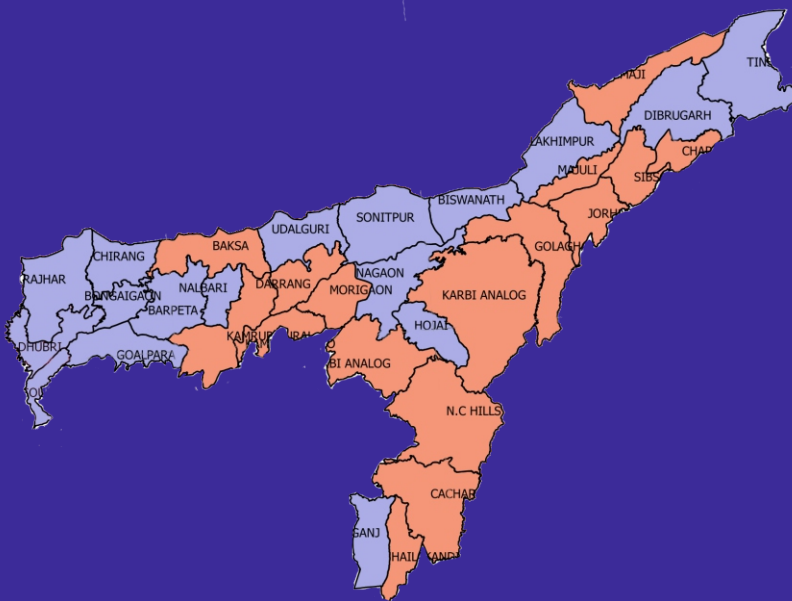




**CLIMATE RESEARCH AND SERVICES
INDIA METEOROLOGICAL DEPARTMENT
MINISTRY OF EARTH SCIENCES
PUNE**

**Observed Rainfall Variability and Changes over
Assam State**



Met Monograph No. : ESSO/IMD/HS/Rainfall Variability/03(2020)/27

**Pulak Guhathakurta, Arti Bandgar, Preetha Menon,
Ashwini Kumar Prasad, Neha Sangwan and S C Advani**



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16	Abstract	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 recent 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.
17	Key Words	Rainfall trend, variability, extreme events, dry days

1. Introduction

Assam state is in the northeastern region of India. The state lies between $89^{\circ}46'$ - $96^{\circ}01'$ E longitude and $24^{\circ}03'$ - $27^{\circ}58'$ N latitude and covers an area of 78,438 km². The state is bounded in the north by Bhutan and Arunachal Pradesh, in the east by Arunachal Pradesh, Nagaland and Manipur, in the south by Meghalaya and Mizoram and in the west by West Bengal, Tripura and Bangladesh.

The state can be divided into three principal geographical regions:

1. Brahmaputra Valley region in the foothills of the Himalayas in northern part of the state.
2. Barak Valley in the southern part.
3. Mikir (KarbiAnglong) and Cachar hills that divide the two valleys region.

Assam has mostly plain areas of low elevation, a large number of rivers and hills of low elevation in KarbiAnglong, North Cachar Hills and Cachar districts in the southern region. The peak height of hill in the state is about 1850 metres above mean sea level in North Cachar Hills district. Due to heavy rainfall in Eastern Himalayan and other watersheds of the north-eastern part of India, Assam has extensive rivers system consisting of Brahmaputra, Barak and other main rivers like Burhidihing, Danshiri, Subansiri, Kopili, Dihang, Disang, Dikhou, Lohit, Puthimari, Kalang, Manas, Jinjiram, Dikrang, Kulsi, Janji, Aai, Nonoi, Gangadhar, Dhanshiri, Ronganadi, Krishna, Kushiara etc.

All the rivers in Assam are liable to floods, mainly because they receive heavy rainfall within a short time in the state and its neighbourhood (Himalaya) where water runs very fast into Assam which has mostly low elevation. These rivers are in their early stage of maturity and are very active agents of erosion. The river water collects a tremendous amount of silt and other debris from the hilly terrains and raises the level of the riverbeds. Therefore, it becomes impossible for the main channel to cope with the vast volumes of water received during the rains so that over flow water creates the floods in adjacent areas of the rivers.

Many studies are available on the observed trends and variability of rainfall and also extreme rainfall events, but all the studies are based on past 100 years or more data and also the recent years are not included (Gharphalia et al, 2018; Guhathakurta et al, 2015; Guhathakurta et al, 2011; Guhathakurta & Rajeevan, 2008 etc). 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. 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 gives the location of the districts of the state.

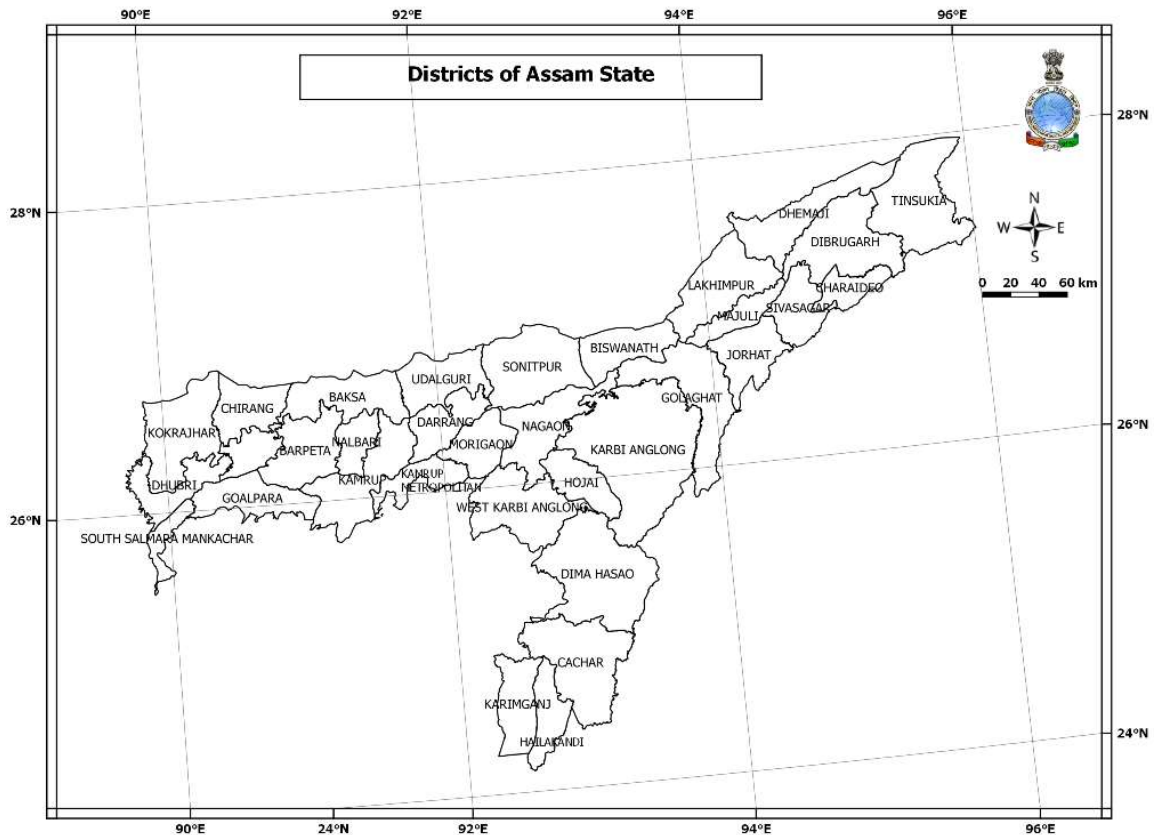


Fig. 1 Location of the districts of Assam

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 (28.7%) of southwest monsoon rainfall in July followed by 28.6% in June. August and September receive 23.8% and 18.9% of south west monsoon rainfall. Also, more than 66% of annual rainfall receives during the southwest monsoon season only. The variability of monsoon or annual rainfall is also very less (12%).

	June	July	August	September	JJAS	Annual
Mean	400.8	401.4	332.5	265.0	1399.8	2134.6
CV	22.7	21.0	25.9	26.1	12.9	12.1

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

Fig. 2 and 3 show the time series of rainfall in mm for the months of June, July, August and 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 all months from June-September show slight decreasing trend. Both seasonal and annual rainfall also show slight decreasing trend. During the last 30 years highest rainfall of June and July received in the year 2012 and 2004 (677.5 mm and 640.4 mm respectively) while highest rainfall of 484.4 in August received in the year 2015 and of 416.6mm in September received in the year 1990. Highest annual rainfall of 2564.3mm received in the year 2010 and highest southwest monsoon rainfall of 1716.7mm received in the year 2006.

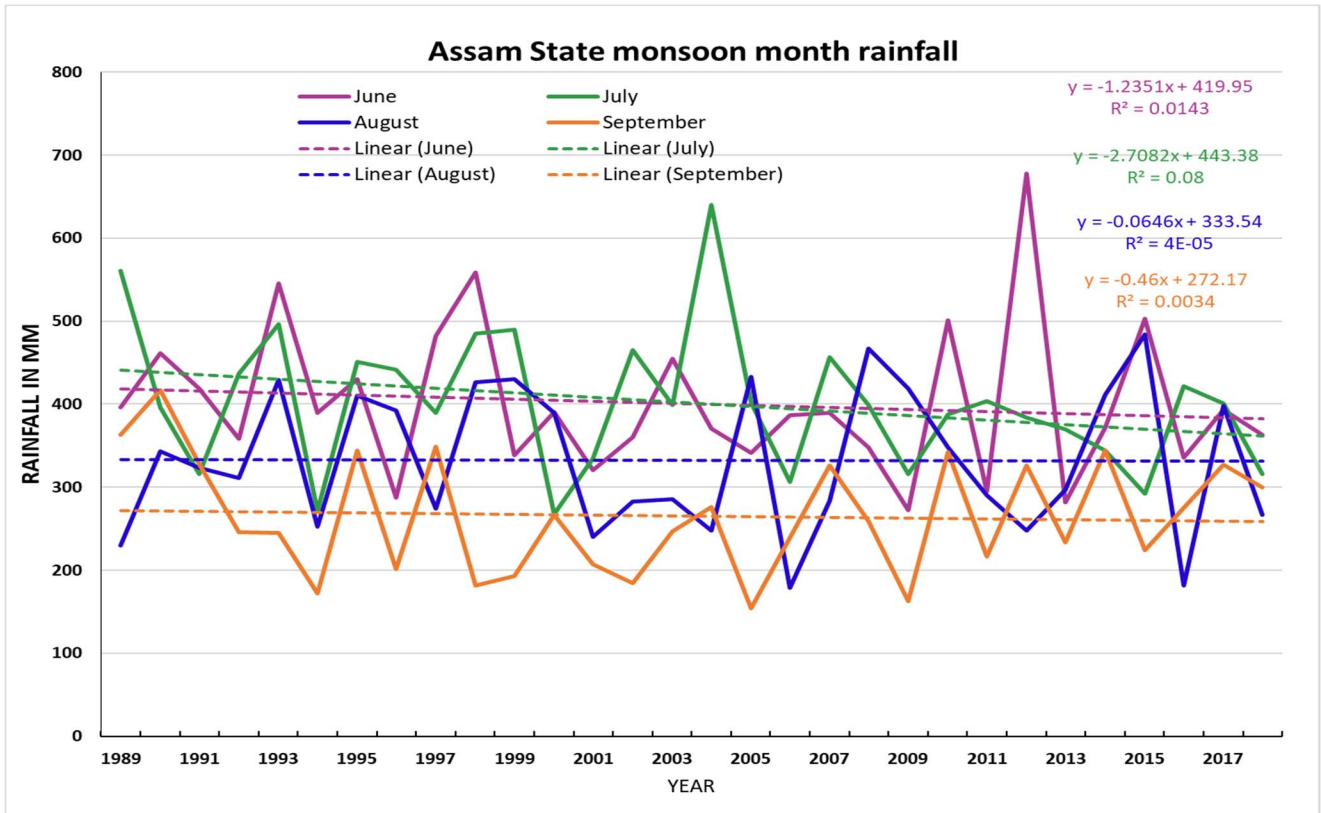


Fig. 2 Time series of rainfall in mm for the months of June, July, August, September and trends

