Characterization of Extreme precipitation over India

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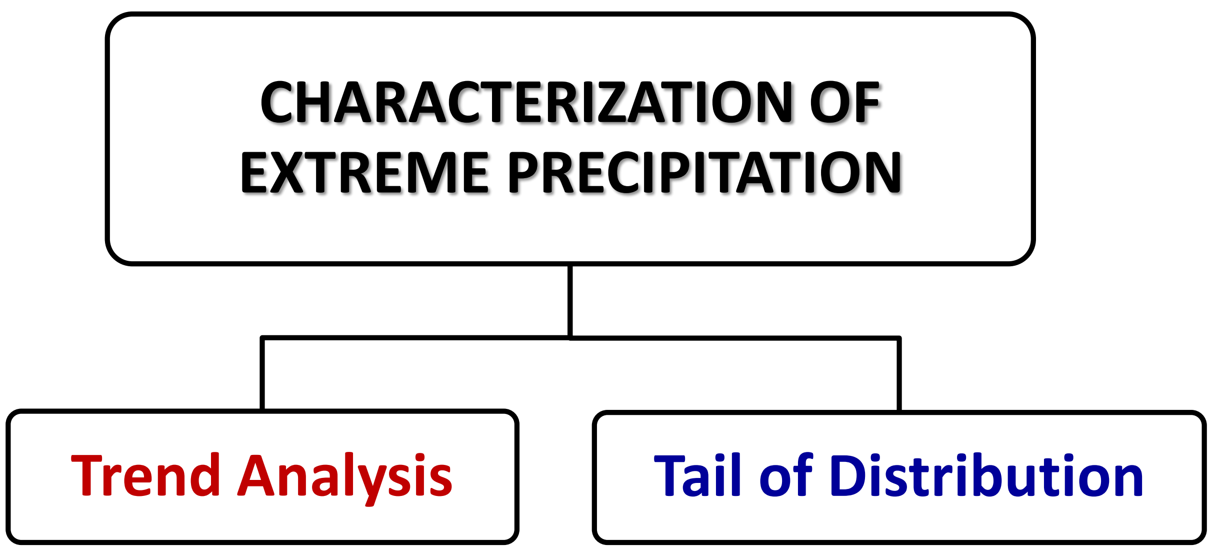
Introduction

- What are extreme events and why do we need to study extreme events
- Why do we need to characterize the Extremes
- How is it done ?



Objectives

1. **To assess presence of potential trends in annual maximum daily precipitation series by using a variety of non-parametric methods**

    - **Monotonic Trend: Original and Modified Mann Kendall (MK) tests, Spearman rank correlation (SRC) and innovative trend analysis (ITA)**
    - **Abrupt change/step : Pettitt's test**
    - **Quantitative assessment of monotonic trend : Sens's slope**

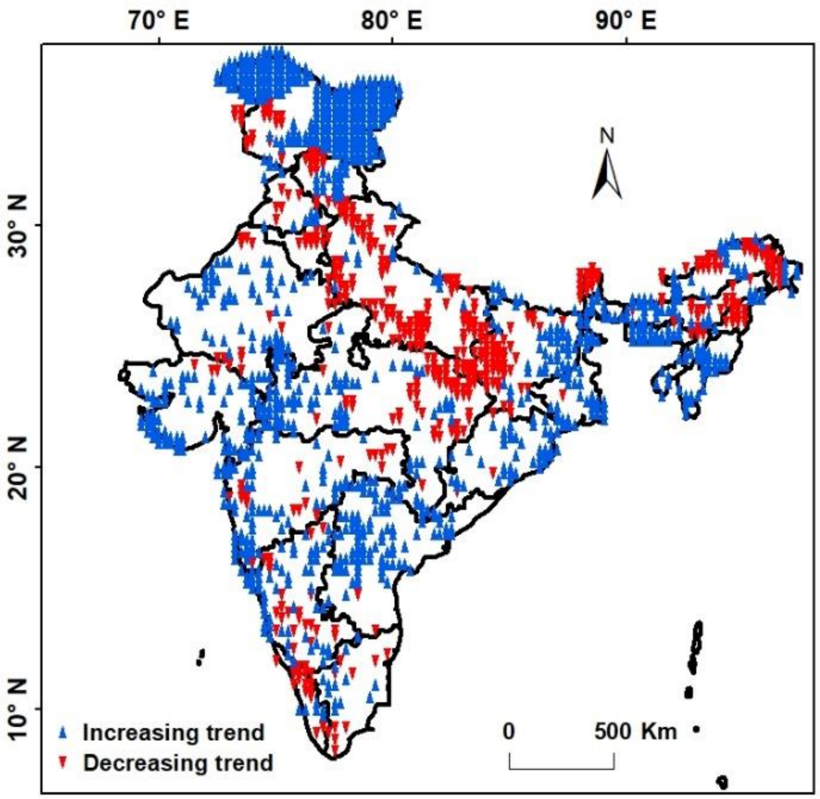
2. **To investigate the upper tail behavior of daily precipitation series**
    - **Using algorithmic diagnostic tool (advanced version of Mean Excess Function)**
    - **Using framework of generalized extreme value (GEV) theory**

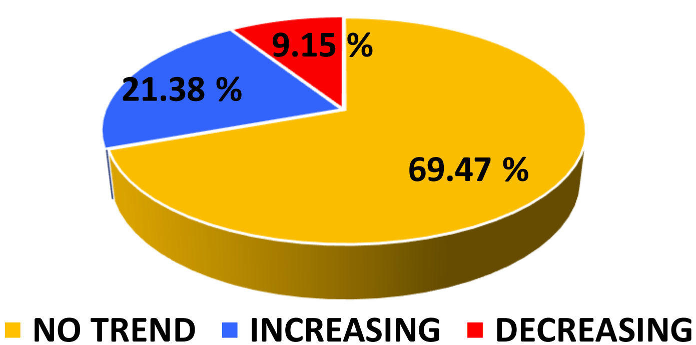
Objective : Trend detection analysis in Annual maximum daily precipitation series

IMD Gridded Dataset (4949 grids)

