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Climate Research and Services (CRS) Division, Pune

Observed Monsoon Rainfall Variability and Changes during Recent 30 years (1989-2018)

HIGHLIGHTS

- India Meteorological Department (IMD) has carried out an analysis of observed monsoon rainfall variability and changes of 29 States & Union Territory at State and District levels based on the IMD's observational data of recent 30 years (1989-2018) during the Southwest monsoon season from June to September (JJAS). The reports on observed rainfall variability and its trend for each State and Union Territory are available in IMD website (https://mausam.imd.gov.in/) under "PUBLICATIONS" as well as in IMD Pune website http://www.imdpune.gov.in/hydrology/rainfall%20variability%20page/rainfall%20trend.html
- Five states viz., Uttar Pradesh, Bihar, West Bengal, Meghalaya and Nagaland have shown significant decreasing trends in southwest monsoon rainfall during the recent 30 years period (1989-2018).
- The annual rainfall over these five states along with the states of Arunachal Pradesh and Himachal Pradesh also show significant decreasing trends.
- Other states do not show any significant changes in southwest monsoon rainfall during the same period.
- Considering district-wise rainfall, there are many districts in the country, which show significant changes in southwest monsoon and annual rainfall during the recent 30 years period (1989-2018).
- With regard to the frequency of heavy rainfall days, significant increasing trend is observed over Saurashtra & Kutch, Southeastern parts of Rajasthan, Northern parts of Tamil Nadu, Northern parts of Andhra Pradesh and adjoining areas of Southwest Odisha, many parts of Chhattisgarh, Southwest Madhya Pradesh, West Bengal, Manipur & Mizoram, Konkan & Goa and Uttarakhand.

The JJAS monsoon rainfall shows high temporal and spatial variability. Further, in view of ongoing climate changes there have been significant changes in the mean rainfall pattern and their variability, exclusively in terms of the intensity and frequencies of heavy rainfall events. Considering

all these, IMD has analysed the observed monsoon rainfall variability and changes of 29 States & Union Territory at State and District levels based on the IMD's observational data of recent 30 years (1989-2018) during the Southwest monsoon season from June to September (JJAS). The reports for each State and Union Territory are available in IMD website (https://mausam.imd.gov.in/) and IMD Pune website (http://www.imdpune.gov.in/). The report brings out the spatial pattern of the mean rainfall as well as different categories of rainfall events like dry days, rainy days and heavy rainfall days during the monsoon months and year as a whole for each state. The salient features of the reports are described below in terms of mean rainfall, trends in rainfall and intensity of rainfall.

(i) Mean rainfall :-

- Mean monthly (June, July, August and September), monsoon season (JJAS) and annual rainfall (mm) over each state & Union Territory during monsoon season and their contribution to annual rainfall are shown in **Fig. 1** and **Annexure I** based on the data of 1989-2018
- The maximum monsoon seasonal rainfall is reported over Goa state with 2878.0 mm followed by 2702.4 mm over Meghalaya.
- Similarly, the lowest monsoon rainfall of 311.7 mm is reported over Tamil Nadu followed by 414.2 mm over Rajasthan.
- Over major states of central India, the mean rainfall ranges from 800 mm to 1400 mm.
- About 60% to 90% of total annual rainfall occur during the monsoon season (June to September) over different states, except Tamil Nadu, which contributes only about 35% to the annual rainfall during monsoon season (**Annexure I**).

(ii) Trend in District rainfall and State Rainfall

- The linear trends of monsoon seasonal rainfall as well as annual rainfall at district level for the period 1989-2018 are shown in **Fig. 2(a-b)** respectively. The corresponding list of districts with significant increasing and decreasing trends during the monsoon season and year as a whole are also listed in **Annexure II**.
- Based on these districts level rainfall data, the state level trends in rainfall are also analyzed. Only five states viz. Uttar Pradesh Bihar, West Bengal, Meghalaya and Nagaland have shown significant decreasing trends in southwest monsoon rainfall. Other states do not show any significant changes in monsoon rainfall. All these five states along with two more states viz. Arunachal Pradesh and Himachal Pradesh have also shown significant decreasing trends in annual rainfall.
- Considering different monsoon months, Arunachal Pradesh, Meghalaya and West Bengal in June; Meghalaya in July; Nagaland in August and Uttar Pradesh & Nagaland in September show significant decreasing trend in rainfall. Goa is the only state which shows significant increasing trend of rainfall in September. No state has shown any significant increasing trend in

rainfall in remaining months as well as during the southwest monsoon season JJAS and year as a whole.