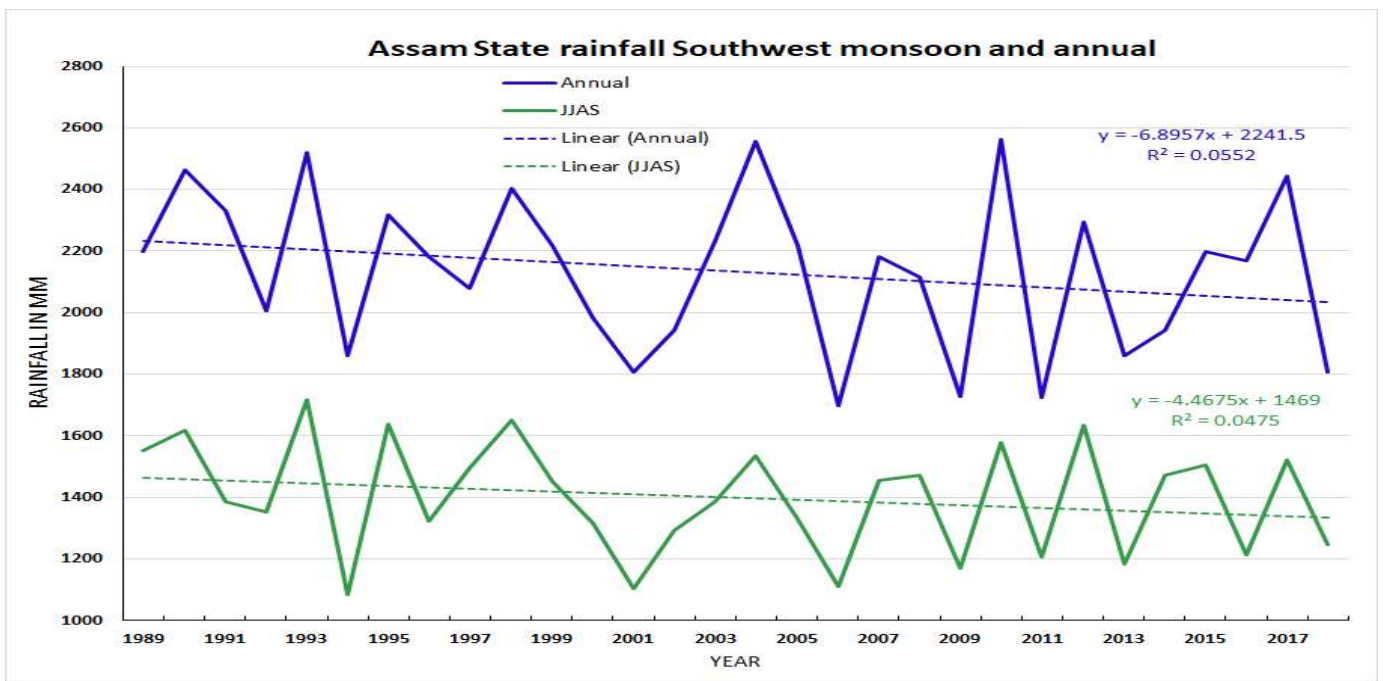


Fig. 3 Time series of rainfall in mm for the southwest monsoon season and annual trends

4. District rainfall mean, variability and trend

4.1 Mean and coefficient of variation

Table 2 gives the rainfall statistics for the districts of Assam for the four monsoon months, southwest monsoon season and annual while Fig. 4-5 show the spatial pattern of these statistics. Kokrajhar received highest rainfall over other districts during June (757mm), July (714mm) and August (561mm) whereas Chirang received highest rainfall during September (456 mm). Rainfall received was maximum in Kokrajhar for SW monsoon (2482 mm) and in Karim Ganj annually (3465 mm). Lowest rainfall was received over Karbi Anglong district during the SW monsoon season (885 mm) as well as annual (1360 mm).

DISTRICT	JUNE		JULY		AUGUST		SEPTEMBER		MONSOON		ANNUAL	
	MEAN	CV	MEAN	CV	MEAN	CV	MEAN	CV	MEAN	CV	MEAN	CV
CACHAR	494.7	29	505.7	26	469.3	26	354.4	37	1824.1	16	2939.2	15
DARRANG	327.1	196	256.6	229	217.1	260	167.9	309	968.7	84	1592.6	99
GOALPARA	492.0	38	431.8	74	311.3	89	267.6	55	1502.7	33	2339.7	39
KAMRUP	363.0	35	327.9	52	240.1	55	190.7	56	1121.7	46	1834.7	32
LAKHIMPUR	504.5	29	560.6	31	456.2	28	367.1	42	1888.3	18	2721.0	19
N.C. HILLS	393.1	161	318.9	193	318.7	188	255.1	216	1285.7	85	2071.4	99
NOWGONG	229.7	32	263.5	92	275.3	43	195.3	117	963.7	46	1468.5	55
SIBSAGAR	278.5	29	365.0	27	298.4	32	228.8	43	1170.7	16	1824.2	17
BARPETA	612.4	38	543.0	61	370.9	87	355.0	82	1881.2	39	2694.0	35
DHUBRI	633.5	35	509.9	80	372.6	86	309.2	92	1825.2	55	2688.9	53
DIBRUGARH	345.8	28	416.1	24	325.6	30	253.7	43	1341.3	21	2111.2	22
JORHAT	269.7	93	380.7	71	286.0	86	250.9	98	1187.3	54	1869.9	37
KARBI ANGLONG	212.9	33	247.9	39	226.6	47	195.4	30	882.8	25	1356.1	28
KARIMGANJ	602.8	86	582.1	81	526.0	97	415.5	100	2126.5	60	3461.7	52
KOKRAJHAR	757.3	34	713.8	40	561.4	53	448.2	45	2480.7	19	3400.5	21
SONITPUR	328.7	85	319.4	86	299.0	94	199.6	117	1146.8	35	1788.8	43
NALBARI	497.6	92	386.7	118	304.8	117	237.0	138	1426.1	60	2179.9	59
BONGAIGAON	750.1	75	701.3	61	513.7	95	365.4	129	2330.4	51	3246.0	57
MORIGAON	284.6	39	329.5	107	297.9	87	228.0	47	1140.1	53	1658.0	52
GOLAGHAT	248.5	33	309.0	24	261.5	24	203.1	33	1022.2	16	1624.1	16
TINSUKIA	351.4	28	438.8	25	346.9	34	299.5	39	1436.6	14	2299.7	16
DHEMAJI	463.9	125	477.3	125	476.2	105	289.0	118	1706.3	72	2414.0	65
HAILAKANDI	433.9	72	411.3	73	405.9	74	270.8	41	1521.8	51	2557.4	47
UDALGURI	420.6	153	361.3	162	256.5	207	227.5	227	1265.9	78	1941.8	90
BAKSA	479.8	38	409.8	43	306.1	92	242.7	49	1438.3	42	2242.0	37
CHIRANG	756.9	88	708.2	98	553.8	98	456.2	114	2475.1	62	3374.3	64
KAMRUP METROPOLI	316.7	34	299.7	38	237.5	48	171.5	46	1025.3	44	1643.2	21

Table 2. Rainfall statistics for the districts of Assam for the four monsoon months, southwest monsoon season and annual

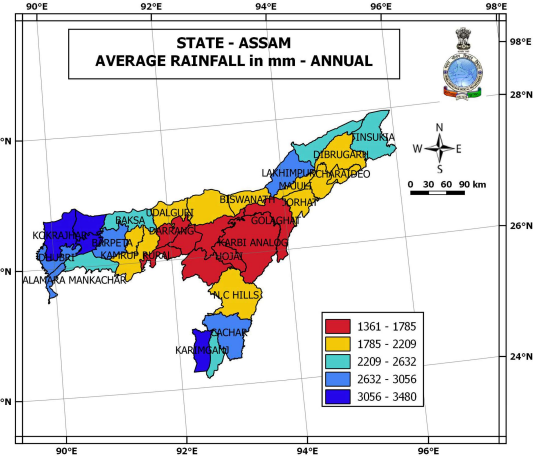
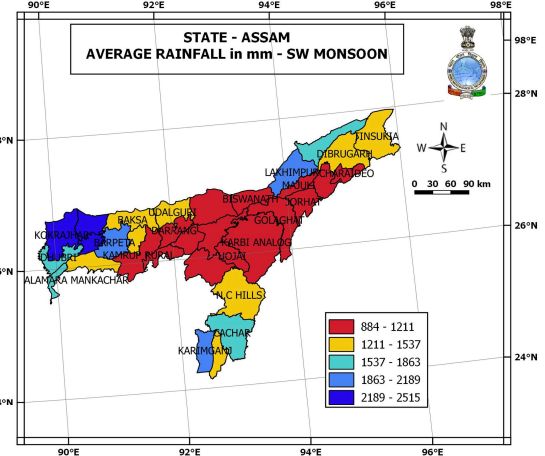
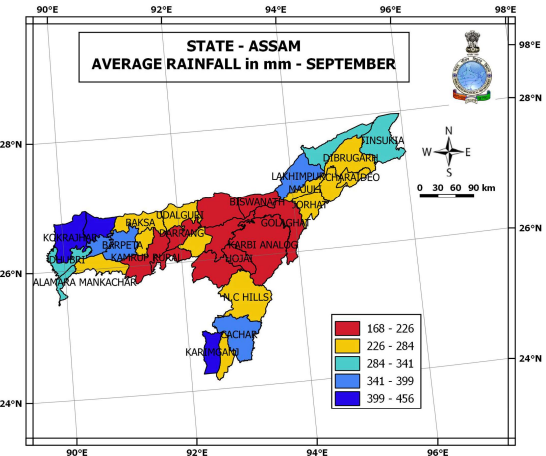
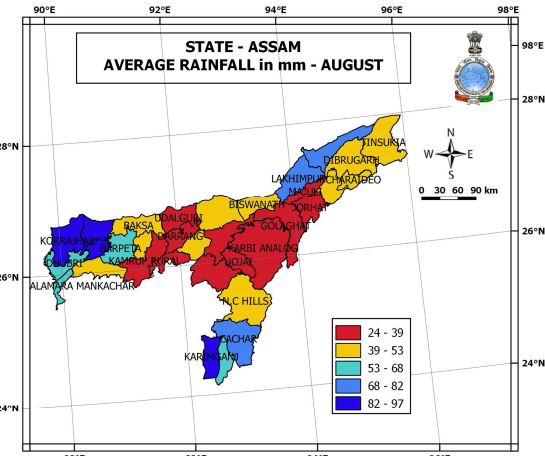
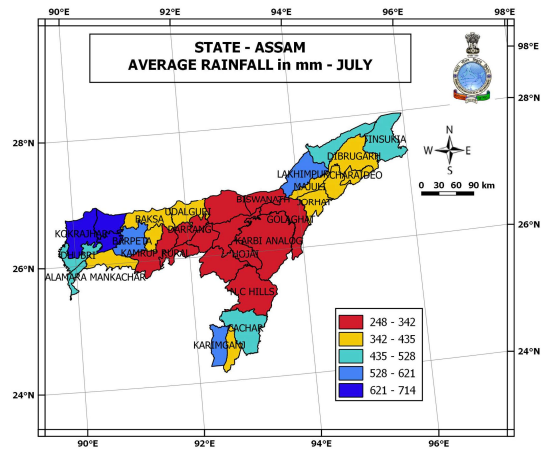
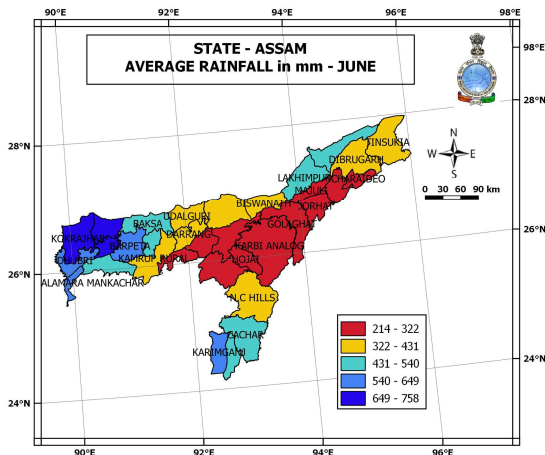