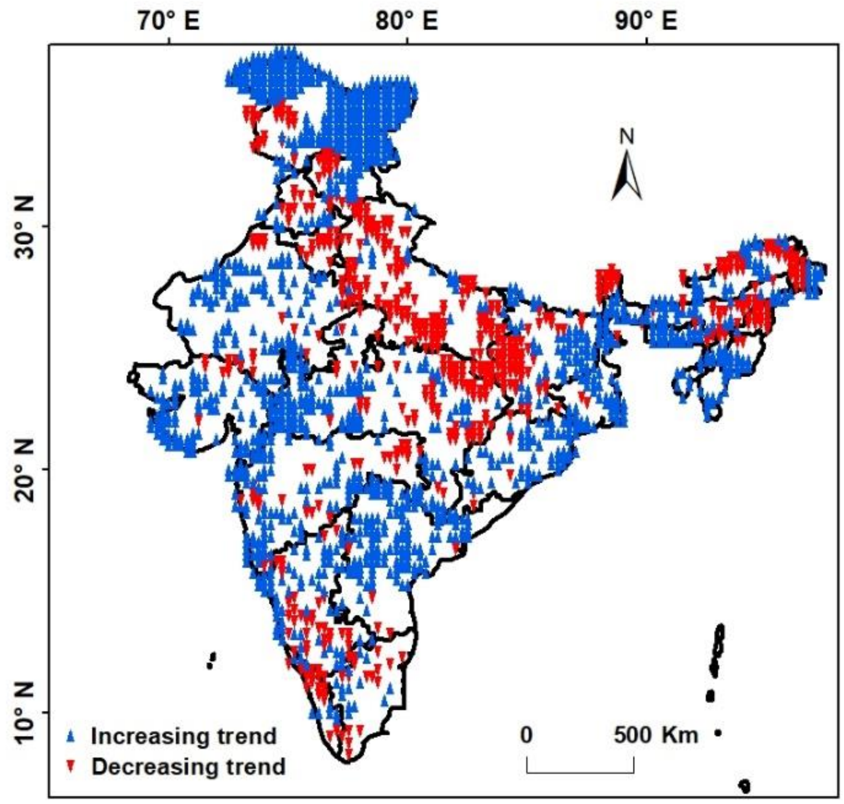
Mann–Kendall test

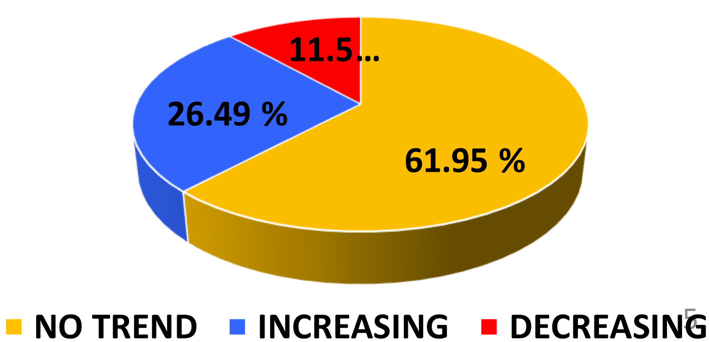
5 % Significance level





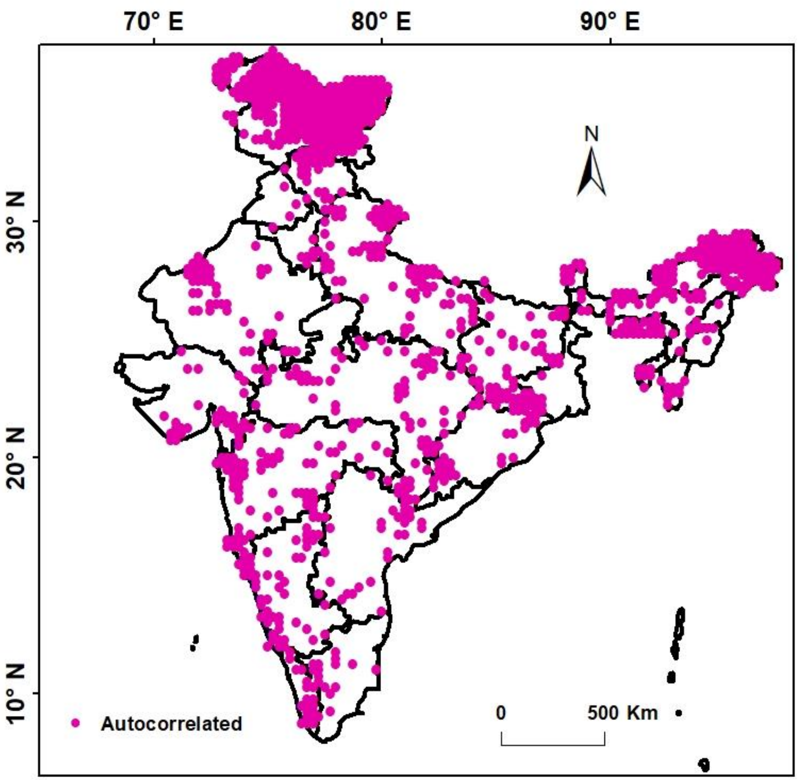
10 % Significance level

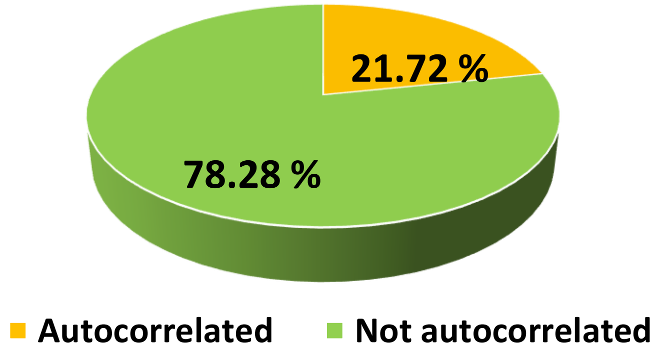




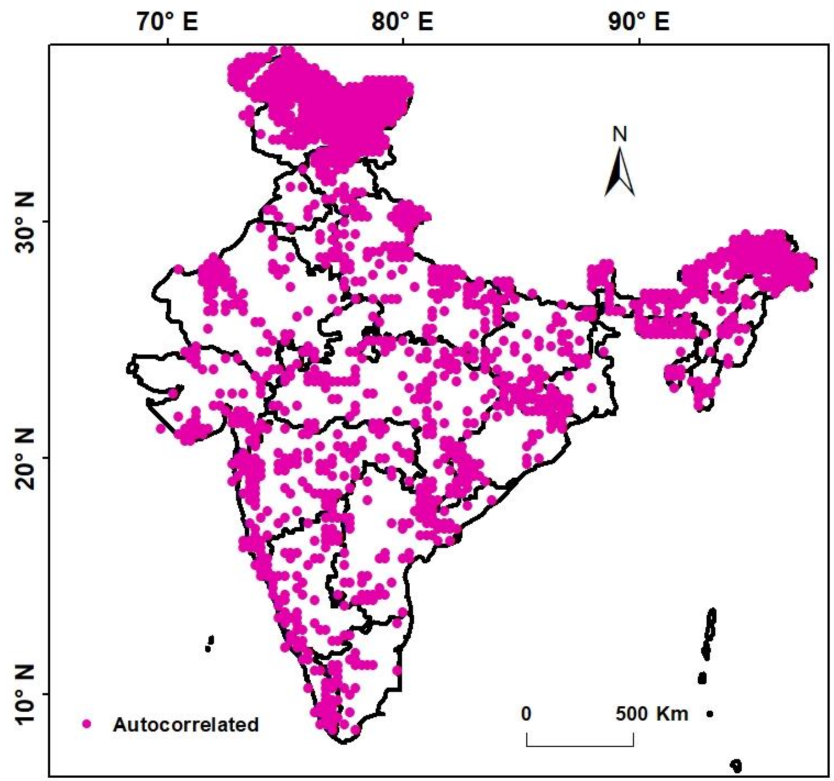
Auto Correlation

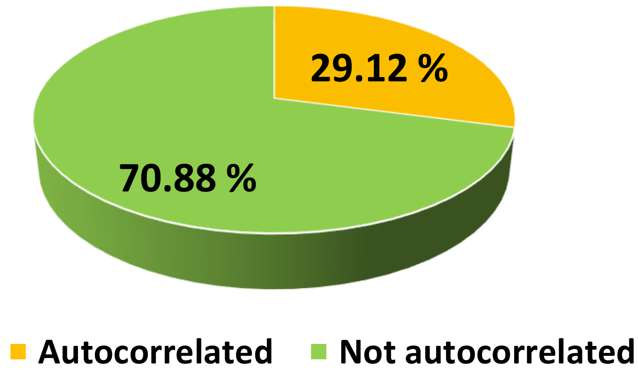
5 % Significance level





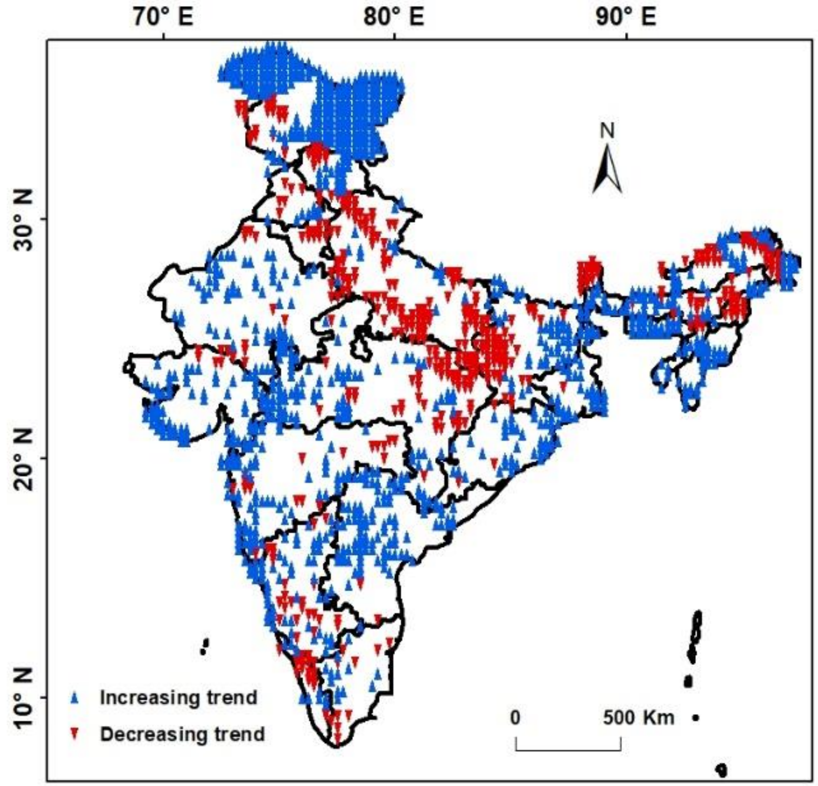
10 % Significance level

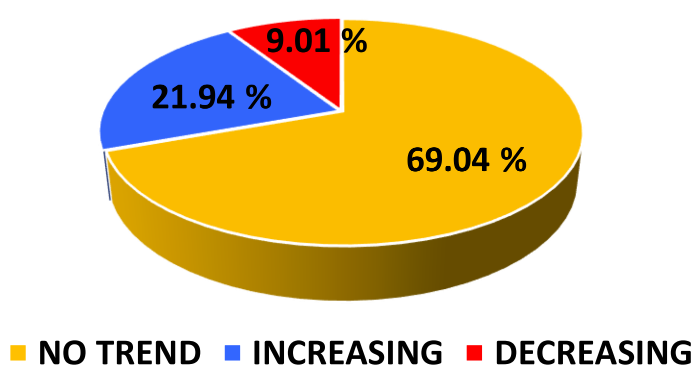




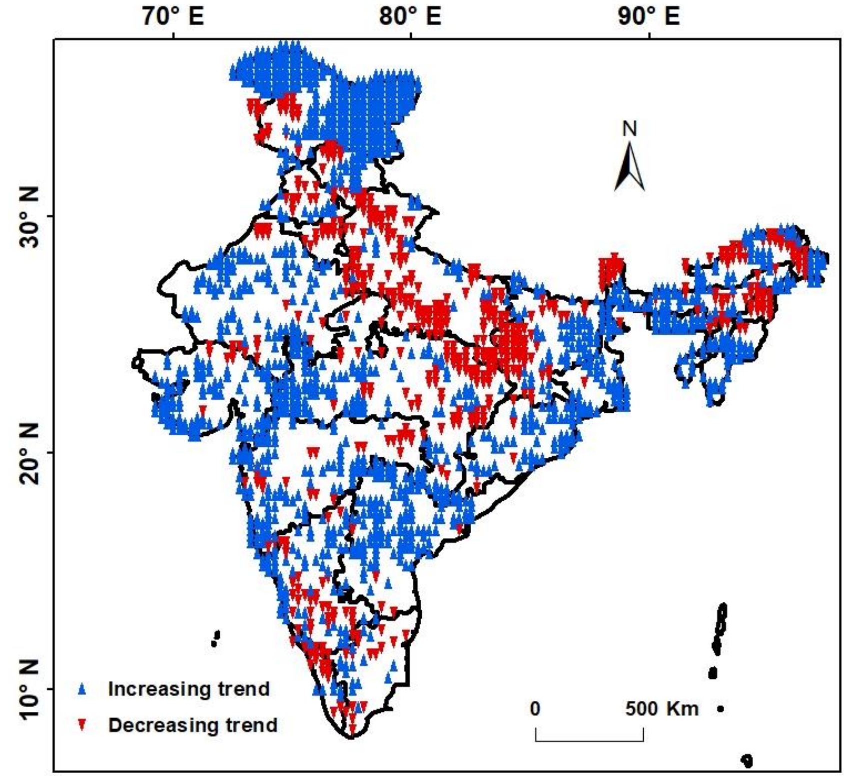
Trend-free pre-whitening (TFPW) with MK test (Yue et al., 2002b)

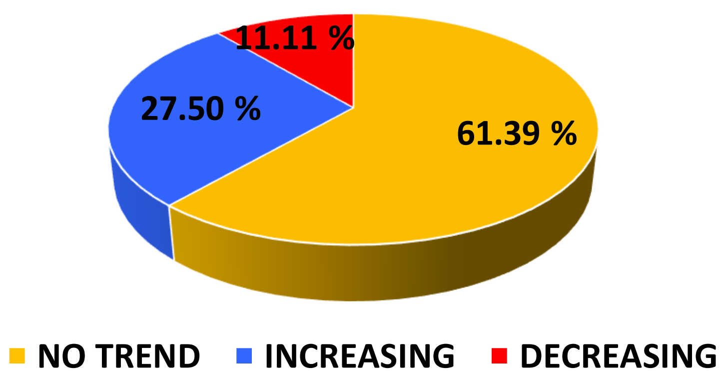
5 % Significance level





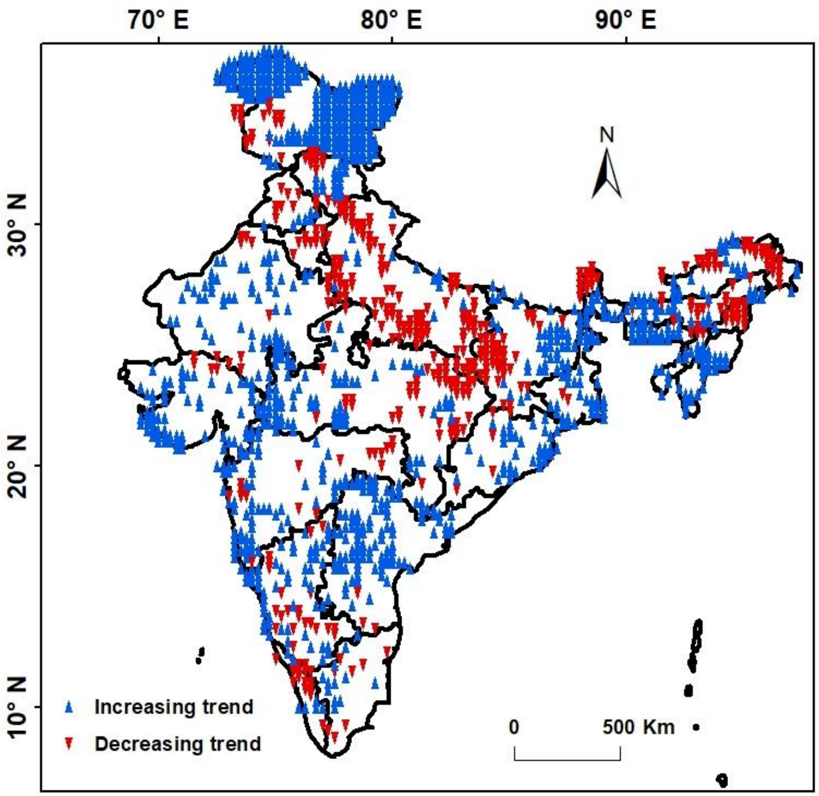
10 % Significance level

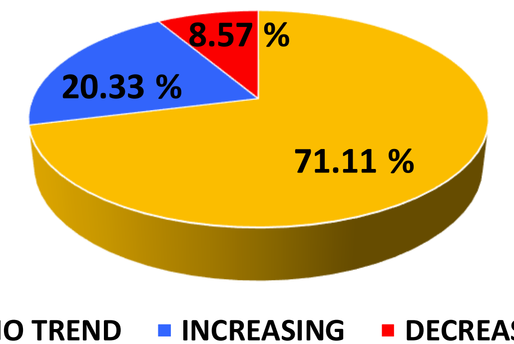




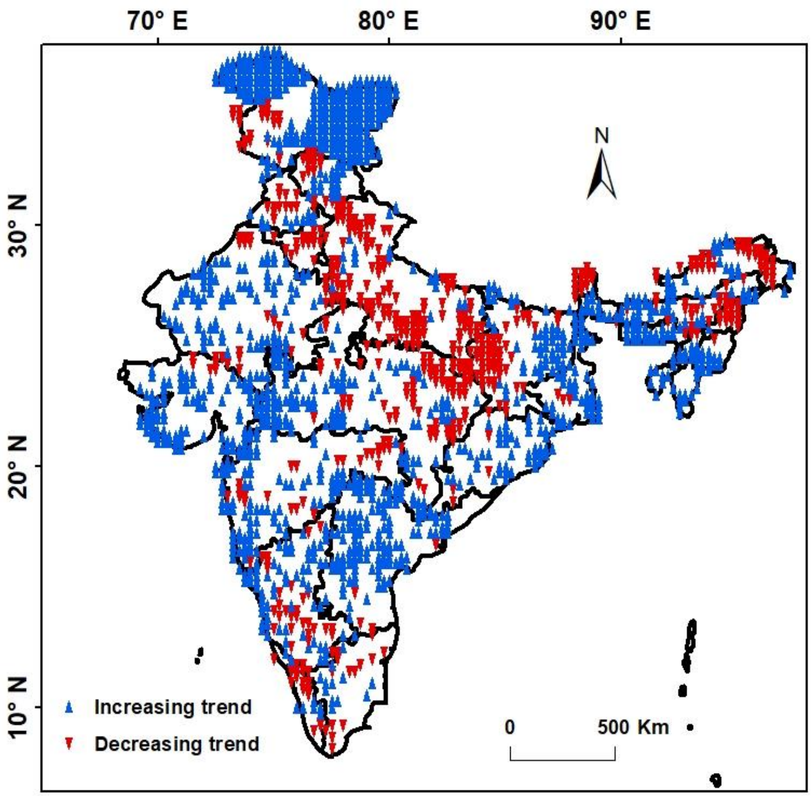
Variance correction (VC) approach with MK test based on Hamed and Rao (1998) (MK-CF1)