(iii) Mean frequency of dry days, rainy days and heavy rainfall days

- The mean patterns of dry days (No rain in a day), rainy days (rainfall of amount 2.5 mm or more but less than 6.5 cm) and heavy rainfall days (rainfall of amount 6.5 cm or more) based on the recent 30 years of data from IMD (1989-2018) during the monsoon season JJAS are shown in **Fig.3 (a-c)** respectively.
- The main region of dry days includes northwest India and south-eastern coastal regions of India, whereas the rainy days are just the opposite being highest over west coast and northeast states (**Fig.3a-b**).
- The number of heavy rainfall days (**Fig. 3c**) is higher over the west coast, northeastern states, northern parts of Uttar Pradesh, Bihar and central parts of India covering West Bengal, Jharkhand, Odisha, Chhattisgarh, Madhya Pradesh and Gujarat.

(iv) Trend in frequency of dry days, rainy days and heavy rainfall days

The linear trends of frequency of dry days, rainy days and heavy rainfall days are shown in **Figs. 4 (a-c)** respectively. The highlights of these trends are given below.

- ***Trend in dry days***

There is significant increasing trend in the number of dry days during monsoon season over south coastal regions of Andhra Pradesh, Bihar, northern parts of Chhattisgarh, Jharkhand, Madhya Pradesh, Odisha, Tamilnadu, Uttar Pradesh and West Bengal (**Fig.4a**). During year as a whole, all these states along with Telangana also show significant increasing trends in dry days, whereas Gujarat, Karnataka, Maharashtra, Rajasthan and Punjab states show significant decreasing trends in dry days.

- ***Trend in rainy days***

The frequency of rainy days (**Fig. 4b**) indicates significant increasing trends over Rajasthan, Gujarat, Maharashtra, Andhra Pradesh, northern parts of Madhya Pradesh and parts of Odisha and Chhattisgarh, whereas significant decreasing trends are seen over Uttar Pradesh, Bihar, Jharkhand, Punjab and northeastern parts of the country.

- ***Trend in heavy rainfall days***

With regard to the frequency of heavy rainfall days, significant increasing trend is observed over Saurashtra & Kutch, Southeastern parts of Rajasthan, Northern parts of Tamil Nadu, Northern parts of Andhra Pradesh and adjoining areas of Southwest Odisha, many parts of Chhattisgarh, Southwest Madhya Pradesh, West Bengal, Manipur & Mizoram, Konkan & Goa and Uttarakhand.