Fig.4 Mean rainfall pattern over districts of Assam

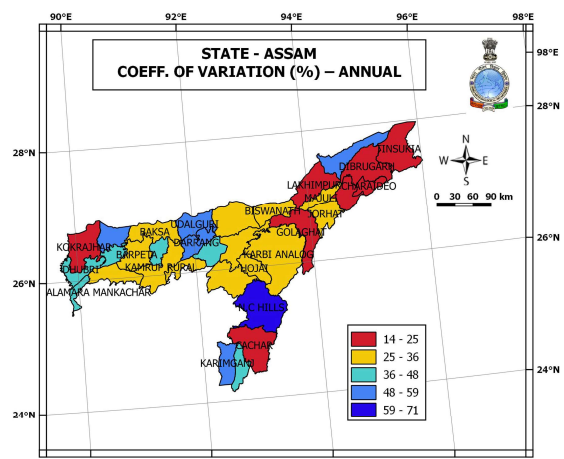
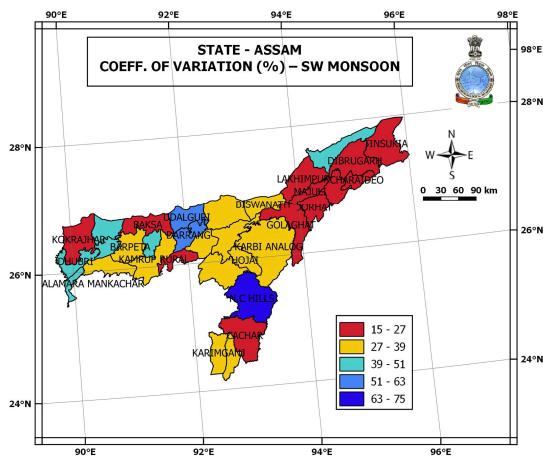
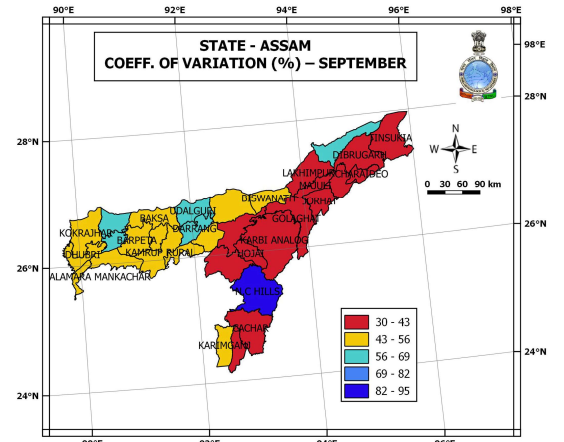
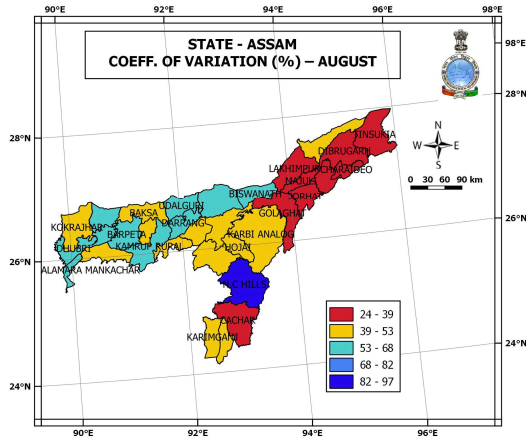
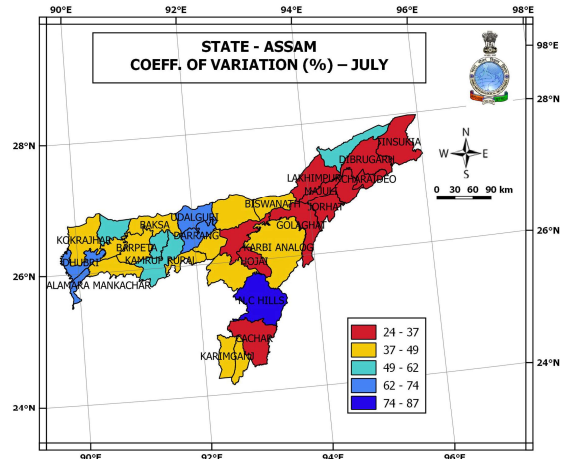
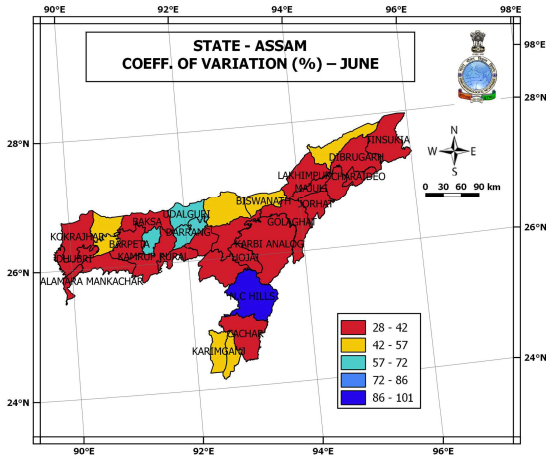
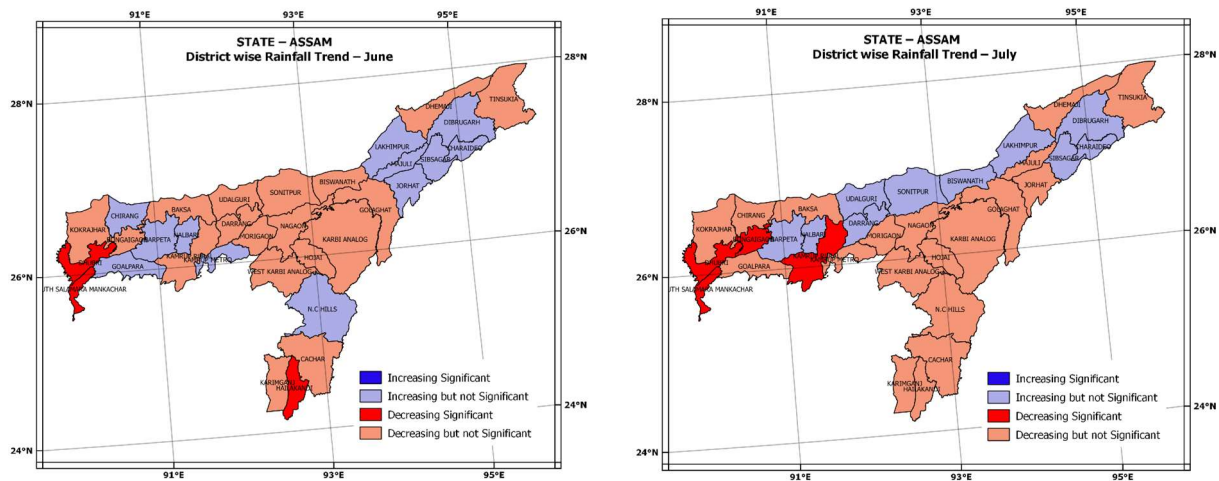


Fig.5 Coefficient of Variation (%) over districts of Assam

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 district Hailakandi and South Salimara Mankachar while no district has shown any significant increasing trend. For the July month significant decreasing trend has been noticed in Dhubri, South Salimara Mankachar, Bongaigaon and Kamrup Rural districts. Dhubri and South Salimara Mankachar have shown significant decreasing trend in August rainfall also while September rainfall of Majuli, Jorhat, Golaghat, Karbi Anglong and West Karbi Anglong have shown significant decreasing trend. Districts like Udalgiri, Chirang, Nalbari, Barpeta and Bongaigaon have shown significant increasing trend during September.

During the whole southwest monsoon season no district has shown significant increasing trend whereas Dhubri, South Salimara Mankachar, Golaghat, Hailakandi and Morigaon have shown significant decreasing trend. For the annual rainfall Dhubri, South Salimara Mankachar, Golaghat, Hailakandi, Karbi Anglong, Hojai, Morigaon, Nagaon and West Karbi Anglong show significant decreasing trend while no district showed significant increasing trend.