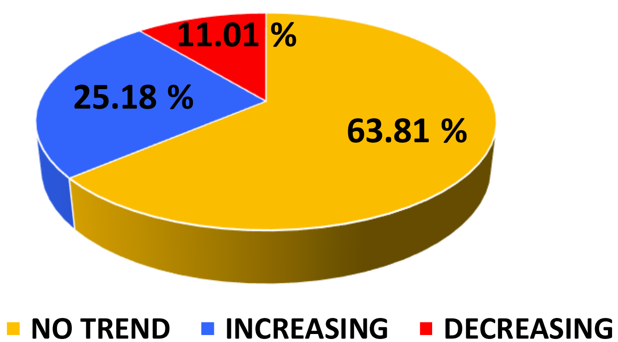
5 % Significance level





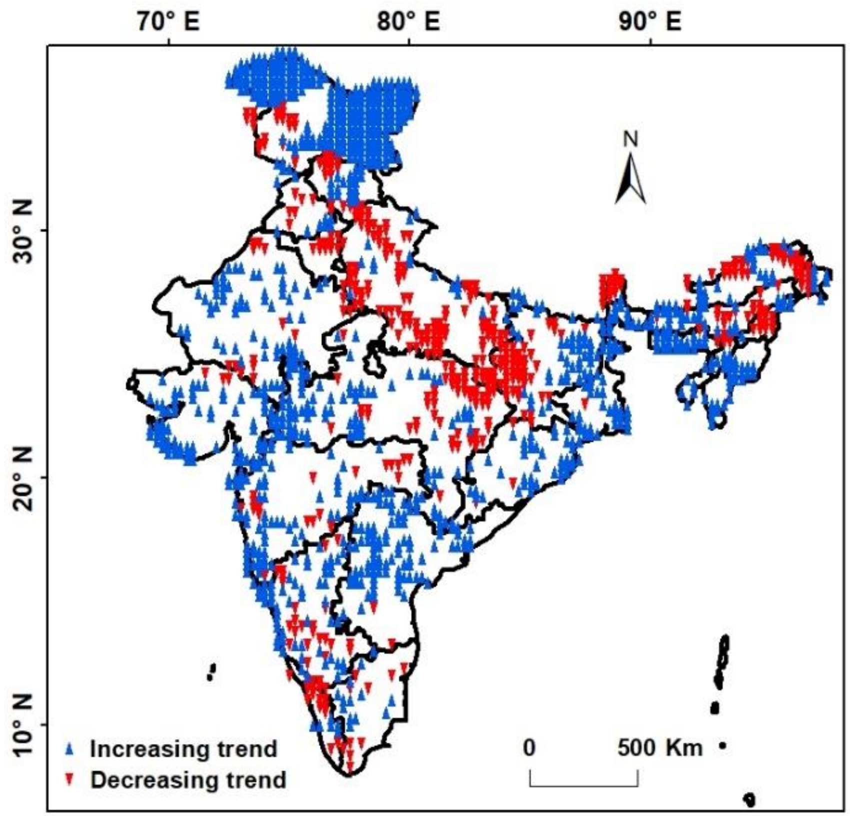
10 % Significance level

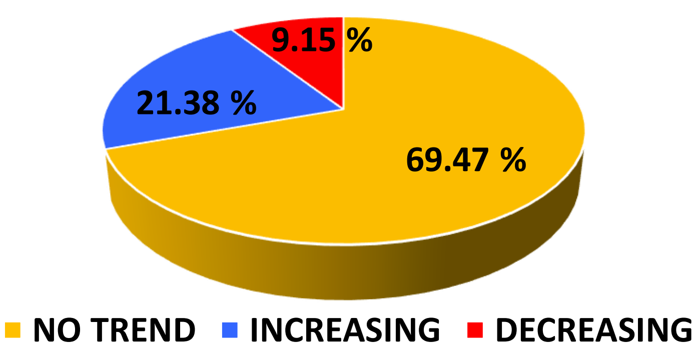




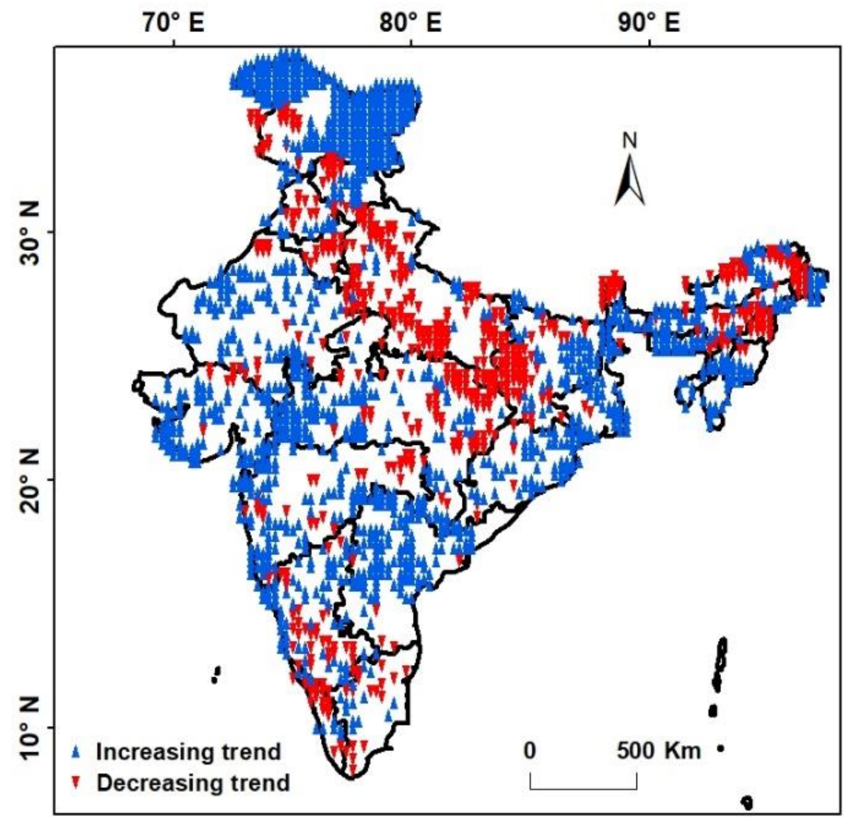
Variance correction (VC) approach with MK test based on Yue and Wang (2004) (MK-CF2)