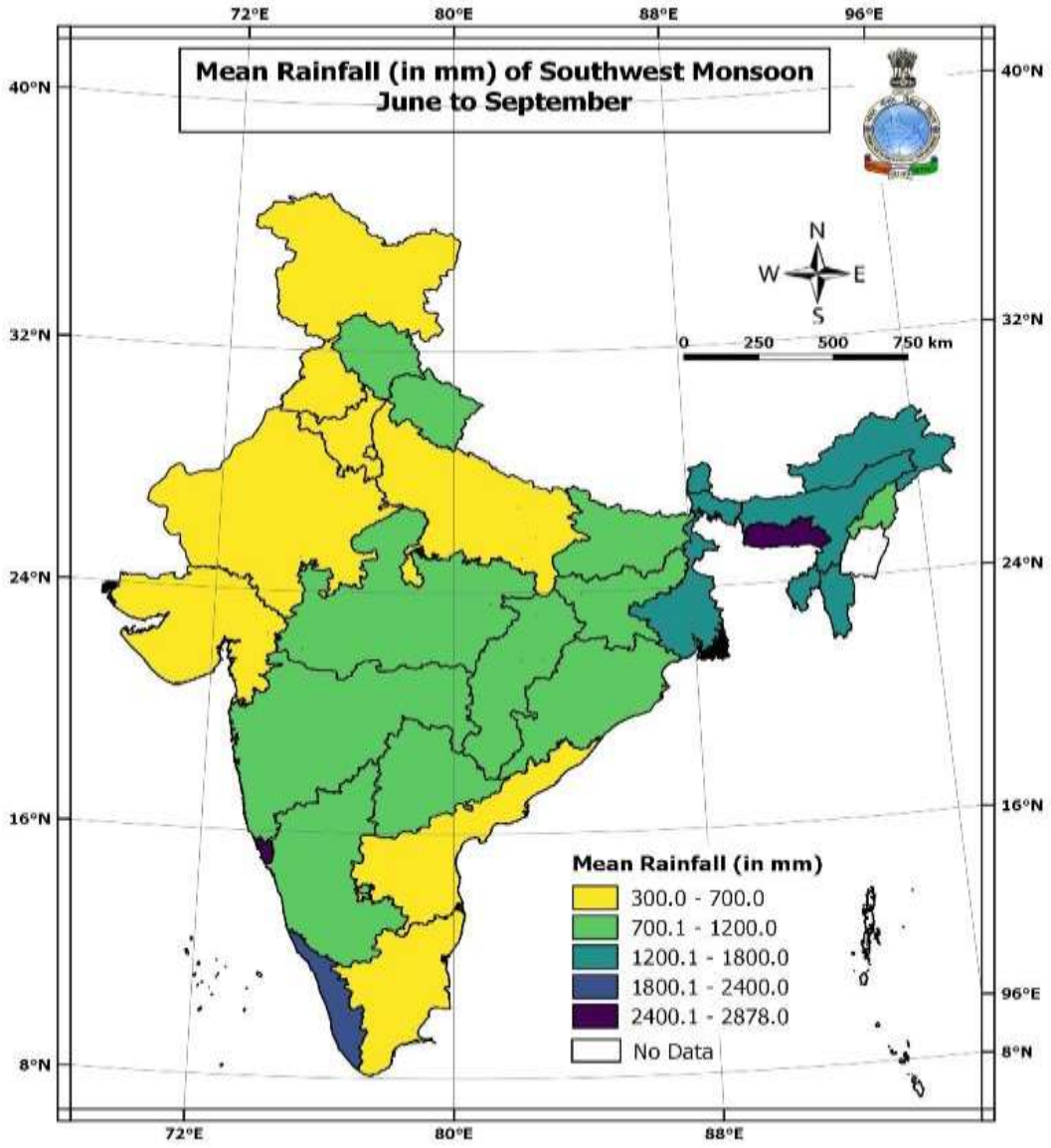


Fig. 1 : Mean southwest monsoon seasonal rainfall (mm) over different States of India based on 1989-2018