a

b

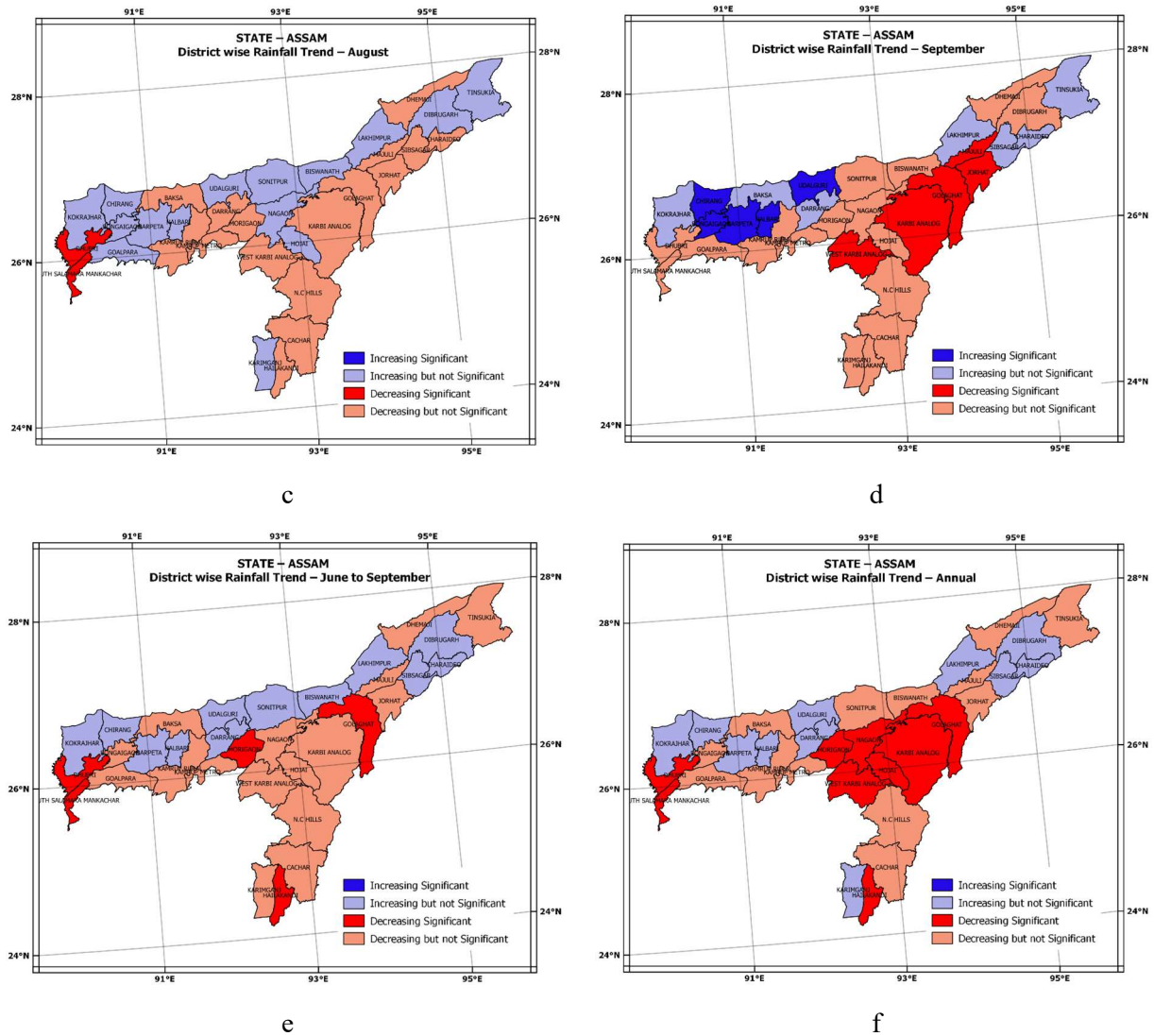


Fig.7 Trends in district rainfall for (a) June (b) July (c) August (d) September (e) JJAS and (f) annual

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 Assam for June, July, August, September, June to September and Annual. In the month of June (Figure 7), the maximum number of rainy days lies in the range of 17.2 to 19 days especially in some parts of Cachar, Hailakandi, Lakhimpur and Dhemaji districts. While minimum number of rainy days lies in the range of 11 to 13.2 days especially in some parts of Karbi Anglong, Hojai, West Karbi Anglong, Dima Hasao, Nagaon and Golaghat districts. Whereas in remaining districts, the number of rainy days lies in the range of 13.2 to 17.2 days.

Figure 8 shows that in the month of July the maximum number of rainy days lies in the range of 19.3 to 21 days especially in some parts of Karim Ganj, Hailakandi, Cachar, Lakhimpur, Dhemaji and

Dibrugarh districts. While minimum number of rainy days lies in the range of 13 to 14.8 days especially in some parts of Karbi Anglong, Hojai, West Karbi Anglong, Udalguri, Darrang, Kamrup, Nalbari, Dima Hasao, Nagaon and Golaghat districts. Whereas in remaining districts, the number of rainy days lies in the range of 14.8 to 19.3 days.

It can be seen that in the month of August the maximum number of rainy days lies in the range of 16.8 to 19 days especially in some parts of Karimganj, Hailakandi, Cachar and Lakhimpur districts (Figure 9). Minimum number of rainy days lies in the range of 11 to 12.8 days especially in some parts of Golaghat, Karbi Anglong, Hojai, West Karbi Anglong, Baksa, Udalguri, Sonitpur, Nalbari, Kamrup and Darrang districts. Whereas in remaining districts, the number of rainy days lies in the range of 12.8 to 16.8 days.

In the month of September (Figure 10) the maximum number of rainy days lies in the range of 13.6 to 15 days especially in some parts of Karimganj, Hailakandi, Cachar, Lakhimpur, Dhemaji, Dibrugarh and Tinsukia districts. While minimum number of rainy days lies in the range of 9 to 10.6 days especially in some parts of Baksa, Udalguri, Sonitpur, Nalbari, Golaghat, Hojai, Karbi Anglong, Kamrup and Darrang districts. Whereas in remaining districts, the number of rainy days lies in the range of 10.6 to 13.6 days.

During June to September (Figure 11) the maximum number of rainy days lies in the range of 62.3 to 68 days especially in some parts of Cachar, Hailakandi, Lakhimpur and Dhemaji districts. While minimum number of rainy days lies in the range of 40 to 45.7 days especially in some parts of Baksa, Udalguri, Nalbari, Kamrup, Darrang, Golaghat, Karbi Anglong, Hojai, Nagaon and West Karbi Anglong districts. Whereas in remaining districts, the number of rainy days lies in the range of 45.7 to 62.3 days.

During the entire year the maximum number of rainy days lies in the range of 102 to 112 days especially in some parts of Cachar, Hailakandi, Lakhimpur, Dhemaji, Dibrugarh and Tinsukia districts (Figure 12). Minimum number of rainy days lies in the range of 67 to 76.2 days especially in some parts of Golaghat, Karbi Anglong, Hojai, Dima Hasao, West Karbi Anglong, Nagaon, Udalguri, Darrang, Kamrup and Goalpara districts. Whereas in remaining districts, the number of rainy days lies in the range of 76.2 to 102 days.

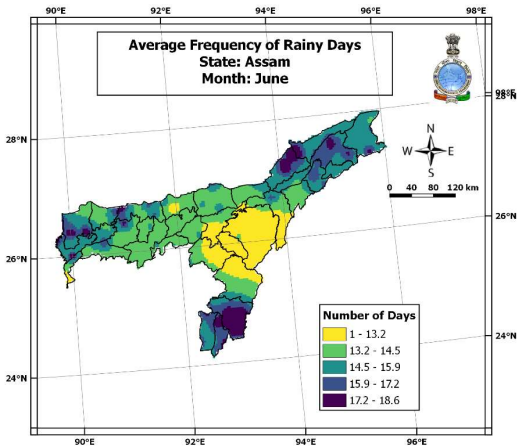


Fig. 7 Average frequency of rainy days: June

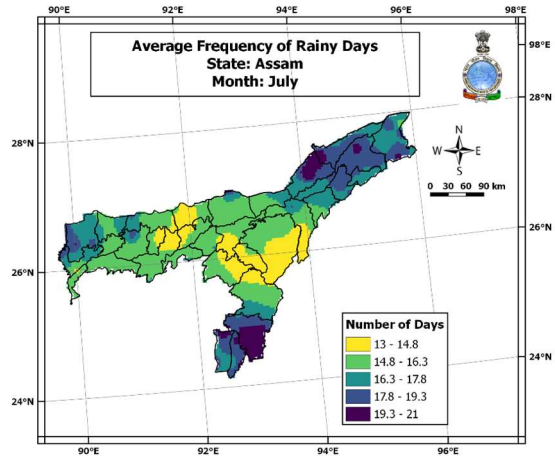


Fig. 8 Average frequency of rainy days: July

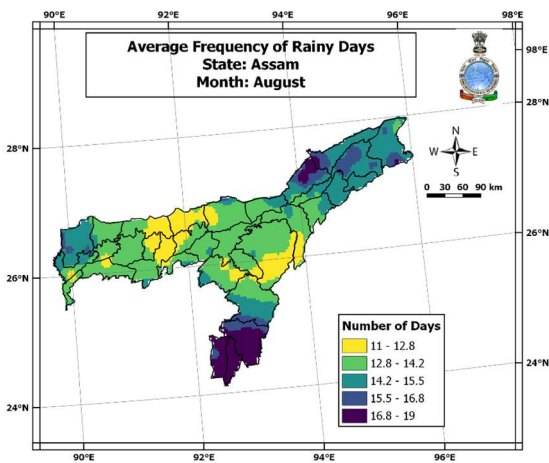


Fig. 9 Average frequency of rainy days: August

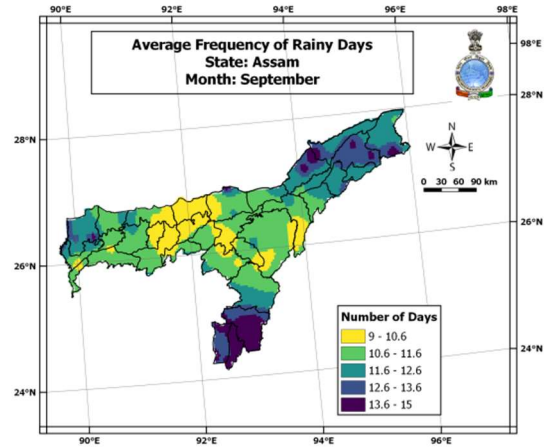


Fig. 10 Average frequency of rainy days: September

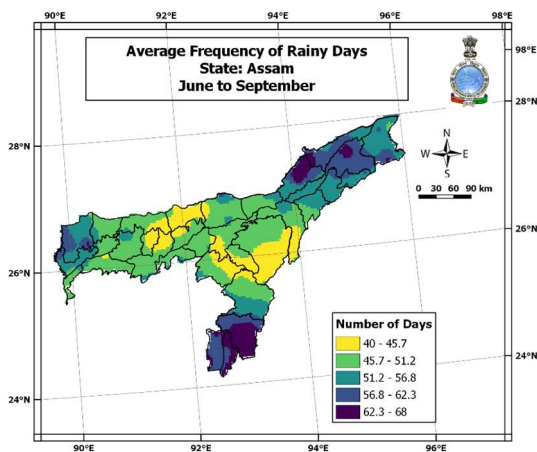


Fig. 11 Average frequency of rainy days: JJAS

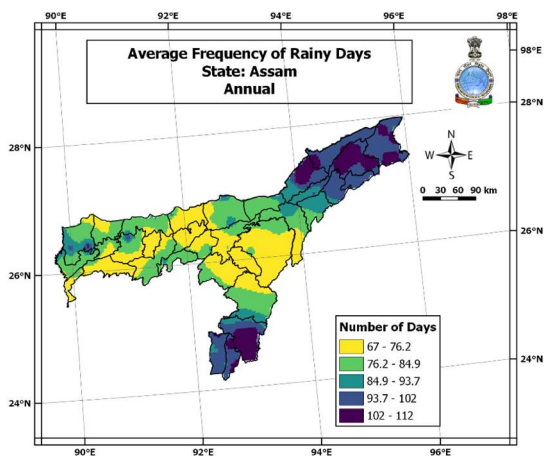


Fig. 12 Average frequency of rainy days: Annual

5.2 Average frequency of Heavy rainfall days

The average frequency of Heavy rainfall days is calculated for Assam for June, July, August, September, June to September and Annual. As shown in Figure 13, 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 Kokrajhar, Chirang, Baksa and Lakhimpur districts. While minimum number of Heavy rainfall days lies in the range of 0.4 to 0.91 days especially in some parts of Tinsukia, Charaideo, Sivasagar, Majuli, Jorhat, Golaghat, Karbi Anglong, Hojai, Nagaon, Morigaon, West Karbi Anglong and Dima Hasaodistricts. Whereas in remaining districts, the number of Heavy rainfall days lies in the range of 0.91 to 2.35 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 2.5 to 3 days especially in some parts of Dhubri, Kokrajhar, Chirang, Baksa Lakhimpur and Dhemaji districts. While minimum number of Heavy rainfall days lies in the range of 0.5 to 1.06 days especially in some parts of Golaghat, Karbi Anglong, Hojai, Nagaon, Morigaon, West Karbi Anglong, Dima Hasao, Jorhat and Majuli districts. Whereas in remaining districts, the number of Heavy rainfall days lies in the range of 1.06 to 2.5 days.