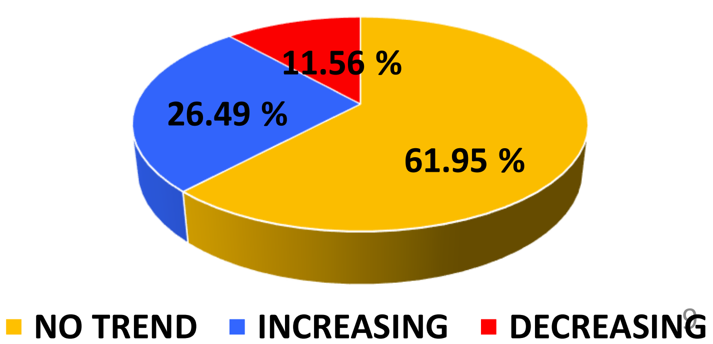
5 % Significance level





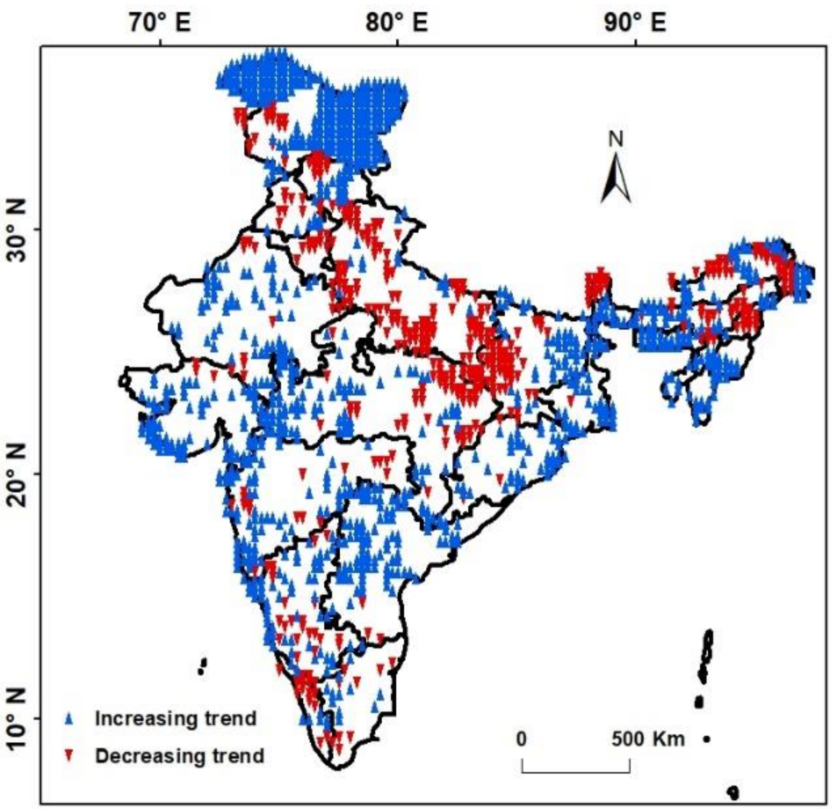
10 % Significance level

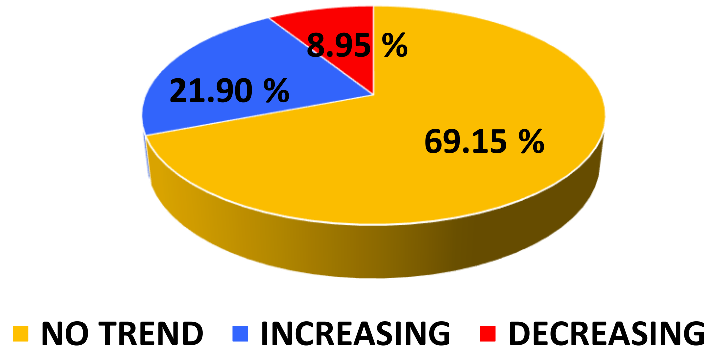




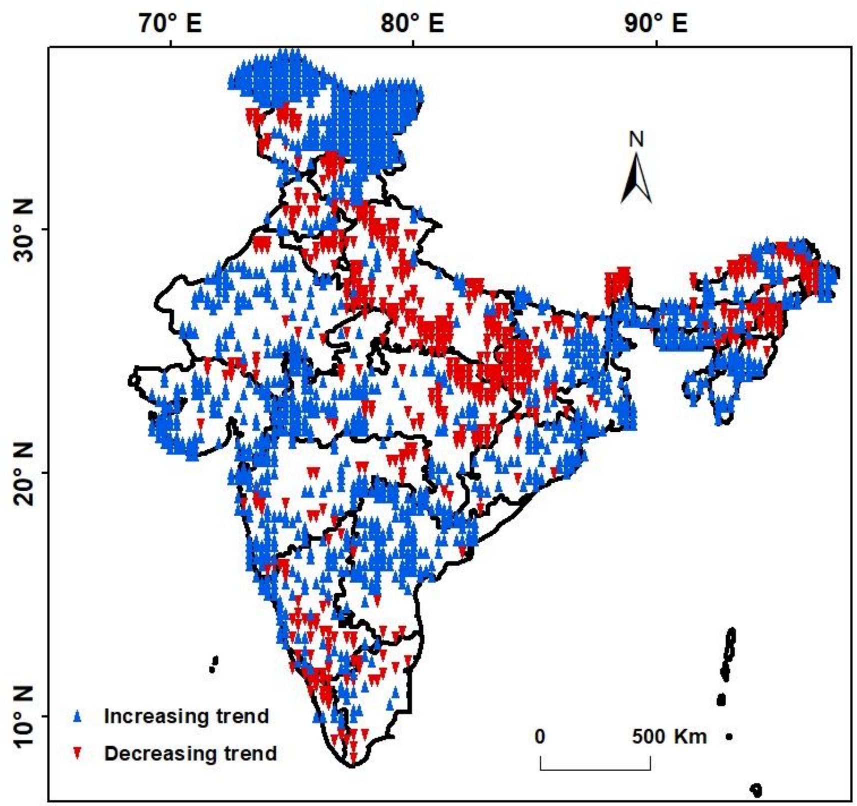
Spearman rank correlation (SRC) test

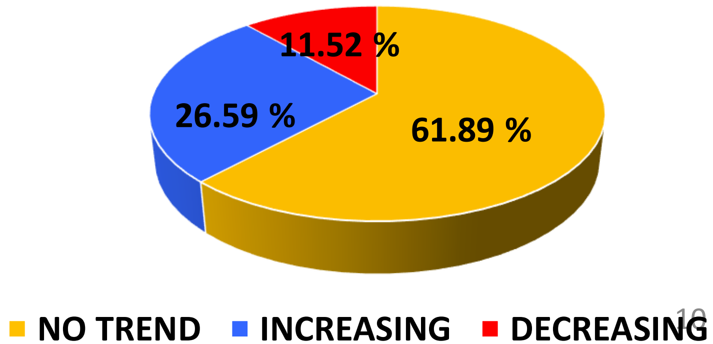
5 % Significance level





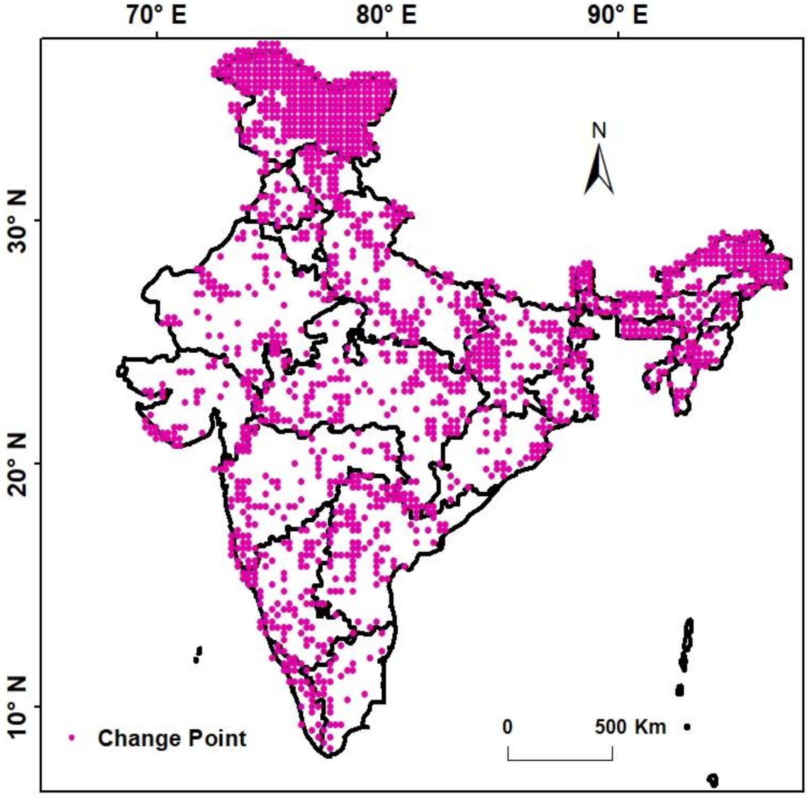
10 % Significance level

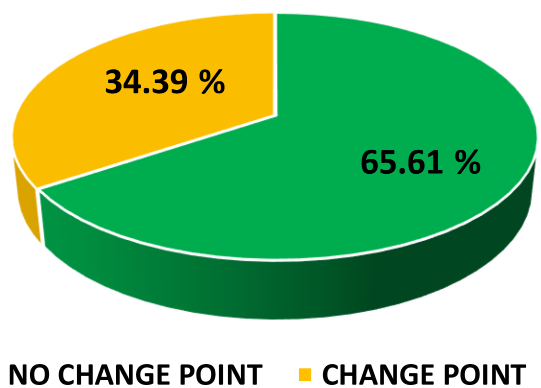




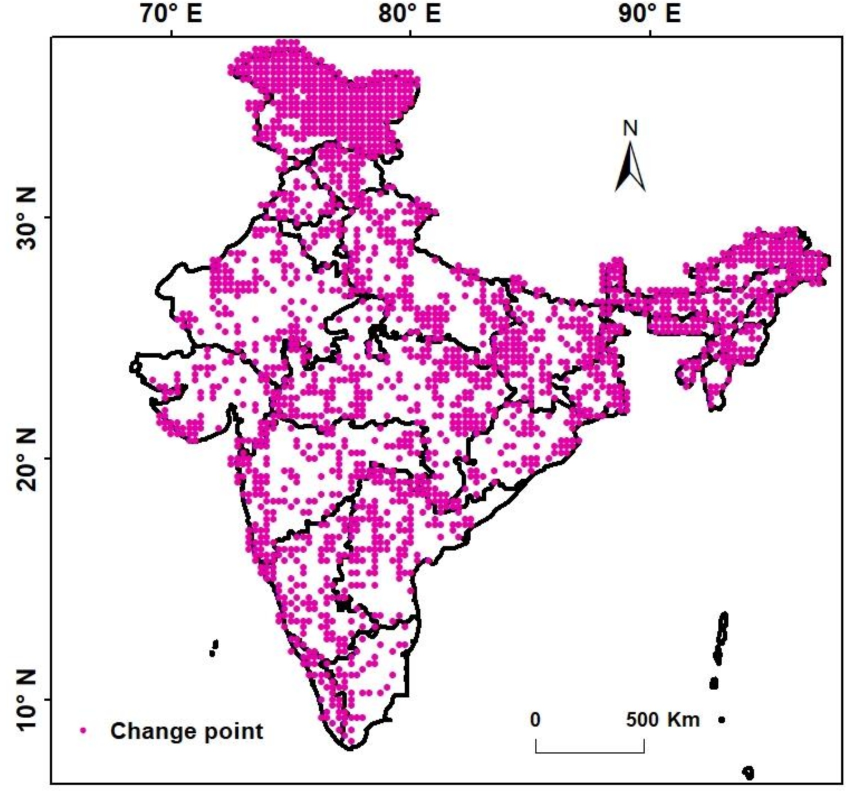
Pettitt's test

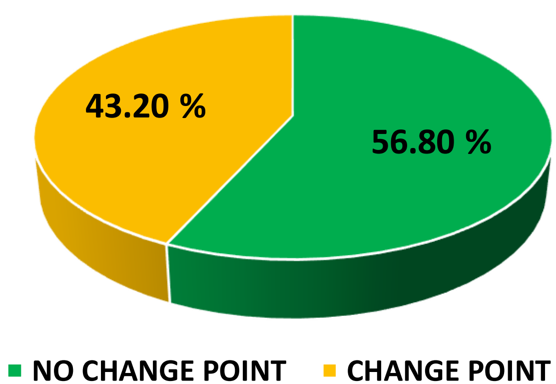
5 % Significance level





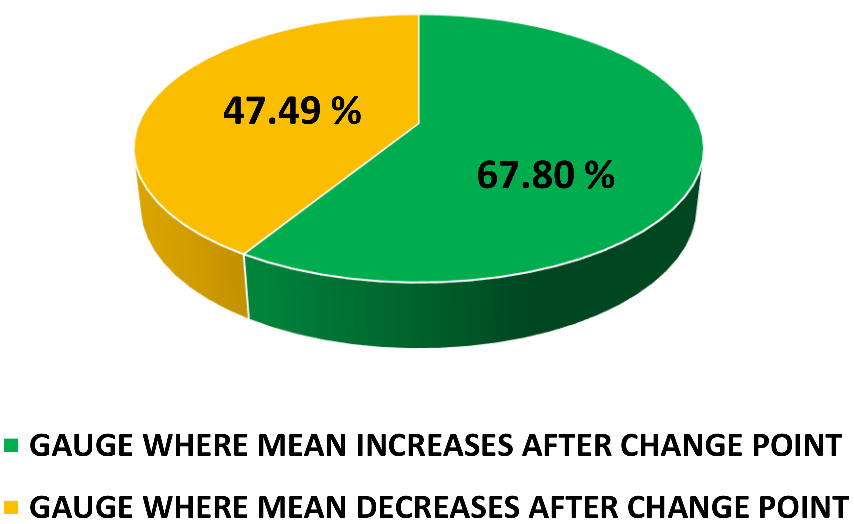
10 % Significance level



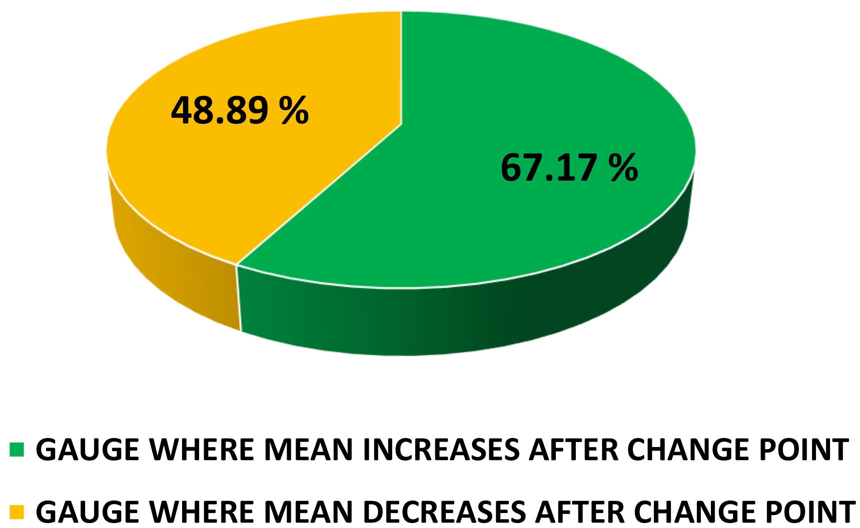


Pettitt's test

5 % Significance level

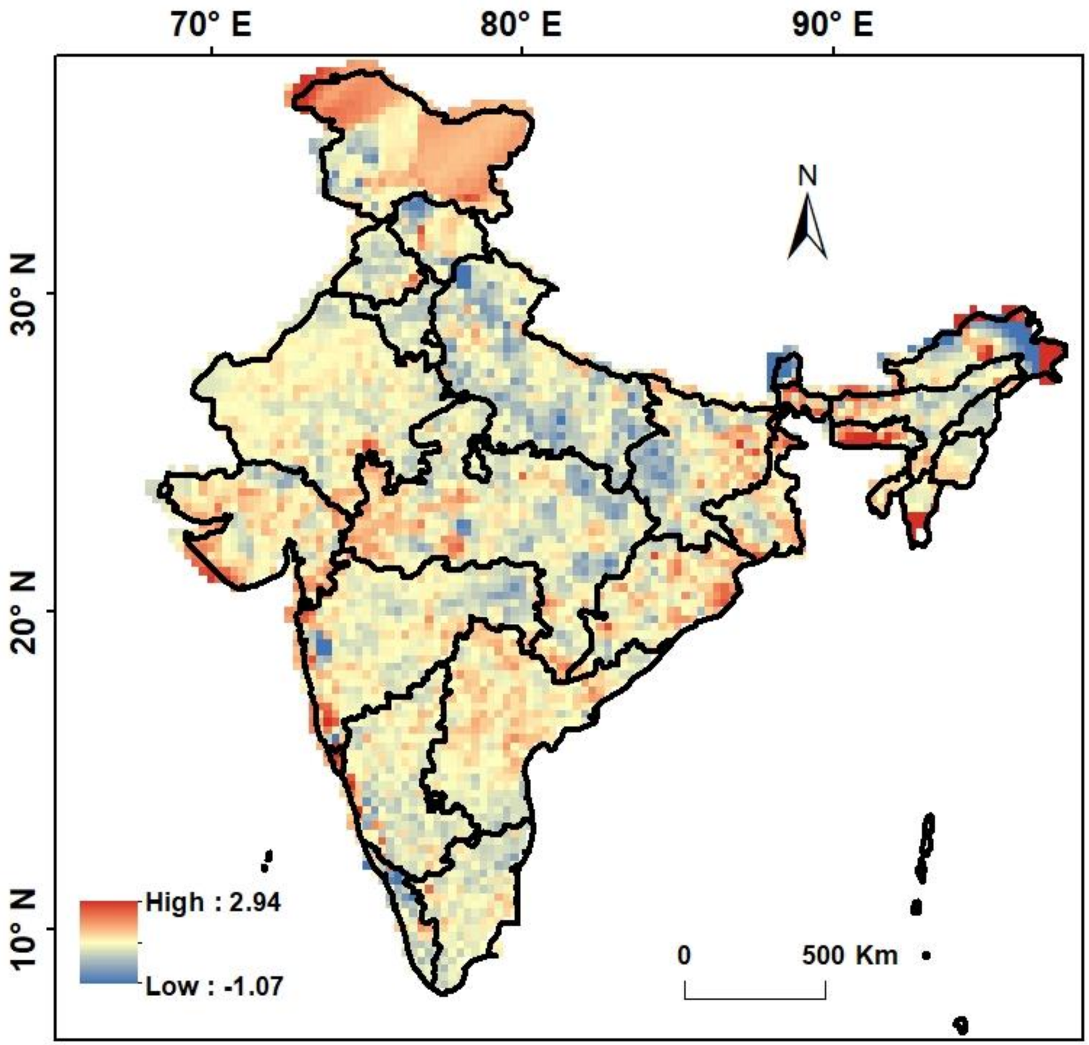


10 % Significance level



- **The most probable change year for the annual maximum series is 1972 at both the significant level**

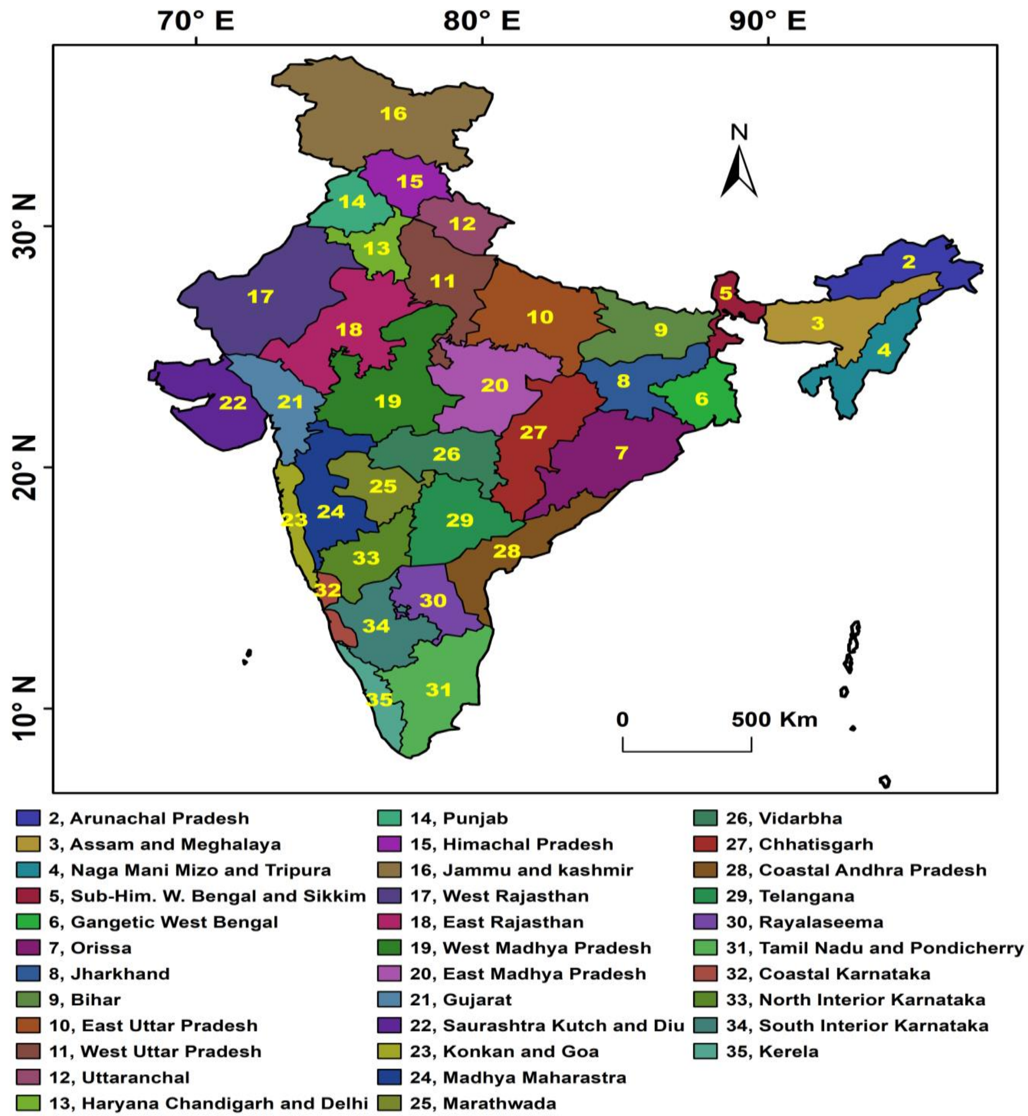
Sens slope



Magnitude of trend is given by Sens slope in mm/year and changes are significant in Northern , Western and Central south eastern region

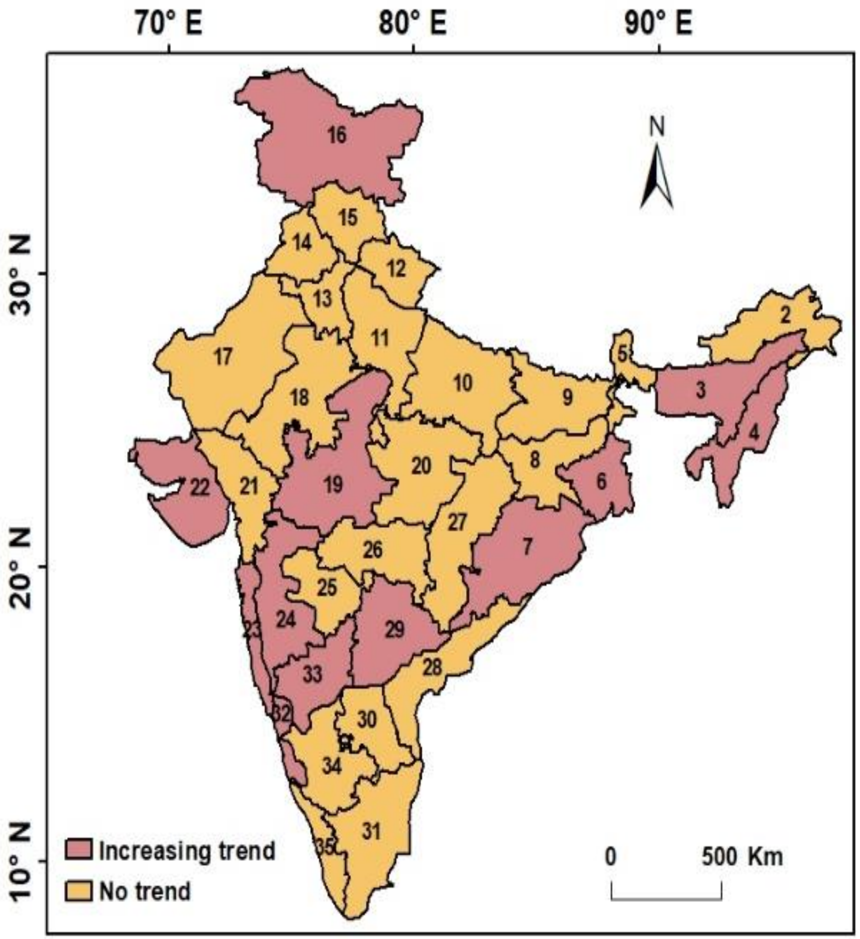
Objective : Trend detection analysis (Annual maximum daily precipitation)