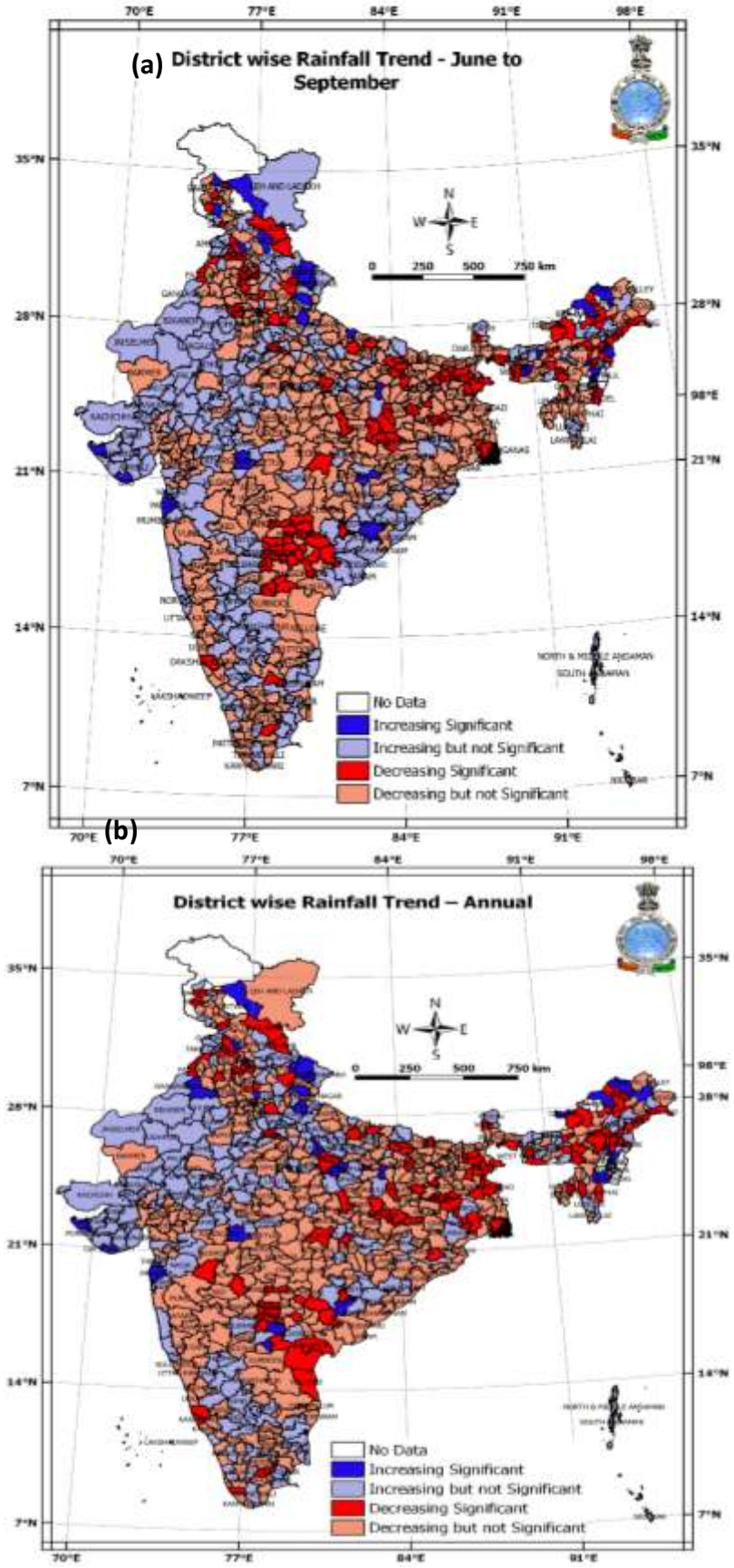
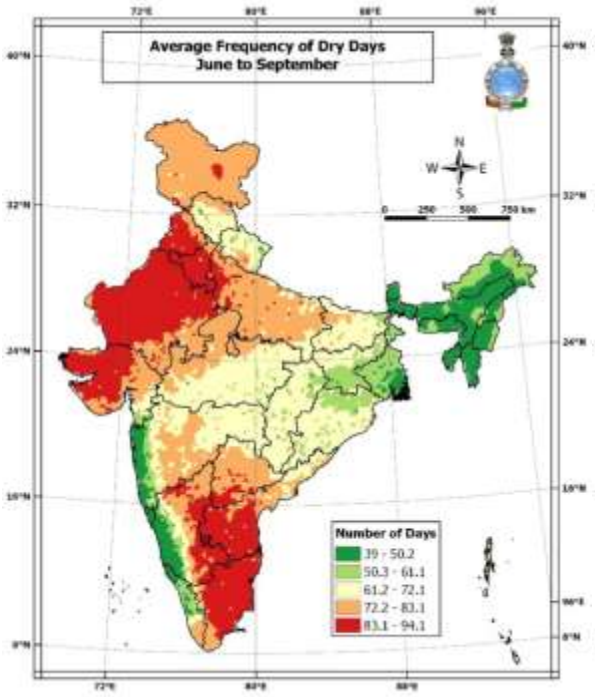
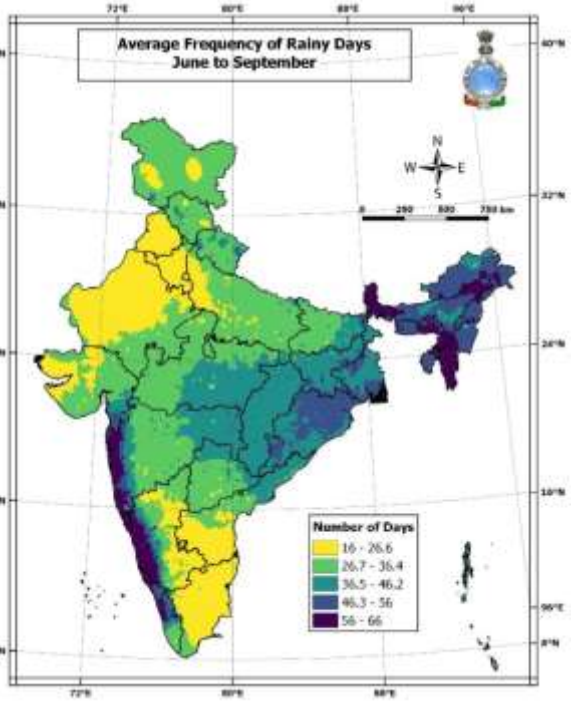


Fig. 2 : Trend in district rainfall during (a) monsoon season (JJAS) and (b) annual rainfall during the period, 1989-2018.

