range of 111 to 125 days especially East Sikkim. While minimum number of rainy days lies in the range of 54 to 68 days especially in some parts of North Sikkim and West Sikkim districts. Whereas in remaining districts, the number of rainy days lies in the range of 68 to 111 days.

During the entire year (figure 12) the maximum number of rainy days lies in the range of 167 to 191 days especially in some parts of East Sikkim. While minimum number of rainy
days lies in the range of 76 to 98 days especially in some parts of North Sikkim and West Sikkim districts. Whereas in remaining districts, the number of rainy days lies in the range of 98 to 167 days.

5.2 Average frequency of Heavy rainfall days

The average frequency of Heavy rainfall days is calculated for Sikkim for June, July, August, September, June to September and Annual. Figure 13 shows that in the month of June the maximum number of heavy rainfall days lies in the range of 2 to 3 days especially in some parts of East Sikkim. While minimum number of Heavy rainfall days lies in the range of 0.6 to 1.05 days especially in some parts of North Sikkim and West Sikkim. Whereas in remaining districts, the number of Heavy rainfall days lies in the range of 1.05 to 2.2 days.

From figure 14, it can be seen that in the month of July the maximum number of heavy rainfall days lies in the range of 2.29 to 3 days especially in some parts of East Sikkim. While minimum number of Heavy rainfall days lies in the range of 0.7 to 1.15 days especially in some parts of North Sikkim. Whereas in remaining districts, the number of Heavy rainfall days lies in the range of 1.15 to 2.29 days.

As per figure 15, in the month of August the maximum number of heavy rainfall days lies in the range of 1.74 to 3 days especially in some parts East Sikkim. While minimum number of Heavy rainfall days lies in the range of 0.5 to 0.88 days especially in some parts of North Sikkim. Whereas in remaining districts, the number of Heavy rainfall days lies in the range of 0.88 to 1.2 days.

During September (figure 16), the maximum number of heavy rainfall days lies in the range of 1.14 to 2 days especially in some parts of East Sikkim. While minimum number of Heavy rainfall days lies in the range of 0.42 to 0.6 days especially in some parts of North Sikkim and West Sikkim districts. Whereas in remaining districts, the number of Heavy rainfall days lies in the range of 0.6 to 1.14 days.

During June to September (figure 17), the maximum number of heavy rainfall days lies in the range of 1.14 to 2 days especially in some parts of East Sikkim districts. While minimum number of Heavy rainfall days lies in the range of 0.42 to 0.6 days especially in some parts of North Sikkim and West Sikkim districts. Whereas in remaining districts, the number of Heavy rainfall days lies in the range of 0.6 to 1.14 days.

It can be seen from figure 18 that during the entire year the maximum number of heavy rainfall days lies in the range of 8 to 10 days especially in some parts of East Sikkim. While minimum number of Heavy rainfall days lies in the range of 3 to 4 days especially in some parts of North Sikkim and West Sikkim districts. Whereas in remaining districts, the number
of Heavy rainfall days lies in the range of 4 to 8 days.

Fig. 13 Average frequency of heavy rainfall days: June

Fig. 14 Average frequency of heavy rainfall days: July

Fig. 15 Average frequency of heavy rainfall days: August

Fig. 16 Average frequency of heavy rainfall days: September

Fig. 17 Average frequency of heavy rainfall days: JJAS

Fig. 18 Average frequency of heavy rainfall days: Annual
5.3 Average frequency of Dry days

The average frequency of dry days is calculated for Sikkim for June, July, August, September, June to September and Annual. Figure 19 shows that in the month of June the maximum number of dry days lies in the range of 13 to 16 days especially in some parts of North Sikkim and West Sikkim districts. While minimum number of dry days lies in the range of 5 to 7.5 days especially in some parts of North Sikkim and East Sikkim districts. Whereas in remaining districts, the number of dry days lies in the range of 7.5 to 13 days.

It can be seen from figure 20, that in the month of July the maximum number of dry days lies in the range of 10 to 12 days especially in some parts of North Sikkim and West Sikkim districts. While minimum number of dry days lies in the range of 3 to 5 days especially in some parts of North Sikkim, South Sikkim and East Sikkim districts. Whereas in remaining districts, the number of dry days lies in the range of 5 to 10 days.