For Meteorological Region (Representative series of Max Annual Rainfall) (34 regions)

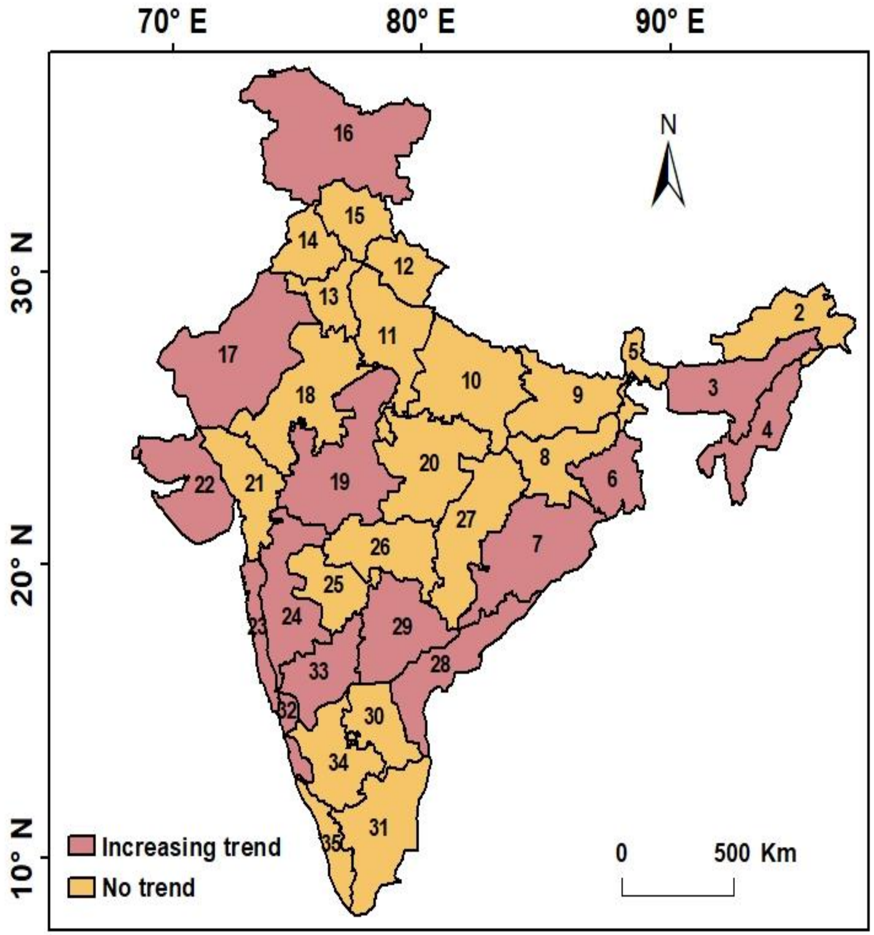


Mann–Kendall test

5 % Significance level



10 % Significance level



Trend detection analysis

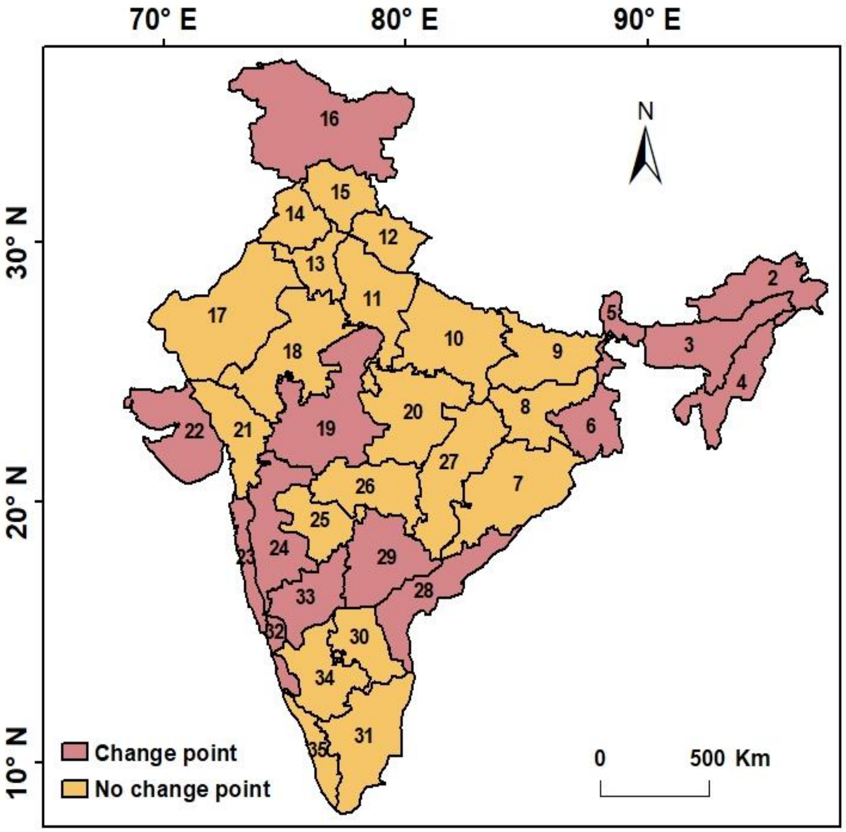
- For the representative series over the Meteorological Subdivision all the trend test shows similar results

- No significant decreasing trend was observed in any sub-division

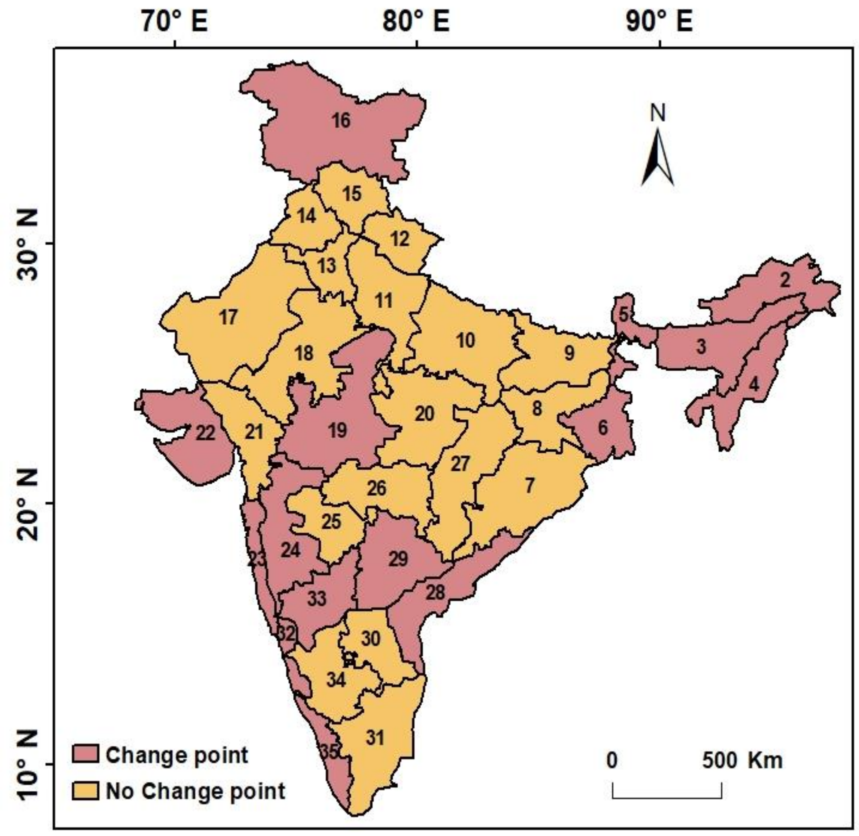
- Increasing trend in 12 subdivision at 5% significance was found significant while at 10% significance level 14 Meteorological sub-division shows significant increasing trend.

- **Assam & Meghalaya , Naga Mizo & Tripura, Gangetic West Bengal, Orissa, Jammu And Kashmir, West Madhya Pradesh, Saurashtra, Kutch And Diu Konkan, Goa, Madhya Maharashtra, Telangana, Coastal Karnataka, North Interior Karnataka , West Rajasthan , Coastal Andhra Pradesh** are the sub-divisions that shows increasing trend.

5 % Significance level



10 % Significance level



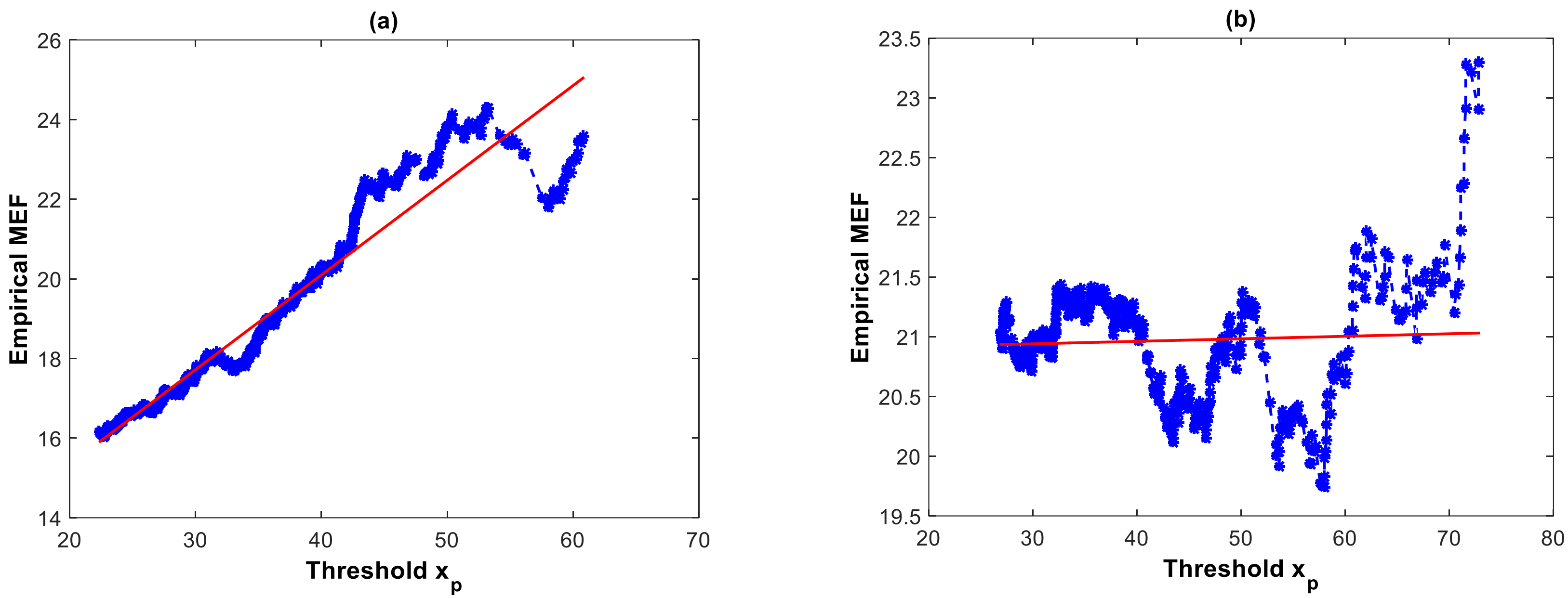
- **Change point is observed 14 subdivision at 5% significance while at 10% significance level 15 Meteorological sub-division shows significant change point**
- **The most probable change year is 1974 at both the significant level**

Objective : Characterization of tail behaviour of probability distribution of daily precipitation over India into heavy and light-tailed classes using using a novel algorithmic diagnostic tool (advanced version of Mean Excess Function)

IMD Gridded Dataset (4949 grids)

Objective : Characterization of tail behaviour

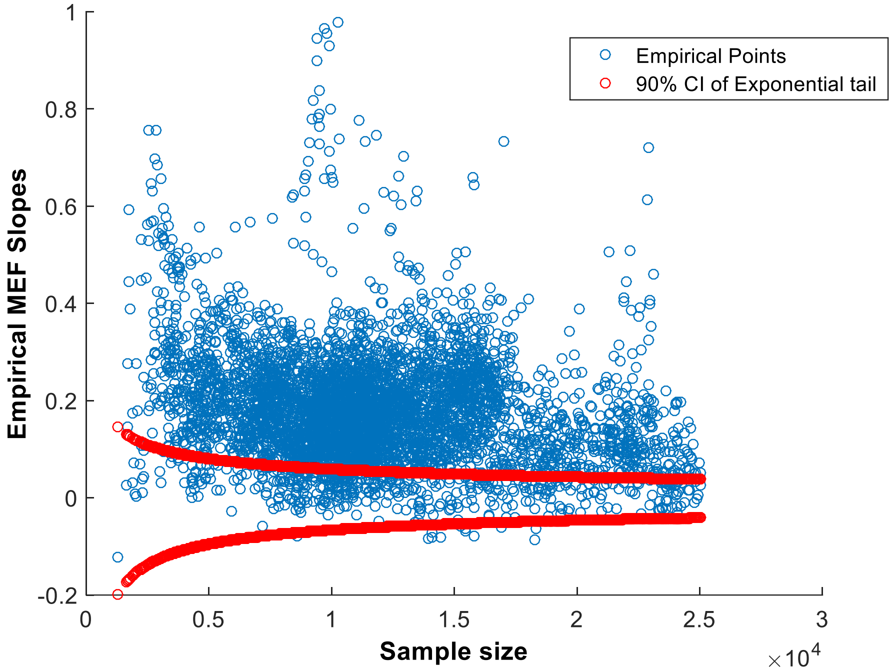
❖ Graphical examples of empirical MEF of daily precipitation :