(a) Mean dry days



(b) Mean rainy days



(c) Mean heavy rainfall days

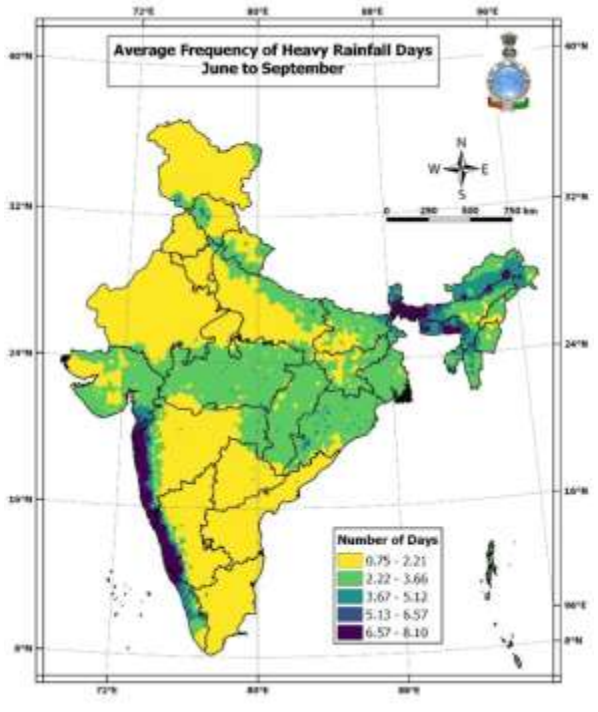
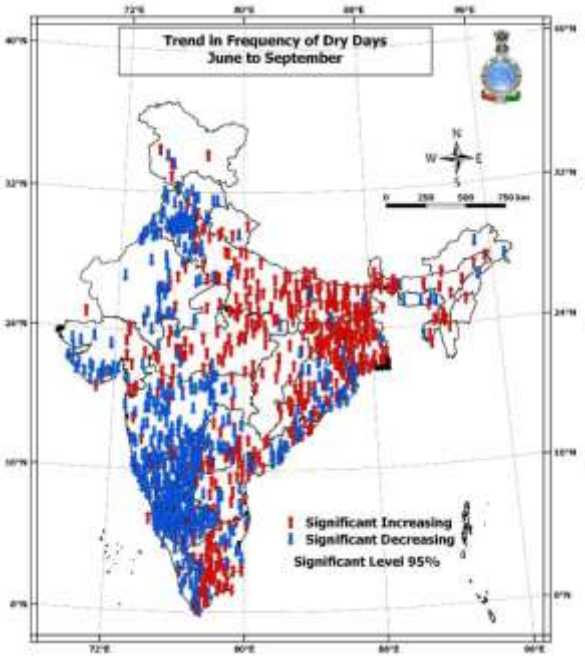
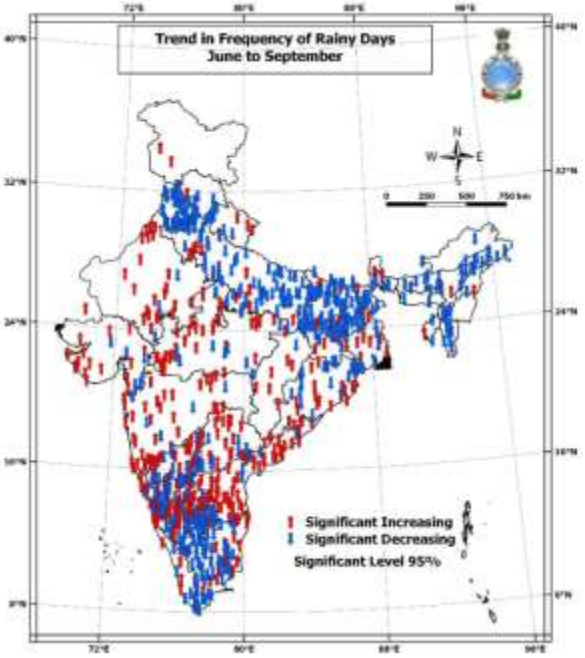


Fig. 3 : Mean patterns of (a) dry days (No rain in a day), (b) rainy days (rainfall of amount 2.5 mm or more but less than 6.5 cm) and heavy rainfall days (rainfall of amount more than or equal to 6.5 cm) based on the IMD data of 1989-2018.