As per shown in figure 21 shows that in the month of August the maximum number of dry days lies in the range of 11 to 14 days especially in some parts of North Sikkim and West Sikkim districts. While minimum number of dry days lies in the range of 4 to 6 days especially in some parts of North Sikkim, South Sikkim and East Sikkim districts. Whereas in remaining districts, the number of dry days lies in the range of 6 to 11 days.

Figure 22 shows that in the month of September the maximum number of dry days lies in the range of 14 to 17 days especially in some parts of North Sikkim and West Sikkim districts. While minimum number of dry days lies in the range of 8 to 10 days especially in some parts of North Sikkim and East Sikkim districts. Whereas in remaining districts, the number of dry days lies in the range of 10 to 14 days.

During June to September (figure 23) the maximum number of dry days lies in the range of 46 to 53 days especially in some parts of North Sikkim and West Sikkim districts. While minimum number of dry days lies in the range of 20 to 26 days especially in some parts of North Sikkim, West Sikkim and East Sikkim districts. Whereas in remaining districts, the number of dry days lies in the range of 26 to 46 days.

During the entire year the, as shown in the figure 24 maximum number of dry days lies in the range of 230 to 243 days especially in some parts of North Sikkim, West Sikkim and East Sikkim districts. While minimum number of dry days lies in the range of 177 to 190 days especially in some parts of North Sikkim, West Sikkim and South Sikkim districts. Whereas in remaining districts, the number of dry days lies in the range of 190 to 230 days.
Fig. 19 Average frequency of dry days: June
Fig. 20 Average frequency of dry days: July
Fig. 21 Average frequency of dry days: August
Fig. 22 Average frequency of dry days: September
Fig. 23 Average frequency of dry days: JJAS
Fig. 24 Average frequency of dry days: Annual
6 Trends in the frequencies of different rainfall events

6.1 Trend in frequency of Rainy days

The Trend in frequency of rainy days is calculated for the rain gauge stations of Sikkim for June, July, August, September, June to September and Annual. Figure 25 shows that in the month of June there is no significant trend in Rainy days in any district.

As shown in the figure 26, in the month of July there is a significant increase in Rainy days in stations in South Sikkim. While remaining districts did not show any significant change.

From figure 27 shows that in the month of August there is a significant increase in Rainy days in stations in South Sikkim. While remaining districts did not show any significant change.

It can be seen from figure 28 shows that in the month of September there is a significant increase in Rainy days in stations in South Sikkim. While remaining districts did not show any significant change.

In the months of June to September (figure 29) there is a significant increase in Rainy days in stations in South Sikkim. While remaining districts did not show any significant change.

During the entire year, as shown in the figure 30, there is a significant increase in Rainy days in stations in South Sikkim. While remaining districts did not show any significant change.
6.2 Trend in frequency of Heavy rainfall days

The Trend in frequency of Heavy days is calculated for Sikkim for June, July, August, September, June to September and Annual. Figure 31 shows that in the month of June, no district showed any significant change.

As seen in the figure 32, it can be seen that in the month of July, no district showed any significant change.

Figure 33 shows that in the month of August, no district showed any significant change.

From Figure 34, in the month of September it is seen that there is a significant increase in Heavy rainfall days in West Sikkim and South Sikkim districts. While remaining districts did not show any significant change.

During June to September (figure 35) there is a significant increase in Heavy rainfall days in South Sikkim. While remaining districts did not show any significant change.

During the entire year, as shown in the figure 36, there is a significant increase in Heavy
rainfall days in South Sikkim. While remaining districts did not show any significant change.

Fig. 31 Trend in frequency of heavy rainfall days: June

Fig. 32 Trend in frequency of heavy rainfall days: July

Fig. 33 Trend in frequency of heavy rainfall days: August

Fig. 34 Trend in frequency of heavy rainfall days: September

Fig. 35 Trend in frequency of heavy rainfall days: JJAS

Fig. 36 Trend in frequency of heavy rainfall days: Annual
6.3 Trend in frequency of Dry days

The Trend in frequency of dry days is calculated for Sikkim for June, July, August, September, June to September and Annual. It can be seen from figure 37, that in the month of June there is a significant increase in dry days in West Sikkim. While remaining districts did not show any significant change.