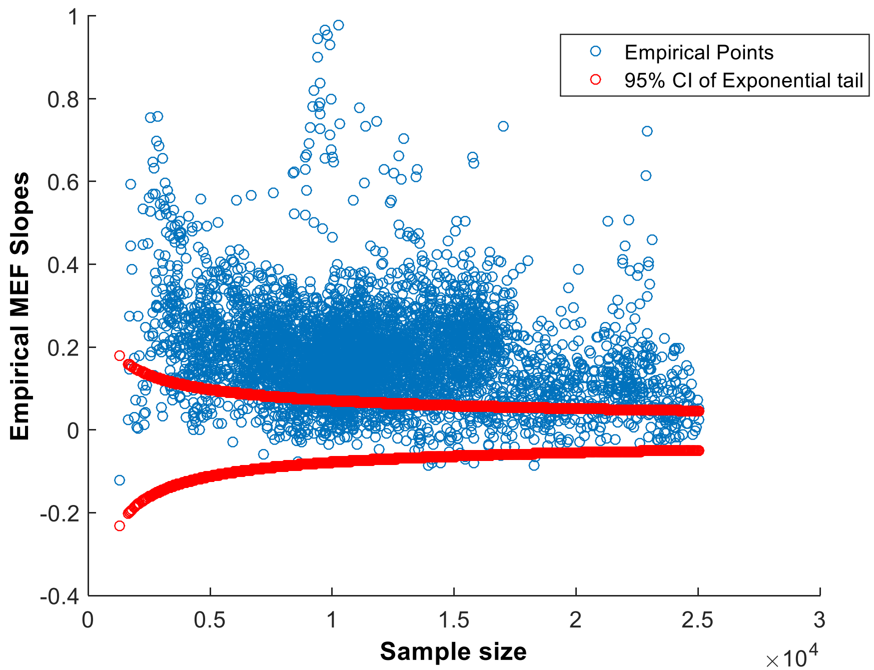


Graphical characteristics of empirical MEF of daily Precipitation

(a) Large positive slope indicate a sub-exponential tail, (b) Plot shows that the hypothesis of exponential tail cannot be rejected owing to small slope. For case (a, station code 1) the value of slope k is around 0.24 and slope's 90% CI for the record sample (n = 7948) is (−0.07, 0.07). For case (b, station code 1069) the estimated slope k is 0.002 and the slope's 90% CI for the record's sample size (n=5399) is (−0.09, 0.08)

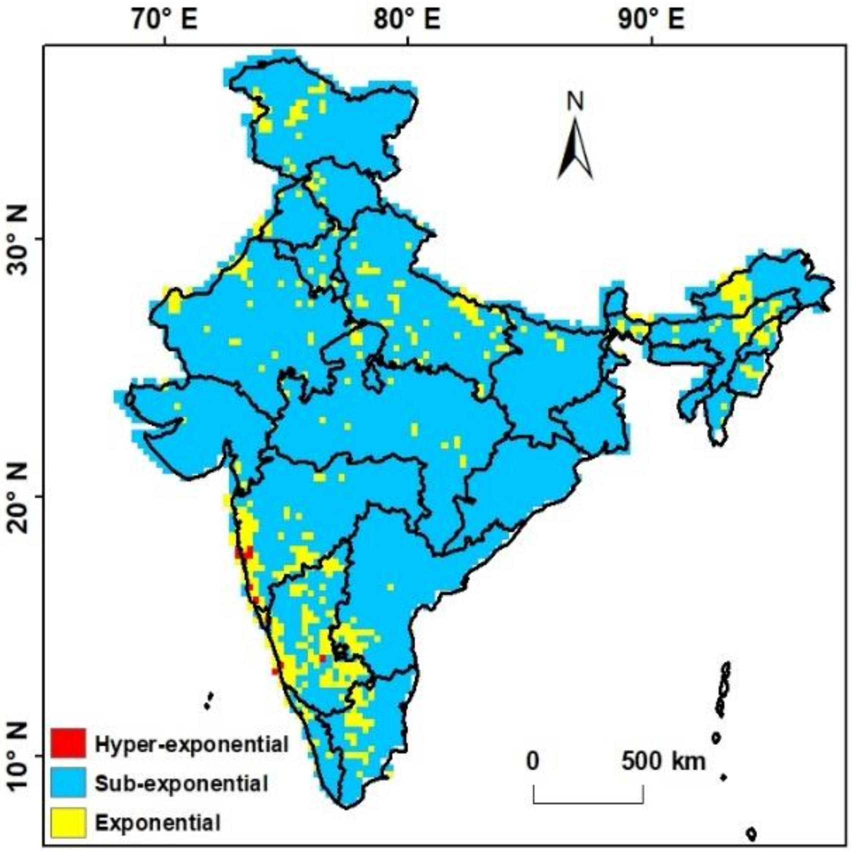
Objective : Characterization of tail behaviour

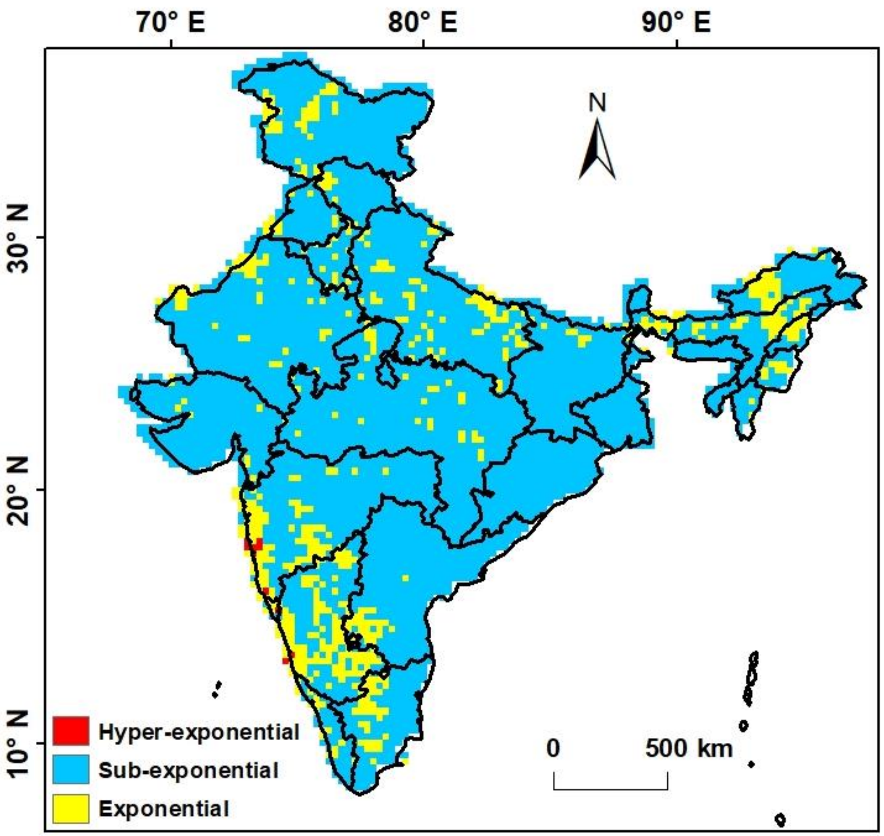




Comparison of 4949 empirical MEF slopes of daily Precipitation Records with (a) 90% confidence interval (b) 95 % confidence interval for the Exponential tail.

Objective : Characterization of tail behaviour

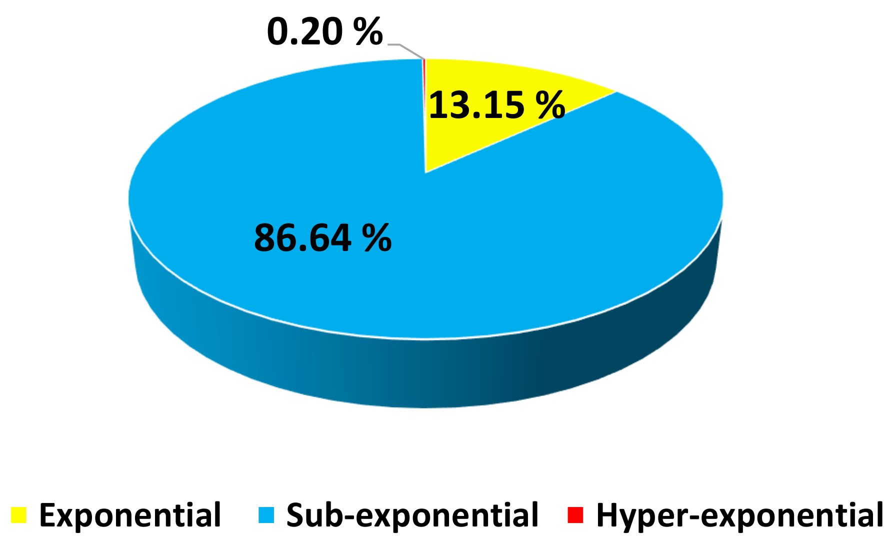




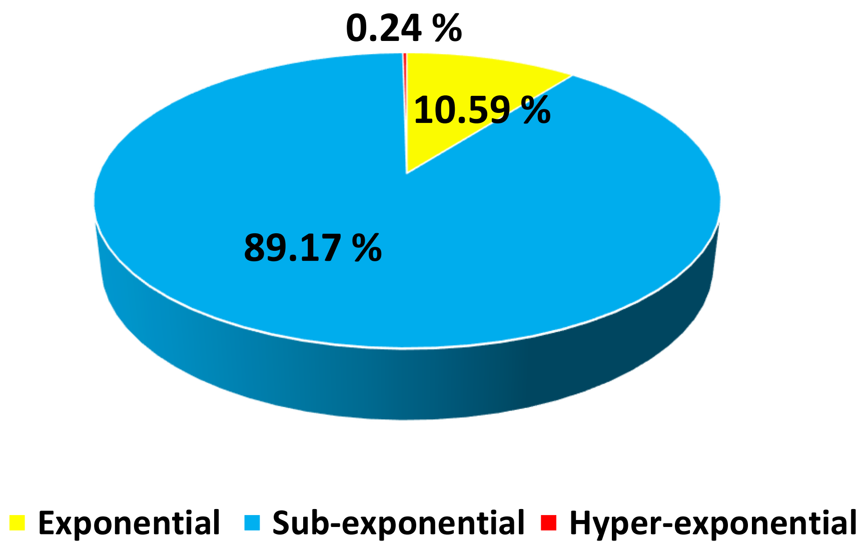
Spatial distribution of exponential and subexponential tails over India based on graphical method (Mean Excess Plot) considering the empirical MEF slope estimate for (a) 90% confidence interval (b) 95 % confidence interval for the Exponential tail. Since very few hyperexponential tails are found they are merged and shown with exponential class

- **For 4949 Grids : Tail behaviour type**

5 % Significance level



10 % Significance level



Variable	Min	Max
Sample length	1263	25027
Slope	-0.12	0.9772

	10 % Significance			5 % Significance		
Meteorological Region	Percentage of grids in each region (%) Heavy Tail	Light Tail	Dominant Tail Type	Percentage of grids in each region (%) Heavy Tail	Light Tail	Dominant Tail Type
2- Arunachal Pradesh	82.19	17.81	Heavy	78.77	21.23	Heavy
3- Assam & Meghalaya	85.54	14.46	Heavy	78.92	21.08	Heavy
4- Naga,Mizo & Tripura	81.13	18.87	Heavy	77.36	22.64	Heavy
5- Sub-Him. W. Bengal &Sikkim	76.67	23.33	Heavy	71.67	28.33	Heavy
6- Gangetic West Bengal	100.00	0.00	Heavy	100.00	0.00	Heavy
7-Orissa	100.00	0.00	Heavy	100.00	0.00	Heavy
8- Jharkhand	100.00	0.00	Heavy	100.00	0.00	Heavy
9- Bihar	95.54	4.46	Heavy	93.63	6.37	Heavy
10- East Uttar Pradesh	83.71	16.29	Heavy	79.19	20.81	Heavy
11- West Uttar Pradesh	87.66	12.34	Heavy	85.06	14.94	Heavy
12- Uttaranchal	96.39	3.61	Heavy	93.98	6.02	Heavy
13- Haryana , Chandigarh And Delhi	87.14	12.86	Heavy	81.43	18.57	Heavy
14-Punjab	89.01	10.99	Heavy	87.91	12.09	Heavy
15-Himachal Pradesh	92.05	7.95	Heavy	88.64	11.36	Heavy
16- Jammu And Kashmir	92.21	7.79	Heavy	90.02	9.98	Heavy
17- West Rajasthan	90.22	9.78	Heavy	88.01	11.99	Heavy
18- East Rajasthan	96.14	3.86	Heavy	94.20	5.80	Heavy
19- West Madhya Pradesh	95.55	4.45	Heavy	94.33	5.67	Heavy
20- East Madhya Pradesh	98.47	1.53	Heavy	94.90	5.10	Heavy
21- Gujarat	96.77	3.23	Heavy	95.16	4.84	Heavy
22-Saurashtra, Kutch And Diu	97.81	2.19	Heavy	97.27	2.73	Heavy
23- Konkan And Goa	22.86	77.14	Light	18.57	81.43	Light
24- Madhya Maharastra	82.24	17.76	Heavy	75.66	24.34	Heavy
25-Marathwada	96.63	3.37	Heavy	94.38	5.62	Heavy
26-Vidarbha	97.81	2.19	Heavy	97.08	2.92	Heavy
27-Chattisgarh	97.22	2.78	Heavy	96.11	3.89	Heavy
28- Coastal Andhra Pardesh	100.00	0.00	Heavy	100.00	0.00	Heavy
29-Telangana	99.33	0.67	Heavy	99.33	0.67	Heavy
30- Rayalaseema	74.44	25.56	Heavy	70.00	30.00	Heavy
31- Tamilnadu And Pondichery	82.86	17.14	Heavy	79.43	20.57	Heavy
32- Coastal Karnataka	28.21	71.79	Light	23.08	76.92	Light
33- North Interior Karnataka	75.00	25.00	Heavy	72.12	27.88	Heavy
34-South Interior Karnataka	56.10	43.90	Heavy	51.22	48.78	Heavy

Conclusion

- Algorithmic MEF for discriminating between exponential and heavier distribution tails is effective.