(a) Trend in dry days



(b) Trend in rainy days



(c) Trend in heavy rainfall days

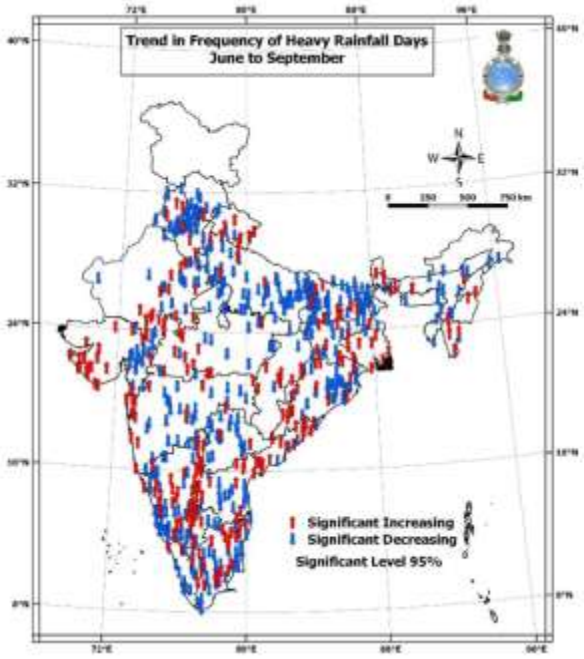


Fig. 4 : Significant trends in the frequency of dry days, rainy days (daily rainfall of 2.5 mm or more but less than 6.5 cm) and heavy rainfall days (rainfall greater than or equal to 6.5 cm) in terms of increasing or decreasing trends based on the IMD data of 1989-2018.

Annexure – I : Mean monthly, season (JJAS) and annual rainfall (mm) over each state & Union Territory during monsoon season and their contribution to annual rainfall

State		June	July	August	September		JJAS	Annual
Andhra Pradesh	Mean (mm)	96.3	127.5	142.5	146.3	Mean (mm)	512.6	903.6
	% of JJAS	18.8	24.9	27.8	28.5	% of Annual	56.7	
Arunachal Pradesh	Mean (mm)	485.6	526.8	389.0	360.9	Mean (mm)	1762.3	2741.6
	% of JJAS	27.6	29.9	22.1	20.5	% of Annual	64.3	
Assam	Mean (mm)	400.8	401.4	332.5	265.0	Mean (mm)	1399.8	2134.6
	% of JJAS	28.6	28.7	23.8	18.9	% of Annual	65.6	
Bihar	Mean (mm)	160.2	313.9	264.5	200.1	Mean (mm)	938.7	1098.9
	% of JJAS	17.1	33.4	28.2	21.3	% of Annual	85.4	
Chhattisgarh	Mean (mm)	185.8	373.4	353.1	211.7	Mean (mm)	1124.0	1249.9
	% of JJAS	16.5	33.2	31.4	18.8	% of Annual	89.9	
Delhi	Mean (mm)	69.5	172.7	188.7	122.8	Mean (mm)	553.8	670.7
	% of JJAS	12.6	31.2	34.1	22.2	% of Annual	82.6	
Goa	Mean (mm)	900.4	1029.0	644.0	304.6	Mean (mm)	2878.0	3187.5
	% of JJAS	31.3	35.8	22.4	10.6	% of Annual	90.3	
Gujarat	Mean (mm)	103.5	275.3	193.0	122.9	Mean (mm)	694.7	722.4
	% of JJAS	14.9	39.6	27.8	17.7	% of Annual	96.2	
Haryana	Mean (mm)	57.7	130.9	137.5	84.5	Mean (mm)	410.6	499.7
	% of JJAS	14.0	31.9	33.5	20.6	% of Annual	82.2	
Himachal Pradesh	Mean (mm)	101.4	236.0	248.7	124.1	Mean (mm)	710.3	1163.3
	% of JJAS	14.3	33.2	35.0	17.5	% of Annual	61.1	
Jammu & Kashmir	Mean (mm)	84.1	184.8	178.5	101.2	Mean (mm)	554.5	1256.1
	% of JJAS	15.2	33.3	32.2	18.2	% of Annual	44.1	
Jharkhand	Mean (mm)	190.3	313.9	289.2	225.7	Mean (mm)	1019.1	1211.4
	% of JJAS	18.7	30.8	28.4	22.1	% of Annual	84.1	