In the month of August the maximum number of heavy rainfall days (Figure 15) lies in the range of 1.89 to 3 days especially in some parts of Kokrajhar, Chirang, Baksa, Lakhimpur and Dhemaji districts. While minimum number of Heavy rainfall days lies in the range of 0.5 to 0.88 days especially in some parts of Golaghat, Karbi Anglong, Hojai, Nagaon, Morigaon, West Karbi Anglong, Dima Hasao, Jorhat, Sivasagar, Kamrup and Dibrugarh districts. Whereas in remaining districts, the number of Heavy rainfall days lies in the range of 0.88 to 1.89 days.

Figure 16 shows that during September the maximum number of heavy rainfall days lies in the range of 1.36 to 2 days especially in some parts of Kokrajhar, Chirang, Baksa, Sonitpur, Lakhimpur and Dhemaji districts. While minimum number of Heavy rainfall days lies in the range of 0.3 to 0.62 days especially in some parts of Golaghat, Karbi Anglong, Hojai, Nagaon, Morigaon, West Karbi Anglong, Dima Hasao, Jorhat, Sonitpur, Udalguri and Kamrup districts. Whereas in remaining districts, the number of Heavy rainfall days lies in the range of 0.62 to 1.36 days.

During June to September, as per Figure 17, the maximum number of heavy rainfall days lies in the range of 7.37 to 9 days especially in some parts of Kokrajhar, Dhubri, Chirang, Baksa, Lakhimpur and Dhemaji districts. While minimum number of Heavy rainfall days lies in the range of 1 to 3.2 days especially in some parts of Golaghat, Karbi Anglong, Hojai, Nagaon, Morigaon, West Karbi Anglong, Dima Hasao, Jorhat, Sonitpur, Udalguri, Nalbari, Kamrup, Sivasagar and Dibrugarh districts. Whereas in remaining districts, the number of Heavy rainfall days lies in the range of 3.2 to 7.37 days.

During the entire year, the maximum number of heavy rainfall days (Figure 18) lies in the range of 8.97 to 11 days especially in some parts of Kokrajhar, Dhubri, Chirang, Baksa, Sonitpur, Lakhimpur and

Dhemaji districts. While minimum number of Heavy rainfall days lies in the range of 2 to 4.02 days especially in some parts of Golaghat, Karbi Anglong, Hojai, Nagaon, Morigaon, West Karbi Anglong, Dima Hasao, Jorhat, Sonitpur, Udalguri, Charaideo, Sivasagar and Majuli districts. Whereas in remaining districts, the number of Heavy rainfall days lies in the range of 4.02 to 8.97 days.

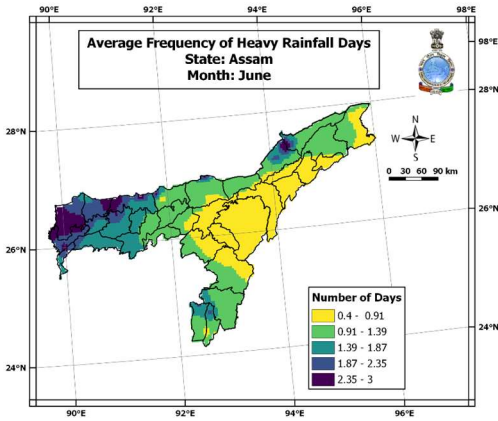


Fig. 13 Average frequency of heavy rainfall days: June

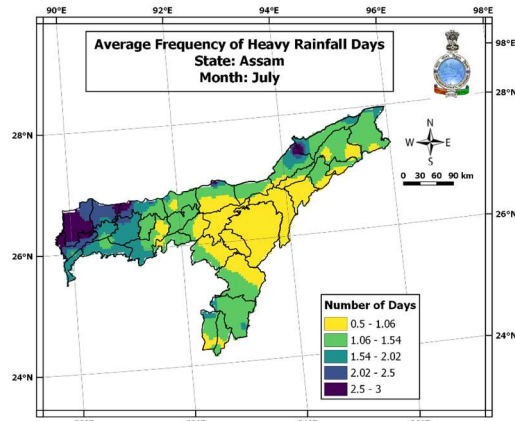


Fig. 14 Average frequency of heavy rainfall days: July

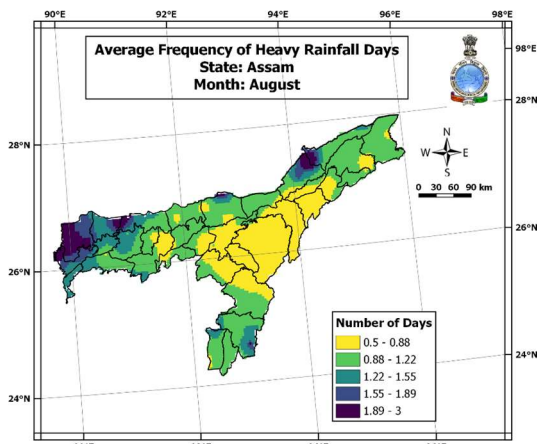


Fig. 15 Average frequency of heavy rainfall days: August

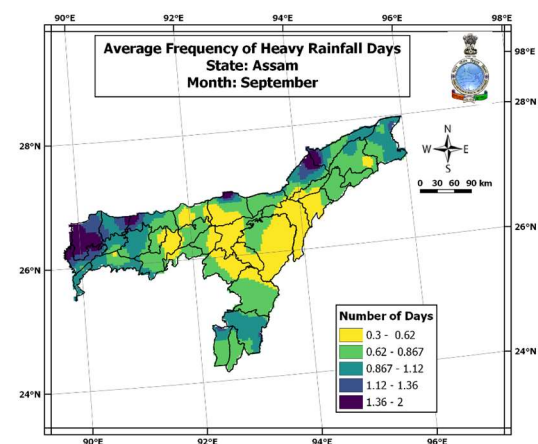


Fig. 16 Average frequency of heavy rainfall days: September

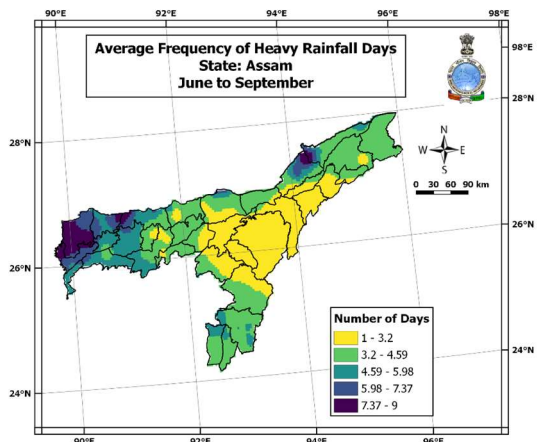


Fig. 17 Average frequency of heavy rainfall days: JJAS

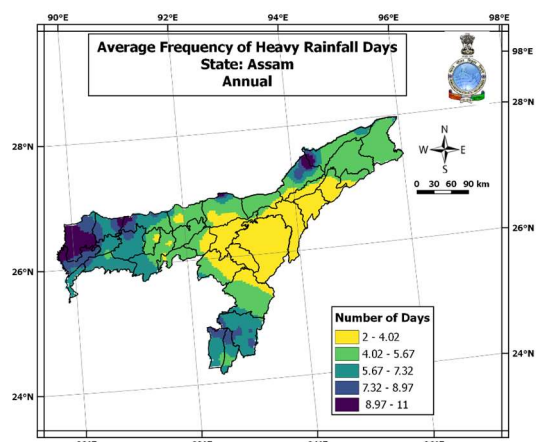


Fig. 18 Average frequency of heavy rainfall days: Annual

5.3 Average frequency of Dry days

The average frequency of dry days is calculated for Assam for June, July, August, September, June to September and Annual. As shown in Figure 19, that in the month of June the maximum number of dry days lies in the range of 13.4 to 15 days especially in some parts of Golaghat, Karbi Anglong, Hojai, Dima Hasao and West Karbi Anglong districts. While minimum number of dry days lies in the range of 7 to 9.19 days especially in some parts of Lakhimpur, Dibrugarh, Cachar and Kokrajhar districts. Whereas in remaining districts, the number of dry days lies in the range of 9.19 to 13.4 days.

Figure 20 shows that in the month of July the maximum number of dry days lies in the range of 12.6 to 15 days especially in some parts of Golaghat, Karbi Anglong, Hojai, Udalguri and Sonitpur districts. While minimum number of dry days lies in the range of 6 to 7.99 days especially in some parts of Cachar, Hailakandi, Lakhimpur and Dibrugarh districts. Whereas in remaining districts, the number of dry days lies in the range of 7.99 to 12.6 days.

In the month of August (Figure 21), the maximum number of dry days lies in the range of 14.6 to 17 days especially in some parts of Karbi Anglong, Golaghat, Baksa, Udalguri and Sonitpur districts. While minimum number of dry days lies in the range of 8 to 10.3 days especially in some parts of Cachar, Hailakandi and Lakhimpur districts. Whereas in remaining districts, the number of dry days lies in the range of 10.3 to 14.6 days.

As seen in the Figure 22, in the month of September the maximum number of dry days lies in the range of 16.27 to 18 days especially in some parts of Baksa, Udalguri, Sonitpur and Karbi Anglong districts. While minimum number of dry days lies in the range of 12 to 13.09 days especially in some parts of Cachar, Hailakandi, Dibrugarh and Lakhimpur districts. Whereas in remaining districts, the number of dry days lies in the range of 13.09 to 16.27 days.

During June to September, as per Figure 23, the maximum number of dry days lies in the range of 49.3 to 54 days especially in some parts of Karbi Anglong, Golaghat, Hojai, Dima Hasao, Udalguri, Sonitpur, Darrang and Kamrup districts. While minimum number of dry days lies in the range of 33 to 37.5 days especially in some parts of Cachar, Hailakandi, Lakhimpur and Dibrugarh districts. Whereas in remaining districts, the number of dry days lies in the range of 37.5 to 49.3 days.

As seen in the Figure 24, during the entire year the maximum number of dry days lies in the range of 223.5 to 230 days especially in some parts of Biswanath, Karbi Anglong, Hojai, West Karbi Anglong, Dima Hasao, Kamrup, Baksa, Chirang and Kokrajhar districts. While minimum number of dry days lies in the range of 198 to 204.7 days especially in some parts of Cachar, Lakhimpur, Dibrugarh, Tinsukia and Sonitpur districts. Whereas in remaining districts, the number of dry days lies in the range of 204.7 to 223.5 days.