- Analysis indicated that for a significance level of 5%, 10% (two-sided test), the hypothesis of the exponential tail is rejected for 86.64 %, 89.16 % of the records respectively. Implies that rainfall extremes over India are better described by heavier than the exponential tails.

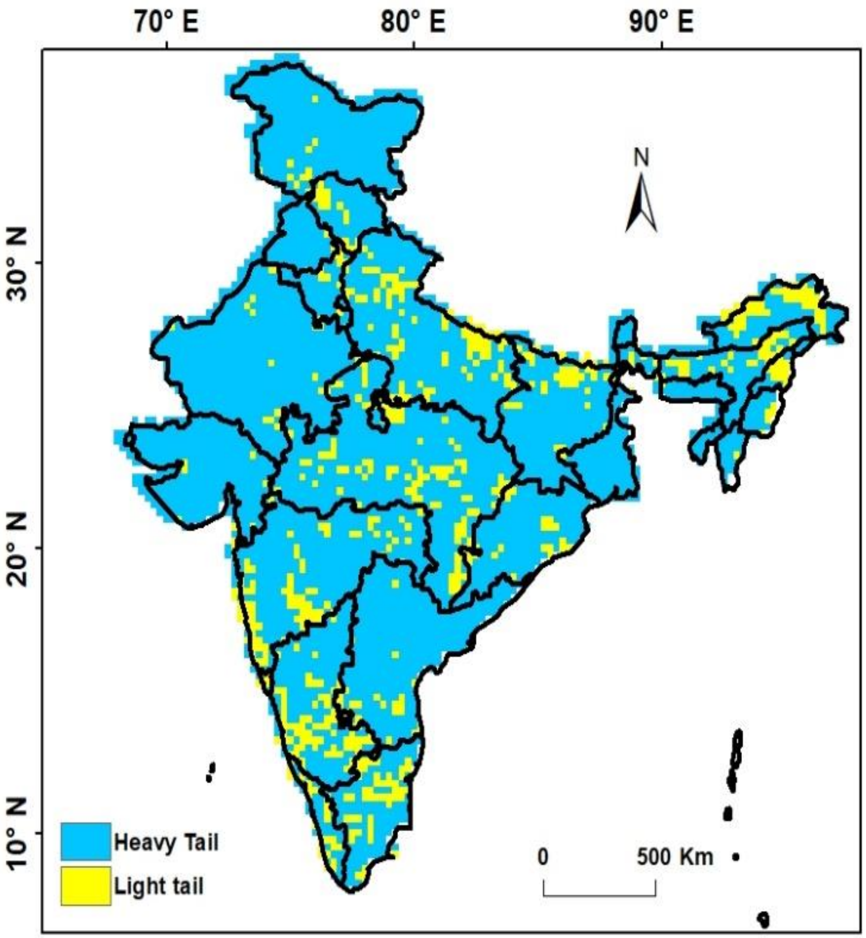
- Spatial variation of tail's heaviness reveals strong spatial patterns. For instance, evidence suggests exponential tails along west coast line , some part of peninsular region and in north eastern region; heavier tails are observed in Northwestern part, some part of central India and Central north eastern region .

- Meteorological regions like West Bengal ,Orrisa , Jharkhand , Uttaranchal , Eastern and Western Madhya Pradesh , Gujarat , Saurastra , kutch and Diu ,Vidarbha, Chhattisgarh, Coastal Andhra Pradesh ,Telangana are highly dominated by the heavy tails grids (heavy tail grids> 95% at 5 and 10% significance level)

Objective : To investigate the upper tail behavior of daily precipitation series Using framework of generalized extreme value (GEV) theory

IMD Gridded Dataset (4949 grids)

Objective : Modeling extremes in the framework of generalized extreme value (GEV)



Maps of the series with change-points and monotonic trends

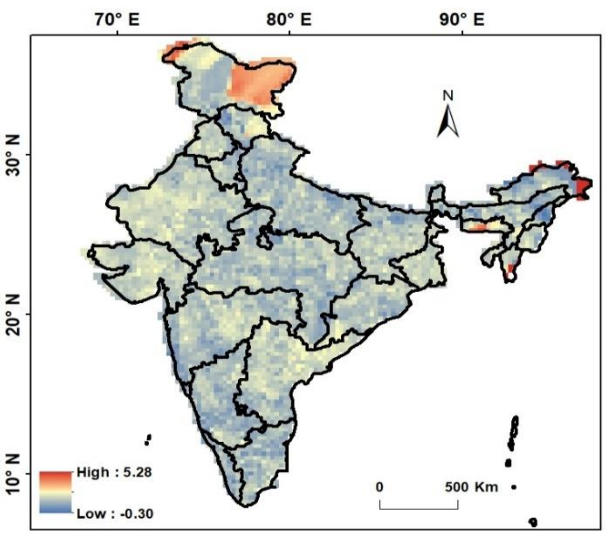
- For Gridded Dataset (Max Annual Series)

Indicator Based on Shape Parameter	Tail Type	No. of Gauges
$\alpha > 0$	HEAVY	4245
$\alpha \rightarrow \mathbf{0}$ & $\alpha < 0$	LIGHT	704

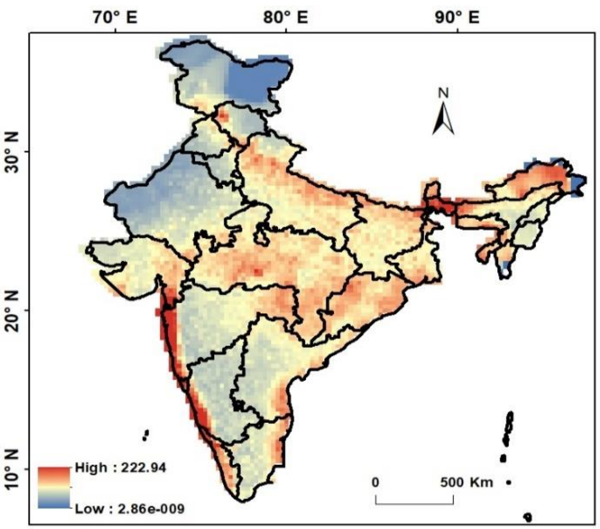
** Based on the analysis without considering any monotonic trends and abrupt change point

Objective : Modeling extremes in the framework of generalized extreme value (GEV)

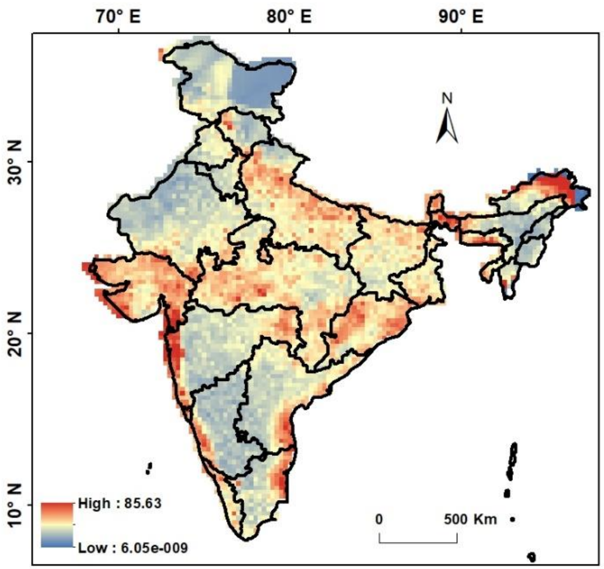
Maps of the parameters of the GEV distribution for the series over India (4949 grids)



Shape Parameter



Location Parameter



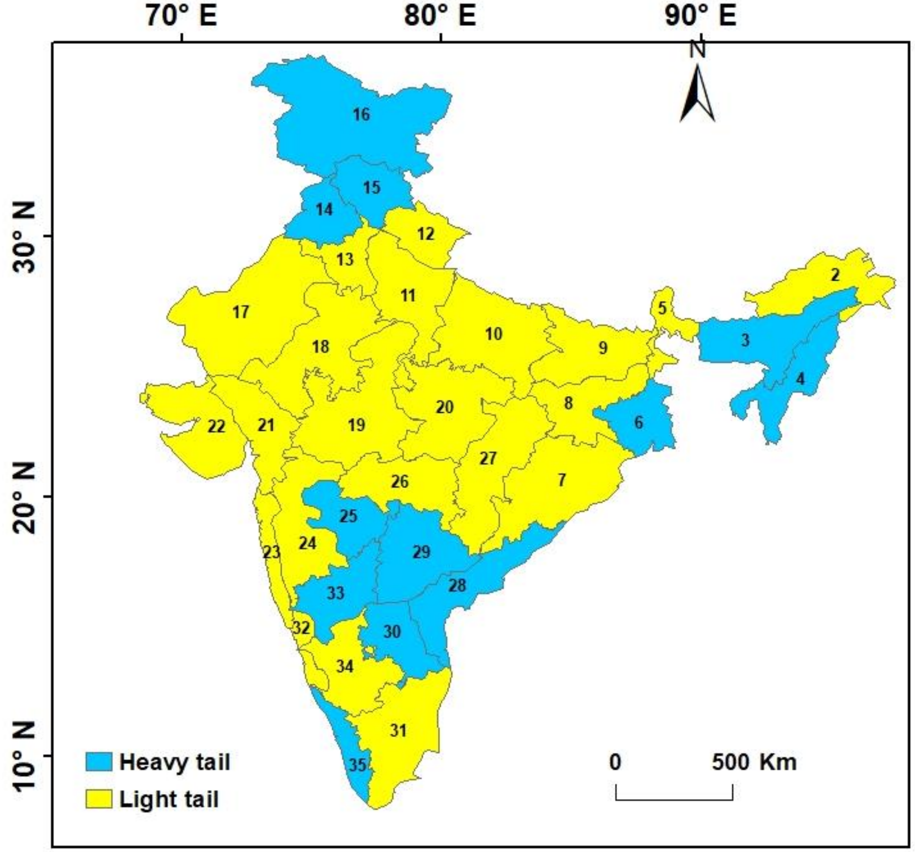
Scale Parameter

Objective : Modeling extremes in the framework of generalized extreme value (GEV)

Meteorological Sub-divisions	Percentage of grids in each region (%)	
	Heavy	Light
2- Arunachal Pradesh	65.07	34.93
3- Assam & Meghalaya	80.72	19.28
4- Naga,mizo & Tripura	82.08	17.92
5- Sub-him. W. Bengal &Sikkim	85.00	15.00
6- Gangetic West Bengal	98.92	1.08
7-orissa	89.81	10.19
8- Jharkhand	97.37	2.63
9-bihar	76.43	23.57
10- East Uttar Pradesh	78.28	21.72
11- West Uttar Pradesh	79.22	20.78
12- Uttranchal	83.13	16.87
13- Haryana , Chandigarh And Delhi	78.57	21.43
14-punjab	97.80	2.20
15-Himachal Pradesh	79.55	20.45
16- Jammu And Kashmir	97.32	2.68
17- West Rajasthan	98.11	1.89
18- East Rajasthan	95.65	4.35
19- West Madhya Pradesh	85.83	14.17
20- East Madhya Pradesh	82.14	17.86
21- Gujarat	94.35	5.65
22-Saurashtra, Kutch And Diu	98.36	1.64
23- Konkan And Goa	44.29	55.71
24- Madhya Maharastra	83.55	16.45
25-marathwada	91.01	8.99
26-vidarbha	86.86	13.14
27-chattisgarh	80.56	19.44
28- Coastal Andhra Pardesh	94.40	5.60
29-Telangana	98.67	1.33
30- Rayalaseema	82.22	17.78
31- Tamilnadu and Pondichery	72.57	27.43
32- Coastal Karnataka	58.97	41.03
33- North Interior Karnataka	92.31	7.69
34-South Interior Karnataka	60.16	39.84
35- Kerala	63.08	36.92

For Meteorological Region (Representative series of Max Annual Rainfall) (34 regions)

Objective : Modeling extremes in the framework of generalized extreme value (GEV)



- For Meteorological Subdivision (Max Annual Series)

Indicator Based on Shape Parameter	Tail Type	No. of Gauges
$\alpha > 0$	HEAVY	12
$\alpha \to 0$ & $\alpha < 0$	LIGHT	22

** Based on the analysis without considering any monotonic trends and abrupt change point

Objective : Modeling extremes in the framework of generalized extreme value (GEV)

	Parameter for Representative series		
Meteorological Sub-divisions	Shape	Scale	Location
2- Arunachal Pradesh	-0.081	23.24	95.12
3- Assam & Meghalaya	0.040	12.27	92.35
4- Naga,mizo & Tripura	0.029	13.48	78.71
5- Sub-him. W. Bengal &Sikkim	-0.032	21.65	125.79
6- Gangetic West Bengal	0.044	18.65	86.97
7-orissa	-0.082	16.33	98.68
8- Jharkhand	-0.095	13.35	84.43
9-bihar	-0.169	13.97	96.47
10- East Uttar Pradesh	-0.109	12.77	92.09
11- West Uttar Pradesh	-0.298	16.05	87.91
12- Uttranchal	-0.025	14.05	76.00
13- Haryana , Chandigarh And Delhi	-0.038	13.25	63.66
14-punjab	0.200	12.50	61.63
15-Himachal Pradesh	0.061	11.94	67.75
16- Jammu And Kashmir	0.348	11.17	38.46
17- West Rajasthan	-0.157	12.90	45.27
18- East Rajasthan	-0.292	13.67	75.36
19- West Madhya Pradesh	-0.265	15.17	91.79
20- East Madhya Pradesh	-0.144	12.62	92.07
21- Gujarat	-0.089	25.94	99.67
22-Saurashtra, Kutch And Diu	-0.157	27.59	77.61
23- Konkan And Goa	-0.146	23.03	157.79
24- Madhya Maharastra	0.000	9.23	64.68
25-marathwada	0.060	13.67	66.46
26-vidarbha	-0.043	15.70	89.25
27-chattisgarh	-0.120	12.35	93.18
28- Coastal Andhra Pardesh	0.016	16.38	86.67
29-Telangana	0.104	12.45	70.87
30- Rayalaseema	0.052	11.47	65.67
31- Tamilnadu and Pondichery	-0.224	15.85	77.96
32- Coastal Karnataka	-0.020	18.58	127.39
33- North Interior Karnataka	0.070	7.53	57.27
34-South Interior Karnataka	-0.129	8.15	64.47
35- Kerela	0.009	14.54	107.04