Karnataka	Mean (mm)	205.5	269.6	221.2	150.5	Mean (mm)	846.8	1146.9
	% of JJAS	24.3	31.8	26.1	17.8	% of Annual	73.8	
Kerala	Mean (mm)	637.2	642.7	414.8	260.2	Mean (mm)	1954.8	2855.6
	% of JJAS	32.6	32.9	21.2	13.3	% of Annual	68.5	
Maharashtra	Mean (mm)	218.6	341.4	281.1	179.5	Mean (mm)	1020.7	1146.5
	% of JJAS	21.4	33.5	27.5	17.6	% of Annual	89.0	
Meghalaya	Mean (mm)	801.5	825.1	612.6	463.2	Mean (mm)	2702.4	3784.3
	% of JJAS	29.7	30.5	22.7	17.1	% of Annual	71.4	
Mizoram	Mean (mm)	430.6	420.0	447.1	368.8	Mean (mm)	1666.6	2483.2
	% of JJAS	25.8	25.2	26.8	22.1	% of Annual	67.1	
Madhya Pradesh	Mean (mm)	127.4	323.6	304.3	166.2	Mean (mm)	921.4	997.8
	% of JJAS	13.8	35.1	33.0	18.0	% of Annual	92.3	
Nagaland	Mean (mm)	259.1	330.9	303.3	232.7	Mean (mm)	1126.0	1664.6
	% of JJAS	23.0	29.4	26.9	20.7	% of Annual	67.6	
Odissa	Mean (mm)	210.7	349.8	357.3	242.5	Mean (mm)	1160.2	1447.8
	% of JJAS	18.2	30.2	30.8	20.9	% of Annual	80.1	
Punjab	Mean (mm)	60.2	149.1	139.6	79.1	Mean (mm)	427.9	538.6
	% of JJAS	14.1	34.8	32.6	18.5	% of Annual	79.5	
Rajasthan	Mean (mm)	51.5	156.1	144.7	61.9	Mean (mm)	414.2	454.9
	% of JJAS	12.4	37.7	34.9	14.9	% of Annual	91.1	
Sikkim	Mean (mm)	416.4	476.2	417.4	317.1	Mean (mm)	1627.0	2554.8
	% of JJAS	25.6	29.3	25.7	19.5	% of Annual	63.7	
Tamilnadu	Mean (mm)	53.6	64.7	88.0	105.4	Mean (mm)	311.7	898.1
	% of JJAS	17.2	20.7	28.2	33.8	% of Annual	34.7	
Telangana	Mean (mm)	132.7	211.5	217.6	151.4	Mean (mm)	713.2	905.1
	% of JJAS	18.6	29.7	30.5	21.2	% of Annual	78.8	
Tripura	Mean (mm)	436.0	385.4	330.9	270.3	Mean (mm)	1422.6	2380.4
	% of JJAS	30.7	27.1	23.3	19.0	% of Annual	59.8	
Uttar Pradesh	Mean (mm)	96.1	238.6	219.0	142.9	Mean (mm)	696.7	784.1
	% of JJAS	13.8	34.3	31.4	20.5	% of Annual	88.9	
Uttarakhand	Mean (mm)	162.1	382.0	360.2	189.7	Mean (mm)	1093.8	1385.5
	% of JJAS	14.8	34.9	32.9	17.3	% of Annual	78.9	
West Bengal	Mean (mm)	318.0	431.8	361.1	307.7	Mean (mm)	1418.7	1851.4
	% of JJAS	22.4	30.4	25.5	21.7	% of Annual	76.6	