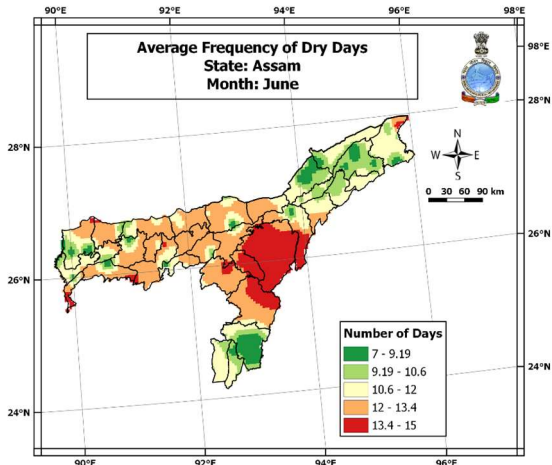


Fig. 19 Average frequency of dry days: June

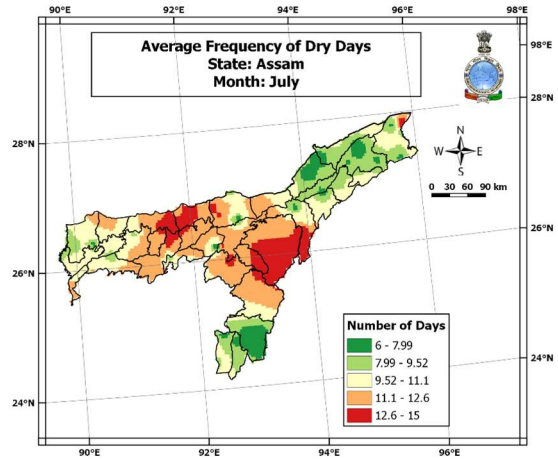


Fig. 20 Average frequency of dry days: July

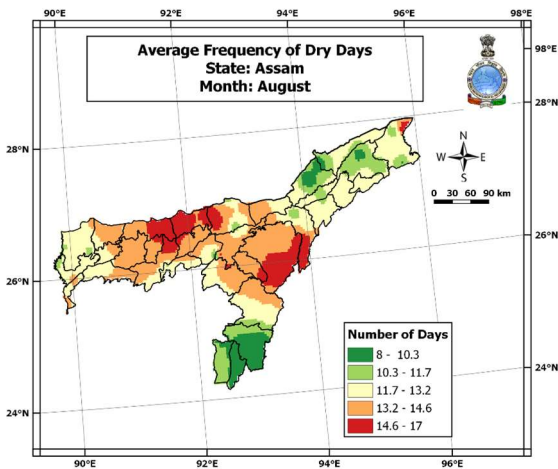


Fig. 21 Average frequency of dry days: August

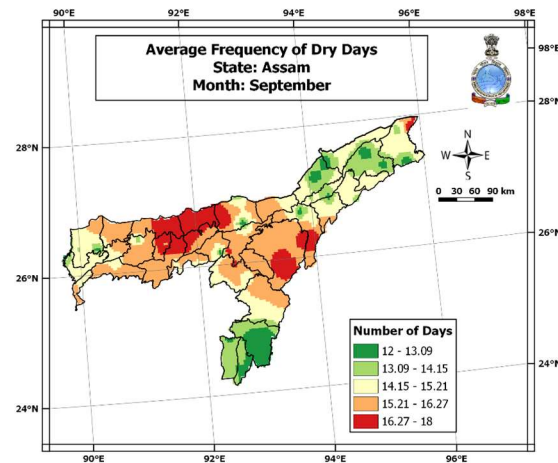


Fig. 22 Average frequency of dry days: September

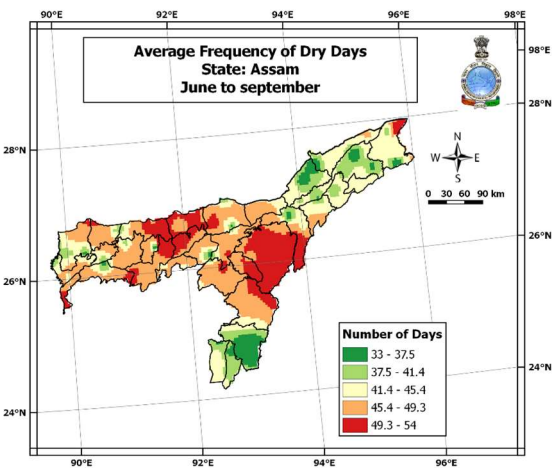


Fig. 23 Average frequency of dry days: JJAS

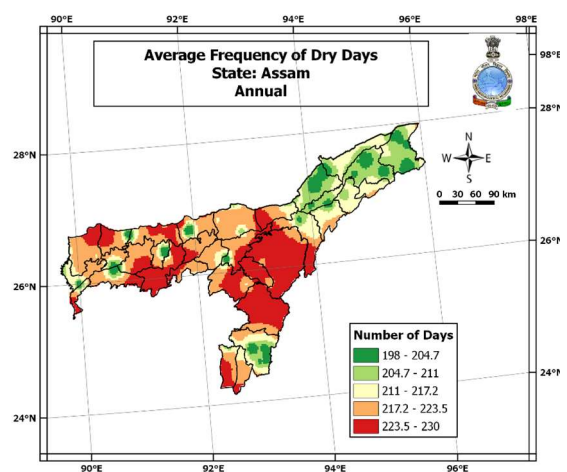


Fig. 24 Average frequency of dry days: Annual

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 raingauge stations of Assam for June, July, August, September, June to September and Annual. It can be seen from the Figure 25, that in the month of June there is a significant increase in Rainy days in stations in KarbiAnglong districts. Whereas there is a significant decrease in Rainy days in stations in Hailakandi, Udalguri, Sonitpur and Tinsukia districts. While remaining districts did not show any significant change.

In the month of July (Figure 26), there is no significant increase in Rainy days in any district. Whereas there is a significant decrease in Rainy days in stations in Karimganj, Hailakandi, Dhubri, Goalpara, Nalbari, Udalguri, West Karbi Anglong, Charaideo, Tinsukia districts. While remaining districts did not show any significant change.

As seen in Figure 27, in the month of August there is a significant increase in Rainy days in stations in Goalpara districts. Whereas there is a significant decrease in Rainy days in stations in Nalbari, West Karbi Anglong, Sivasagar districts. While remaining districts did not show any significant change.

Figure 28 shows that in the month of September there is a significant increase in Rainy days in stations in Goalpara, Nalbari districts. Whereas there is a significant decrease in Rainy days in stations in Hailakandi, Sonitpur, Nagaon, Golaghat, Dibrugarh districts. While remaining districts did not show any significant change.

It can be seen from the Figure 29, that in the months of June to September there is a significant increase in Rainy days in stations in Hojai, Nagaon, Goalpara districts. Whereas there is a significant decrease in Rainy days in stations in Hailakandi, Cachar, Kokrajhar, Barpeta, Baksa, Udalguri, Sonitpur, Morigaon, Golaghat, Majuli, Jorhat, Sivasagar, Dibrugarh, Tinsukia districts. While remaining districts did not show any significant change.

During the entire year (Figure 30), there is a significant increase in Rainy days in Dhubri, Goalpara, Kamrup, Nagaon, Hojai, Cachar districts. Whereas there is a significant decrease in Rainy days in Hailakandi, Cachar, Kokrajhar, Barpeta, Baksa, Udalguri, Sonitpur, Morigaon, Nagaon, West KarbiAnglong, Golaghat, Lakhimpur, Sivasagar, Dibrugarh, Tinsukia districts. While remaining districts did not show any significant change.

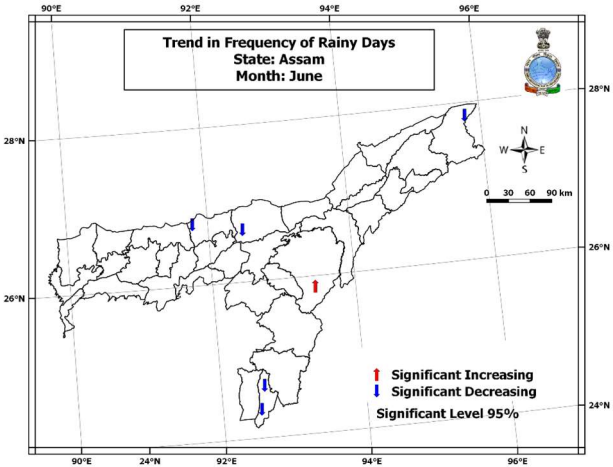


Fig. 25 Trend in frequency of rainy days: June

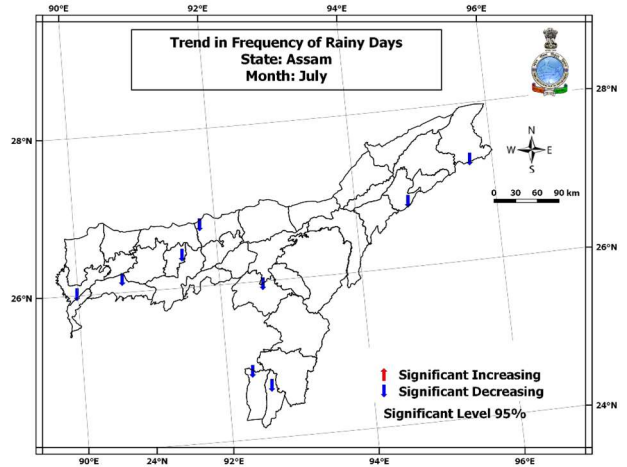


Fig. 26 Trend in frequency of rainy days: July

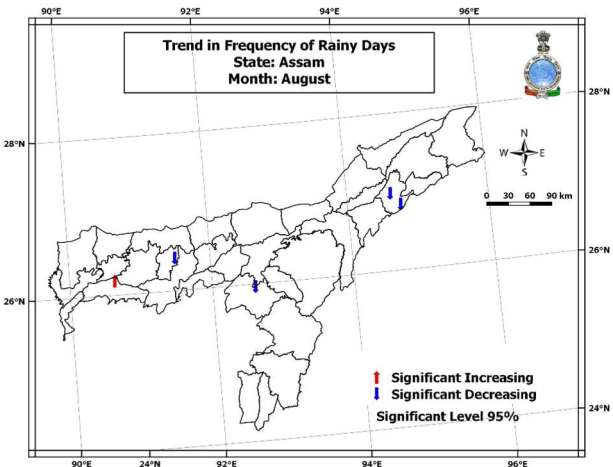


Fig. 27 Trend in frequency of rainy days: August

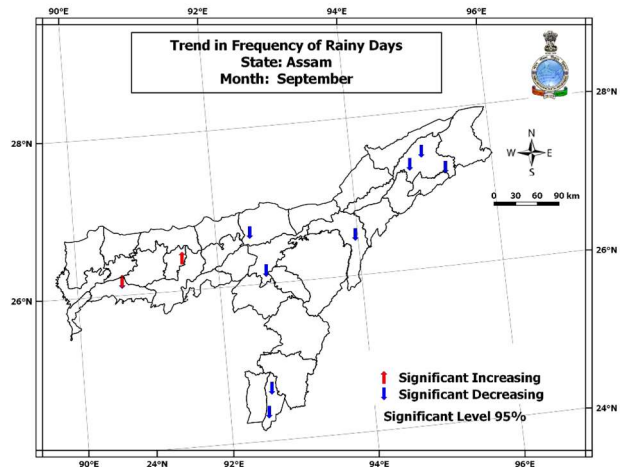


Fig. 28 Trend in frequency of rainy days: September

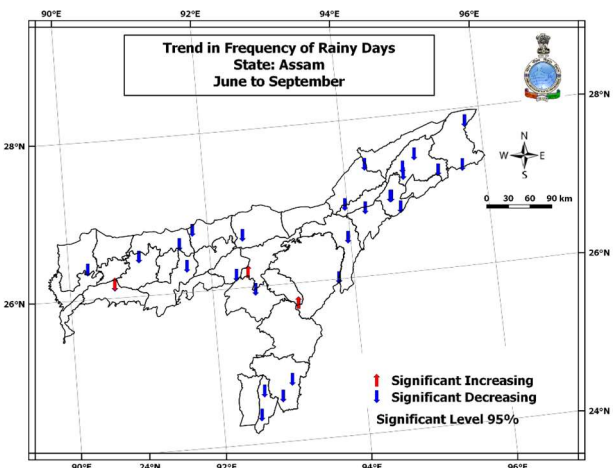


Fig. 29 Trend in frequency of rainy days: JJAS

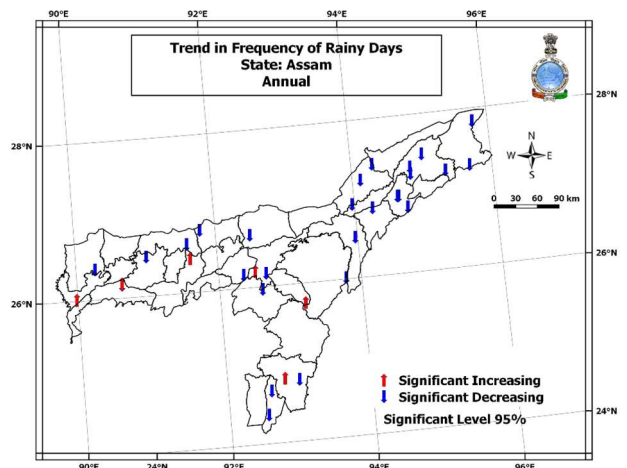


Fig. 30 Trend in frequency of rainy days: Annual

6.2 Trend in frequency of Heavy rainfall days

The Trend in frequency of Heavy days is calculated for Assam for June, July, August, September, June to September and Annual. It can be seen from Figure 31 that in the month of June there is a significant increase in Heavy rainfall days in Golaghat and Sivasagar districts. Whereas there is a significant decrease in Heavy days in Udalguri, Tinsukia districts. While remaining districts did not show any significant change.