Figure 38 shows that in the month of July, no district showed any significant change.

As shown in the figure 39, in the month of August, no district showed any significant change.

In the month of September (figure 40), no district showed any significant change.

In the month of June to September (figure 41), there is a significant increase in dry days in West Sikkim. While remaining districts did not show any significant change.

During the entire year (figure 42) there is a significant increase in dry days in North Sikkim and West Sikkim. While remaining districts did not show any significant change.
7. Conclusions

In the present study we have investigated the rainfall pattern and its variability and also changes based on recent 30 years data. In the analysis we have considered monsoon months, the monsoon season and annual scale. The spatial scale has been considered from state to district for study of rainfall total and stations are being considered for seeing intensities of rainfall. The analysis brought many significant features of rainfall pattern and can be used for water agricultural managements. Some of the important results can be summarized as:

- Sikkim gets maximum rainfall in July (29% of SW monsoon rainfall) followed by August (26% of SW monsoon rainfall).

- 64% of annual rainfall receives during southwest monsoon rainfall (June – September).

- South Sikkim district receives 71-72% of annual rainfall in SW monsoon season while East Sikkim receives 68-69% of annual rainfall in SW monsoon season.

- No significant increasing/decreasing trends in June, July, August, September monthly rainfall.
No significant increasing/decreasing trends in June, July, August, September seasonal rainfall.

Maximum rainfall received during the SW monsoon season over the South Sikkim district (1900mm - 2000mm) while East Sikkim receive lowest rainfall (1400-1500mm).

During the year, South Sikkim district receives maximum rainfall (2700mm - 2800mm) while East Sikkim receives lowest annual rainfall of 2045mm.

Significant increasing trend in SW monsoon rainfall has been noticed in West Sikkim and South Sikkim districts while no district shows significant decreasing trend.

In annual rainfall West Sikkim and South Sikkim show significant increasing trend while no district shows significant decreasing trend.

For southwest monsoon, Sikkim (daily rainfall >=2.5mm) maximum number of rainy days lies in the range of 111 to 125 days especially East Sikkim. While minimum number of rainy days lies in the range of 54 to 68 days especially in some parts of North Sikkim and West Sikkim districts. Whereas in remaining districts, the number of rainy days lies in the range of 68 to 111 days.

For heavy to extremely heavy rainfall (daily rainfall >=6.5mm) during southwest monsoon, the maximum number of heavy rainfall days lies in the range of 1.14 to 2 days especially in some parts of East Sikkim districts. While minimum number of Heavy rainfall days lies in the range of 0.42 to 0.6 days especially in some parts of North Sikkim and West Sikkim districts. Whereas in remaining districts, the number of Heavy rainfall days lies in the range of 0.6 to 1.14 days.

During southwest monsoon season, number the maximum number of dry days lies in the range of 46 to 53 days especially in some parts of North Sikkim and West Sikkim districts. While minimum number of dry days lies in the range of 20 to 26 days especially in some parts of North Sikkim, West Sikkim and East Sikkim
districts. Whereas in remaining districts, the number of dry days lies in the range of 26 to 46 days.

During the period June to September there is a significant increase in the frequency of Rainy days in stations in South Sikkim. Whereas there is no significant decrease in Rainy days in any station.

During the entire year there is a significant increase in Rainy days in South Sikkim. Whereas there is no significant decrease in Rainy days in any other station.

During the period June to September there is a significant increase in Heavy rainfall days in stations in South Sikkim. Whereas there is no significant decrease in Heavy rainfall days in any other station.

During June to September there is a significant increase in dry days in stations in South Sikkim. Whereas there is a significant decrease in dry days in any other station.

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The authors acknowledge Secretary, MOES, DGM, India Meteorological Department and Head, Climate Research and Services for guidance, suggestions and encouragement to carry out the works. Acknowledge also to Hydrology section and National Data Centre of India Meteorological Department Pune for making availability of the data.
References:

The report brings out observed rainfall variability and trends over the state as an impact of climate change based on recent 30 years of data (1981 - 2018).

Rainfall pattern of monsoon months, south west monsoon season and annual of the state and it’s districts as well as extreme rainfall event of different intensity of stations are analysed.