Annexure – II: List of districts with significant increasing and decreasing trends both at district and state levels for the period 1989-2018

Districts showing significant increasing trend in JJAS monsoon rainfall :

Arunachal Pradesh: Upper Siang and Upper Subansiri, **Bihar** : Lakhisarai and West Champaran, **Chhattisgarh:** Mahasamund, **Delhi :** South Delhi, **Gujarat** : Devbhoomi Dwarka and Gir Somnath, **Himachal Pradesh**: Kullu, **J&K :** Bandipora and Riasi, **MP** : Khandwa, **Maharashtra:** Palghar, **Meghalaya**: East Garo Hills, **Nagaland :** Dimapur, Tuensang and Longleng, **Odisha :** Koraput, **UP** : Bareilly, Shravasti and Chandauli, **Uttarakhand :** Nainital, Bageshwar, Chamoli and Rudraprayag.

Districts showing significant decreasing trend in JJAS monsoon rainfall :

Arunachal Pradesh : West Kameng, East Kameng, Papum Pare, Lower Subansiri, West Siang, Central Siang, ChanglangTirap and Longding, **Assam :** Dhubri, South SalimaraMankachar, Golaghat, Hailakandi and Morigaon , **Bihar :** Katihar, Purnia, Madhepura, Saharsa, Khagaria, Begusarai, Bhojpur, Siwan and Gopalganj, **Chhatisgarh** : Jashpur and Surguja, **Delhi :** North West Delhi, North East Delhi, East Delhi, **Haryana :** Panchkula, Ambala, Kaithal, Panipat, Bhiwani, Charkhi Dadri, **Himachal Pradesh** : Lahul&Spiti and Kinnaur, **J&K :** Ganderwal, Badgam, Rajouri, Shopian and Samba, **Jharkand** : Garhwa, Chatra, Koderma, Godda, Sahebganj, Dhanbad, Bokaro and Simdega, **Karnataka :** Dakshin Kannada, **Nagaland :** Mon, Kohima, Mokokchung, Zunheboto and Kiphire, **Punjab :** Hoshiarpur, Jalandhar, Shahid Bhagat Singh Nagar, Ferozepur, Fazilka, Patiala and Fatehgarh Sahib Nagar, **Sikkim** : West Sikkim and South Sikkim, **Tamil Nadu :** Madurai and Dharmapuri, **Telangana :** Warangal, Nirmal, Medak, Siddipet, Jangaon, Suryapet, Wanaparthy, J. Gadwal, Y. Bhuvanagari, B. Kothagudem, J. Bhupalpally, Kamareddy, M. Malkajgiri, Nagar kurnool, Nirmal, Peddapalle, Sangareddy, Vikarabad, Jagtial and Mahabubnagar, **UP :** Ghaziabad, Bulandshahar, Bhimnagar, Agra, Banda, Gonda, Deoria, Ballia and Sidharthanagar **Uttarakhand** : Pauri Garhwal, **West Bengal :** Cooch Behar, Howrah, Malda, South 24 Parganas and Dakshin Dinajpur.

Districts showing significant increasing trend in Annual rainfall (Fig1 B):

Arunachal Pradesh : Upper Siang, Upper Subansiri, Lower Dibang Valley and Tawang, **Bihar** : Lakhisarai and West Champaran, **Chhatisgarh** : Bastar, **Gujarat** : Devbhoomi Dwarka and Gir Somnath, **Himachal Pradesh** : Kullu, **MP :** Khandwa, Maharashtra : Palghar, Nagaland : Dimapur, **Punjab** : SAS Nagar, **Telangana** : Ranga Reddy & Wanaparthy, **UP** : Baghpat, Bareilly, Kanpur, Shahuji Maharaj Nagar, Sant Ravidas Nagar and Chandauli, **Uttarakhand** Nainital, Bageshwar, Chamoli and Rudraprayag,

Districts showing significant decreasing trend in Annual rainfall (Fig1 B) :

Andhra Pradesh : Guntur, Nellore, Prakasam, **Arunachal Pradesh** : West Kameng, East Kameng, Papum Pare, Lower Subansiri, West Siang, Central Siang, Changlang Tirap and Longding, **Assam** Dhubri, South Salimara Mankachar, Golaghat, Hailakandi, Karbi Anglong, Hojai, Morigaon, Nagaon and West Karbi Anglong, **Bihar :** Katihar, Purnia,Siwan, Gopalganj, Bhojpur and Sitamarhi, **Chhatisgarh** Jashpur and Surguja, **Delhi :** North West Delhi, North East Delhi, Central and North West Delhi, **Haryana :** Ambala, Panchkula and Panipat, **Himachal Pradesh** : Chamba, Lahul and Spiti, Kinnaur, **J&K** Baramula, Ganderwal, Poonch and Kathua, **Jharkand** Garhwa, Chatra, Koderma, Godda, Sahebganj, Dhanbad, Bokaro, Ramgarh and Simdega, **Karnataka** : Dakshin Kannada, **Kerala** Kasargod and Kollam, **MP** Balaghat and Shahadol, **Maharashtra :** Aurangabad and Parbhani, **Meghalaya :** West Garo Hills, South Garo Hills, Ri Bhoi, West Jaintia Hills and EastJaintia Hills, **Mizoram** : Mamit and Champhai, **Nagaland:** Mon, Kohima, Mokokchung, Zunheboto and Kiphire, **Odisha** Dhenkanal, **Punjab** : Hoshiarpur, Jalandhar, Shahid Bhagat Singh Nagar, Ferozepur, Fazilka, Patiala and Mansa, **Sikkim** : West Sikkim and South Sikkim, **Tamil Nadu** : Madurai, **Telangana** : B. Kothagudem, J. Bhupalpally, Kamareddy, M. Malkajgiri, Nagar kurnool, Nirmal, Peddapalle, Sangareddy, Vikarabad, Jagtial and Mahabubnagar, **Tripura** : Dhalai **UP** : Shamli, Bulandshahar, Banda, Fatehpur, Gonda, Sidharthnagar and Deoria, **Uttarakhand** : Pauri Garhwal, West Bengal : Cooch Behar, Malda, South 24 Pargana, Murshidabad, Birbhum, Purulia, Jhargram, Pashchim Mednapur and Dakshin Dinajpur.