Figure 32 shows that in the month of July there is a significant increase in Heavy rainfall days in Golaghat district. Whereas there is a significant decrease in Heavy rainfall days in Dhubri, Goalpara, Kamrup, West Karbi Anglong, Nagaon, Karbi Anglong, Jorhat, Dibrugarh districts. While remaining districts did not show any significant change.

In the month of August (Figure 33) there is a significant increase in Heavy rainfall days in Sivasagar, Goalpara districts. Whereas there is a significant decrease in Heavy rainfall days in Baksa, Nagaon, West Karbi Anglong, Golaghat districts. While remaining districts did not show any significant change.

From Figure 34, it is seen that in the month of September there is a significant increase in Heavy rainfall days in Sonitpur, Karbi Anglong, Sivasagar districts. Whereas there is a significant decrease in Heavy rainfall days in Karimganj, Goalpara, West Karbi Anglong, Golaghat, Dibrugarh districts. While remaining districts did not show any significant change.

As per Figure 35, during June to September there is a significant increase in Heavy rainfall days in Goalpara, Golaghat districts. Whereas there is a significant decrease in Heavy rainfall days in Karimganj, Cachar, Karbi Anglong, West Karbi Anglong, Nagaon, Sonitpur, Tinsukia districts. While remaining districts did not show any significant change.

During the entire year (Figure 36) there is a significant increase in Heavy rainfall days in Goalpara, Golaghat, Hojai districts. Whereas there is a significant decrease in Heavy rainfall days in Hailakandi, Cachar, West Karbi Anglong, Nagaon, Sonitpur, Tinsukia districts. While remaining districts did not show any significant change.

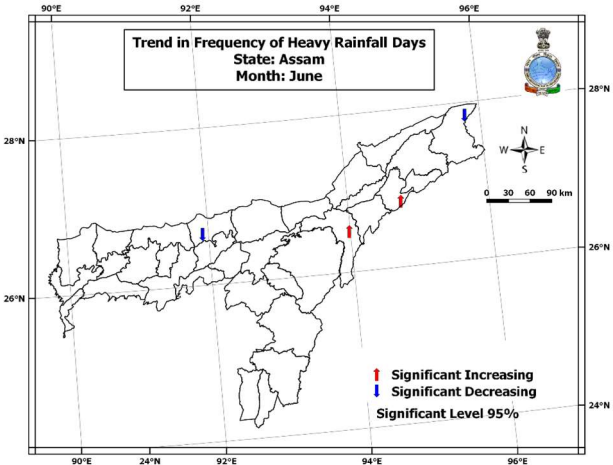


Fig.31 Trend in frequency of heavy rainfall days: June

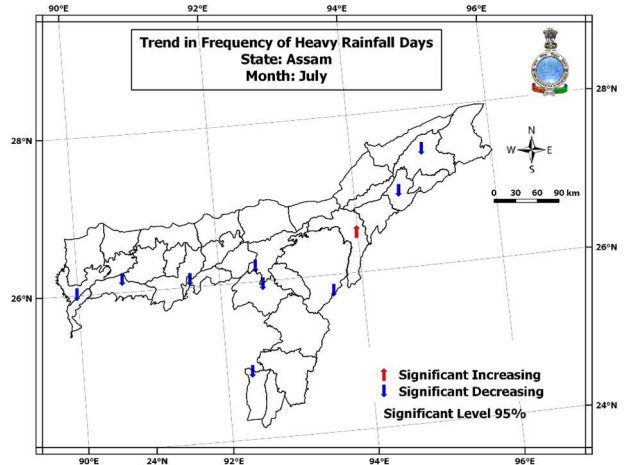


Fig. 32 Trend in frequency of heavy rainfall days: June

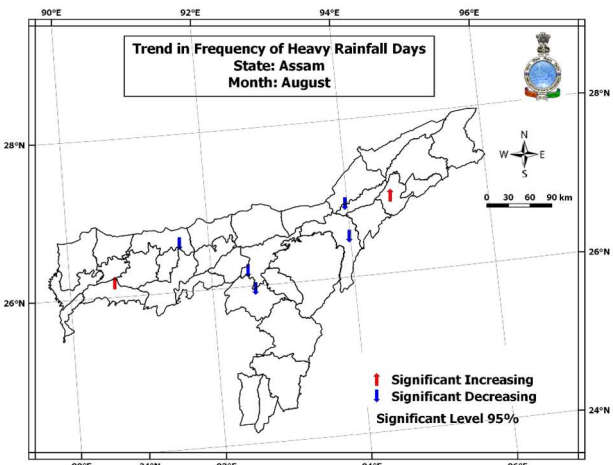


Fig. 33 Trend in frequency of heavy rainfall days: August

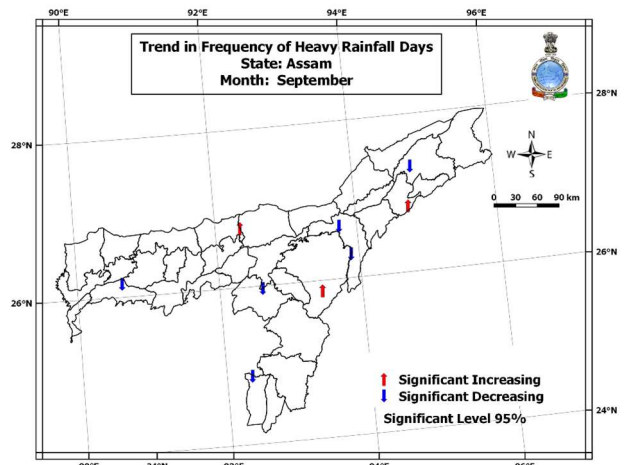


Fig. 34 Trend in frequency of heavy rainfall days: September

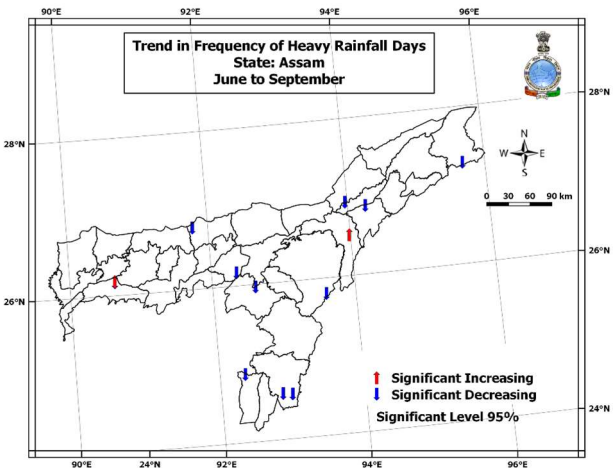


Fig. 35 Trend in frequency of heavy rainfall days: JJAS

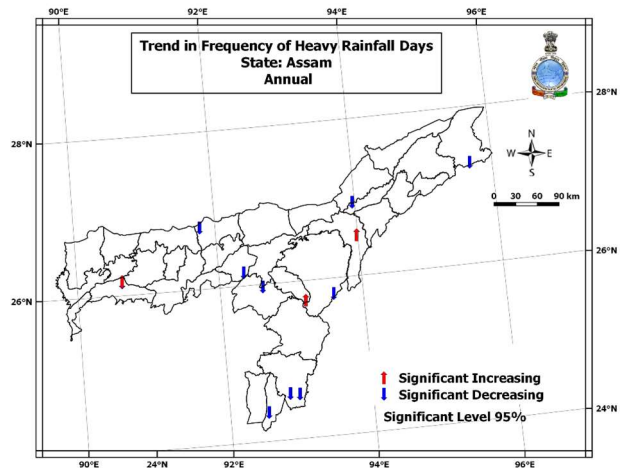


Fig. 36 Trend in frequency of heavy rainfall days: Annual

6.3 Trend in frequency of Dry days

The Trend in frequency of dry days is calculated for Assam for June, July, August, September, June to September and Annual. As shown in Figure 37, in the month of June there is a significant increase in dry days in Goalpara, Hailakandi, Sonitpur, Golaghat, Sivasagar, Tinsukia districts. Whereas there is a significant decrease in dry days in Kokrajhar, Kamrup, Karbi Anglong, Hojai districts. While remaining districts did not show any significant change.

Figure 38 shows that in the month of July there is a significant increase in dry days in Goalpara, West Karbi Anglong, Karimganj, Hailakandi, Golaghat, Majuli, Sivasagar, Dibrugarh, Tinsukia districts. Whereas there is a significant decrease in dry days in Baksa, Udalguri districts. While remaining districts did not show any significant change.

In the month of August (Figure 39) there is a significant increase in dry days in Hailakandi, West Karbi Anglong, Karbi Anglong, Golaghat, Sivasagar, Dibrugarh districts. Whereas there is a significant decrease in dry days in Sonitpur district. While remaining districts did not show any significant change.

As per Figure 40, in the month of September there is a significant increase in dry days in Goalpara, Udalguri, Nagaon, Sonitpur, Hailakandi, Golaghat, Sivasagar, Dibrugarh districts. Whereas there is a significant decrease in dry days in Udalguri districts. While remaining districts did not show any significant change.

It can be seen from Figure 41, that in the month of June to September there is a significant increase in dry days in Hailakandi, Nalbari, Nagaon, Hojai, Golaghat, Dibrugarh, Tinsukia districts. Whereas there is a significant decrease in dry days in Kokrajhar district. While remaining districts did not show any significant change.

During the entire year (Figure 42) there is a significant increase in dry days in Dhubri, Goalpara, Nalbari, Kamrup, Udalguri, Golaghat, Lakhimpur, Dibrugarh, Tinsukia districts. Whereas there is a significant decrease in dry days in Cachar, Baksa, Tinsukia districts. While remaining districts did not show any significant change.

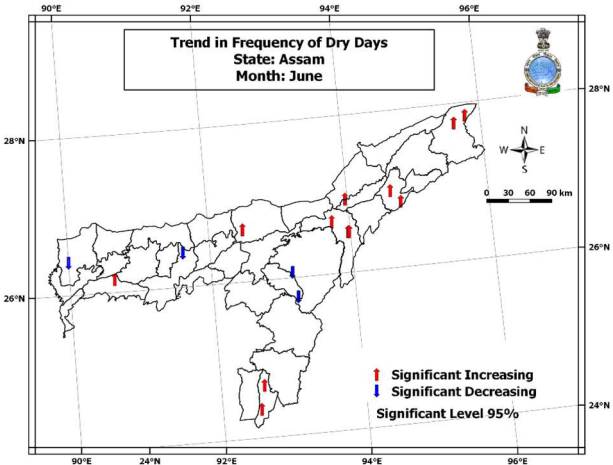


Fig. 37 Trend in frequency of dry days: June

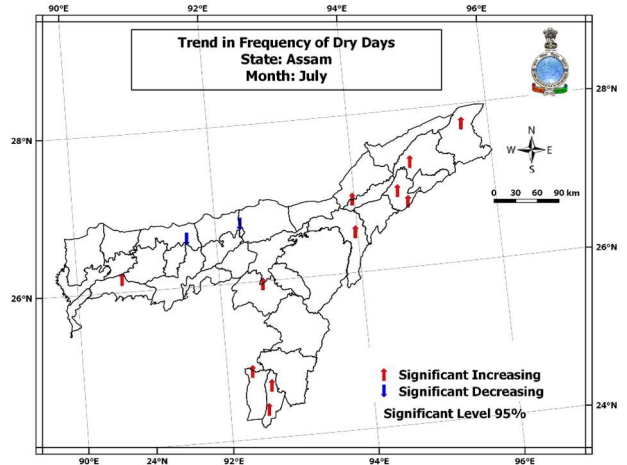


Fig. 38 Trend in frequency of dry days: July

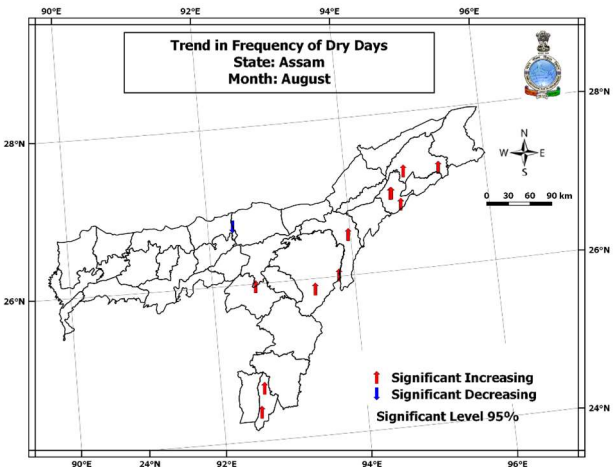


Fig. 39 Trend in frequency of dry days: August

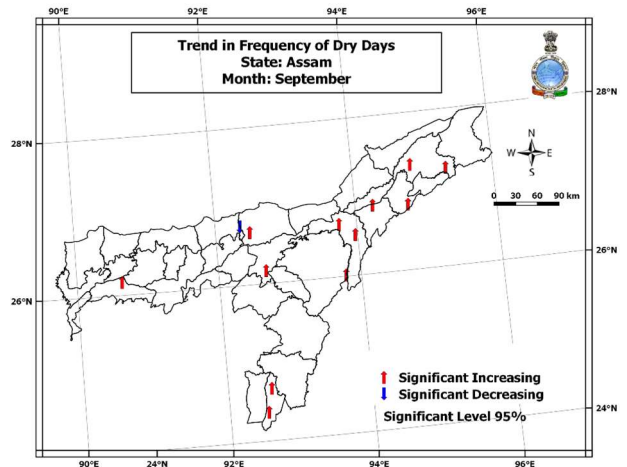


Fig. 40 Trend in frequency of dry days: September

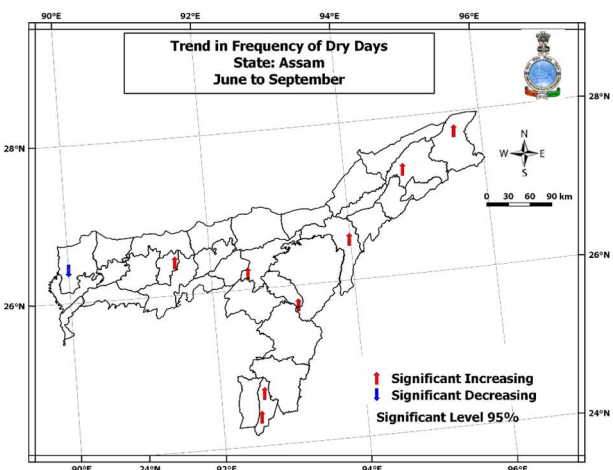


Fig. 41 Trend in frequency of dry days: JJAS

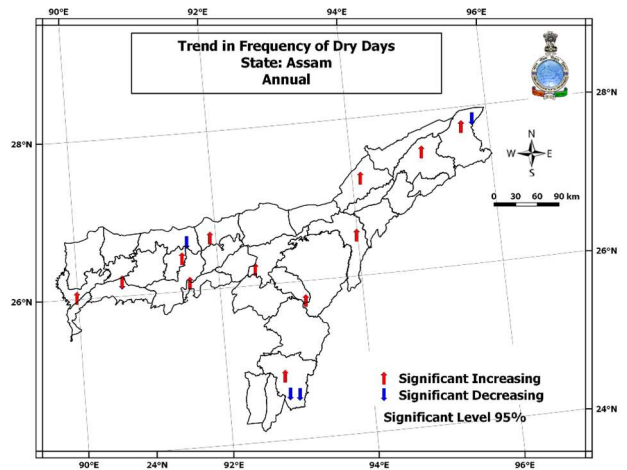


Fig. 42 Trend in frequency of dry days: Annual

7. Conclusions

In the present study, we have investigated the rainfall pattern and its variability and 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 and agricultural managements. Some of the important results can be summarized as:

- Assam gets maximum rainfall in July and August (29% of SW monsoon rainfall) followed by September (24% of SW monsoon rainfall).
- 66% of annual rainfall received during southwest monsoon rainfall (June –September).
- Kokrajhar district of Assam receive 73% of annual rainfall in SW monsoon season while Kabri Anglong and Karimganj, Solapur districts receive 64-65% of annual rainfall in SW monsoon season.
- No significant increasing/decreasing trends observed in June, July, August, September monthly rainfall.
- Maximum rainfall receive during the SW monsoon season over the districts in Kokrajhar and Karimganj districts (2100-2500mm) while Kabri Anglong receive lowest rainfall (800-900mm).
- Minimum rainfall received during the year over the Kabri Anglong district (1300mm-1400mm).
- During the whole southwest monsoon season no district has shown significant increasing trend whereas Dhubri, South Salimara Mankachar, Golaghat, Hailakandi and Morigaon have shown significant decreasing trend.
- For the annual rainfall Dhubri, South Salimara Mankachar, Golaghat, Hailakandi, Karbi Anglong, Hojai, Morigaon, Nagaon and West Karbi Anglong show significant decreasing trend while no district showed significant increasing trend.
- Maximum number of rainy days lies in the range of 62.3 to 68 days (daily rainfall \geq 2.5mm) out of 122 days of SW monsoon season especially in some parts of Cachar, Hailakandi, Lakhimpur and Dhemaji districts. While minimum number of

rainy days lies in the range of 40 to 45.7 days especially in some parts of Baksa, Udalguri, Nalbari, Kamrup, Darrang, Golaghat, Karbi Anglong, Hojai, Nagaon and West Karbi Anglong districts. Whereas in remaining districts, the number of rainy days lies in the range of 45.7 to 62.3 days.

- For heavy to extremely heavy rainfall (daily rainfall $\geq 6.5\text{mm}$) the maximum number of heavy rainfall days lies in the range of 7.37 to 9 days especially in some parts of Kokrajhar, Dhubri, Chirang, Baksa, Lakhimpur and Dhemaji districts. While minimum number of Heavy rainfall days lies in the range of 1 to 3.2 days especially in some parts of Golaghat, Karbi Anglong, Hojai, Nagaon, Morigaon, West Karbi Anglong, Dima Hasao, Jorhat, Sonitpur, Udalguri, Nalbari, Kamrup, Sivasagar and Dibrugarh districts. Whereas in remaining districts, the number of Heavy rainfall days lies in the range of 3.2 to 7.37 days.
- the maximum number of dry days lies in the range of 49.3 to 54 days especially in some parts of Karbi Anglong, Golaghat, Hojai, Dima Hasao, Udalguri, Sonitpur, Darrang and Kamrup districts. While minimum number of dry days lies in the range of 33 to 37.5 days especially in some parts of Cachar, Hailakandi, Lakhimpur and Dibrugarh districts. Whereas in remaining districts, the number of dry days lies in the range of 37.5 to 49.3 days.
- During the entire year the maximum number of dry days lies in the range of 223.5 to 230 days especially in some parts of Biswanath, Karbi Anglong, Hojai, West Karbi Anglong, Dima Hasao, Kamrup, Baksa, Chirang and Kokrajhar districts. While minimum number of dry days lies in the range of 198 to 204.7 days especially in some parts of Cachar, Lakhimpur, Dibrugarh, Tinsukia and Sonitpur districts. Whereas in remaining districts, the number of dry days lies in the range of 204.7 to 223.5 days.
- In the months of June to September there is a significant increase in Rainy days in stations in Hojai, Nagaon, Goalpara districts. Whereas there is a significant decrease in Rainy days in stations in Hailakandi, Cachar, Kokrajhar, Barpeta, Baksa, Udalguri, Sonitpur, Morigaon, Golaghat, Majuli, Jorhat, Sivasagar, Dibrugarh, Tinsukia districts. While remaining districts did not show any significant change.
- During the entire year (Figure 30), there is a significant increase in Rainy days in Dhubri, Goalpara, Kamrup, Nagaon, Hojai, Cachar districts. Whereas there is a

significant decrease in Rainy days in Hailakandi, Cachar, Kokrajhar, Barpeta, Baksa, Udalguri, Sonitpur, Morigaon, Nagaon, West Karbi Anglong, Golaghat, Lakhimpur, Sivasagar, Dibrugarh, Tinsukia districts. While remaining districts did not show any significant change.

- During June to September there is a significant increase in Heavy rainfall days in Goalpara, Golaghat districts. Whereas there is a significant decrease in Heavy rainfall days in Karimganj, Cachar, Karbi Anglong, West Karbi Anglong, Nagaon, Sonitpur, Tinsukia districts. While remaining districts did not show any significant change.
- During the entire year there is a significant increase in Heavy rainfall days in Goalpara, Golaghat, Hojai districts. Whereas there is a significant decrease in Heavy rainfall days in Hailakandi, Cachar, West Karbi Anglong, Nagaon, Sonitpur, Tinsukia districts. While remaining districts did not show any significant change.
- In the month of June to September there is a significant increase in dry days in Hailakandi, Nalbari, Nagaon, Hojai, Golaghat, Dibrugarh, Tinsukia districts. Whereas there is a significant decrease in dry days in Kokrajhar district. While remaining districts did not show any significant change.
- During the entire year there is a significant increase in dry days in Dhubri, Goalpara, Nalbari, Kamrup, Udalguri, Golaghat, Lakhimpur, Dibrugarh, Tinsukia districts. Whereas there is a significant decrease in dry days in Cachar, Baksa, Tinsukia districts. While remaining districts did not show any significant change.

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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.

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HYDROMETEOROLOGY SECTION
CLIMATE APPLICATION AND USER INTERFACE GROUP
CLIMATE RESEARCH AND SERVICES, PUNE**