Objective : Modeling extremes in the framework of generalized extreme value (GEV)

Analysis based on considering change point and trends at grids

- Preliminary analysis (Independence assumption): 21.20 % of the grids out of 4949 has statistically significant lag-one correlation (NO CORRECTION APPLIED)

- Change-point analysis: Pettitt test (change in mean)

- Monotonic trend tests: Mann-Kendall and Spearman tests

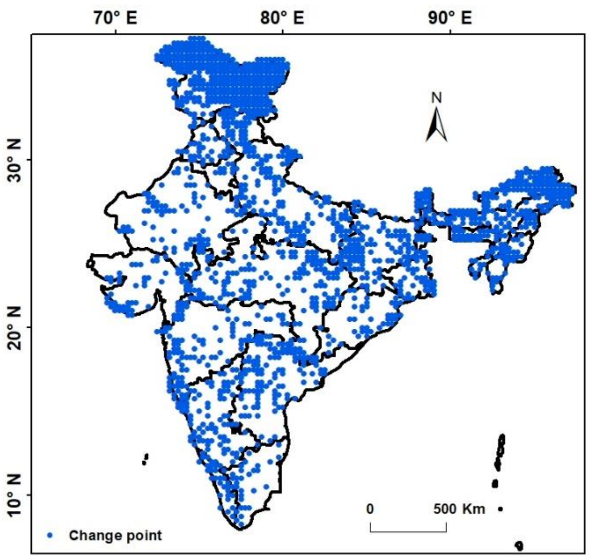
- Significance level for this study is 5 %

- Out of 4949 grids, 34.39% of the stations exhibit a change-point in mean (of these, 67.8% show an increase in mean after the change-point)

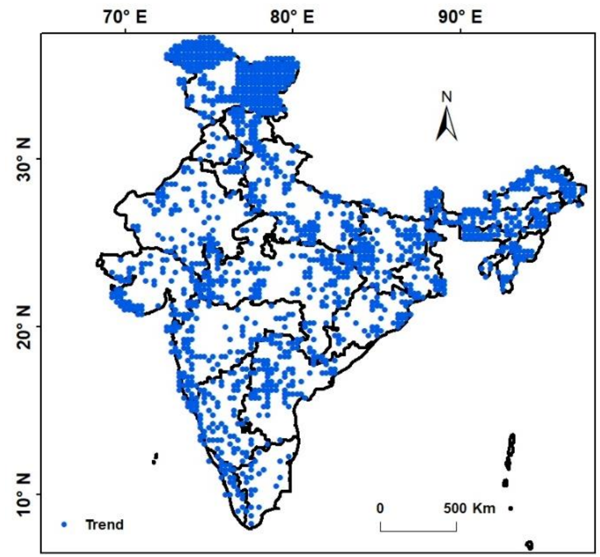
Objective : Modeling extremes in the framework of generalized extreme value (GEV)

- The GEV modeling is performed only on those stations that did not present statistically significant change-points (in mean) and trends (there are 3033 (61.28 %) out of 4949 grids fulfilling this requirement).

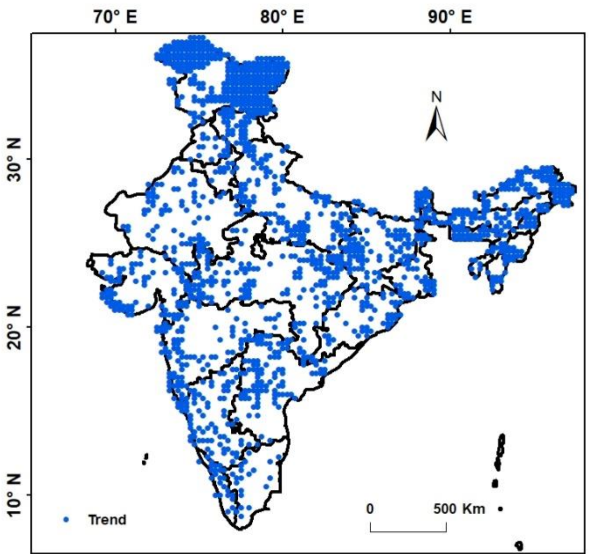
Objective : Modelling extremes in the framework of generalized extreme value (GEV)



Grids with a change-point in mean (3427 grids)

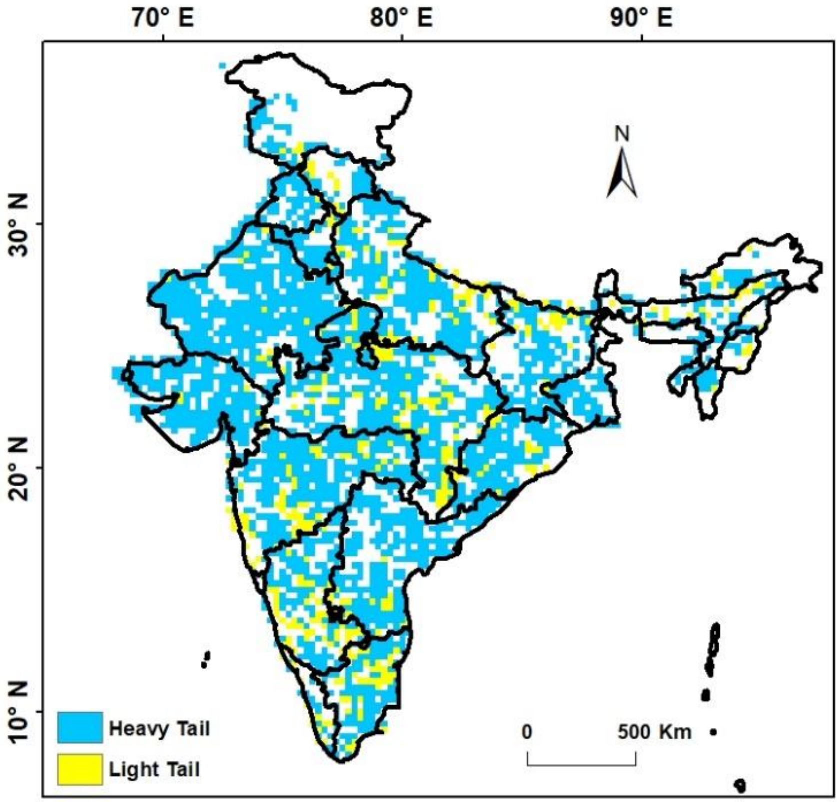


Significant trends by Mann-Kendall (1511 grids)



Significant trends by Spearman test (1527 grids)

Objective : Modelling extremes in the framework of generalized extreme value (GEV)



Maps of the series without change-points and monotonic trends

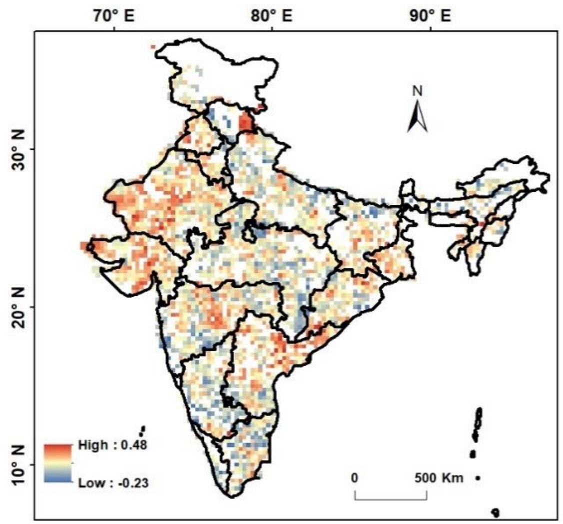
- For Gridded Dataset (With No change point and No Trend (3033 grids))

Indicator Based on Shape Parameter	Tail Type	No. of Gauges
$\alpha > 0$	HEAVY	2581
$\alpha \to \mathbf{0}$ & $\alpha < 0$	LIGHT	452

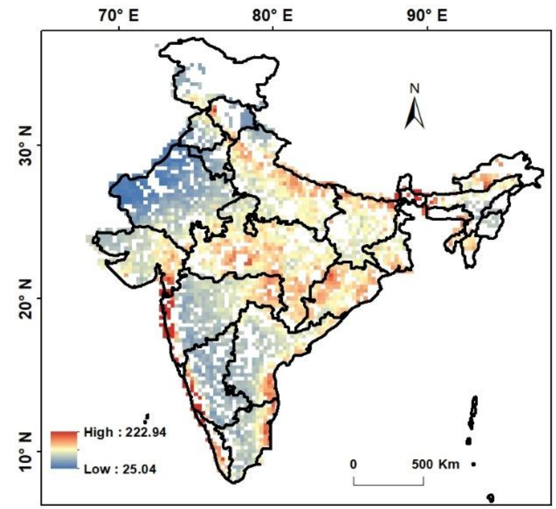
** Based on the analysis with no monotonic trends and no abrupt change point .

Objective : Modelling extremes in the framework of generalized extreme value (GEV)

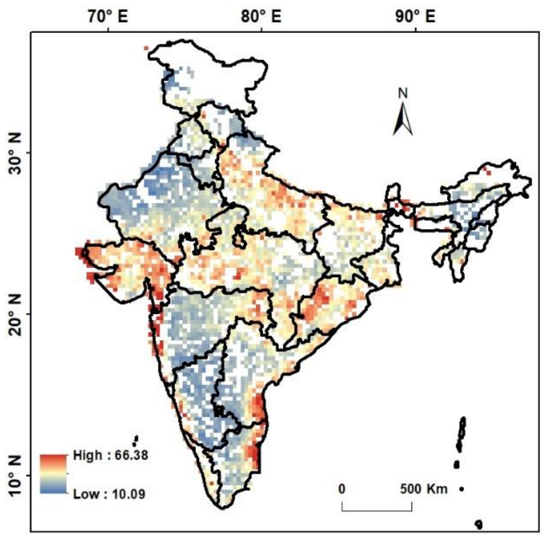
Maps of the parameters of the GEV distribution for the series without change-points and monotonic trends



Shape Parameter



Location Parameter



Scale Parameter

Objective : Modeling extremes in the framework of generalized extreme value (GEV)

- **Conclusion**

- Records shows dominant behavior heavy-tail behavior in nearly 85.77 % (4245 out of 4949 grids) based on shape parameter for annual maximum rainfall records for the all grids.

- Records point to an unbounded-above and heavy-tail behavior in nearly 85.09 % (2581 out of 3033 grids) as the shape parameter for annual maximum rainfall records was generally larger than zero for the grids with no change point and no monotonic trend.

- Location and scale parameters exhibit a pronounced increasing gradient from the northwestern to southeastern part of the study region. They are quite high in values along the south western coastline and in Northeastern region of the country.

- The shape parameter did not exhibit a marked spatial pattern but have high range of values in the western and Northern part of the Country.

Objective : Change magnitude as Percentage of Mean

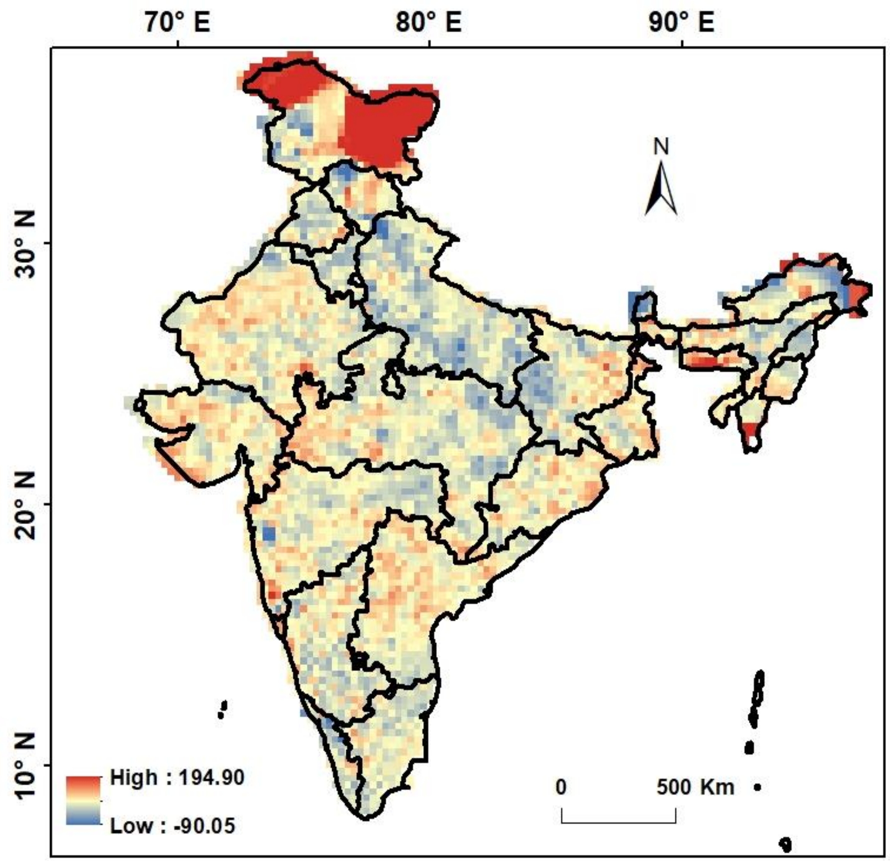
- Some trends may not be evaluated to be statistically significant while they might be of practical interest, and vice versa (Yue and Hashino, 2003). Even if a climate change component is present, it does not need to be detected by statistical tests at a satisfactory significance level (Radziejewski and Kundzewicz, 2004)

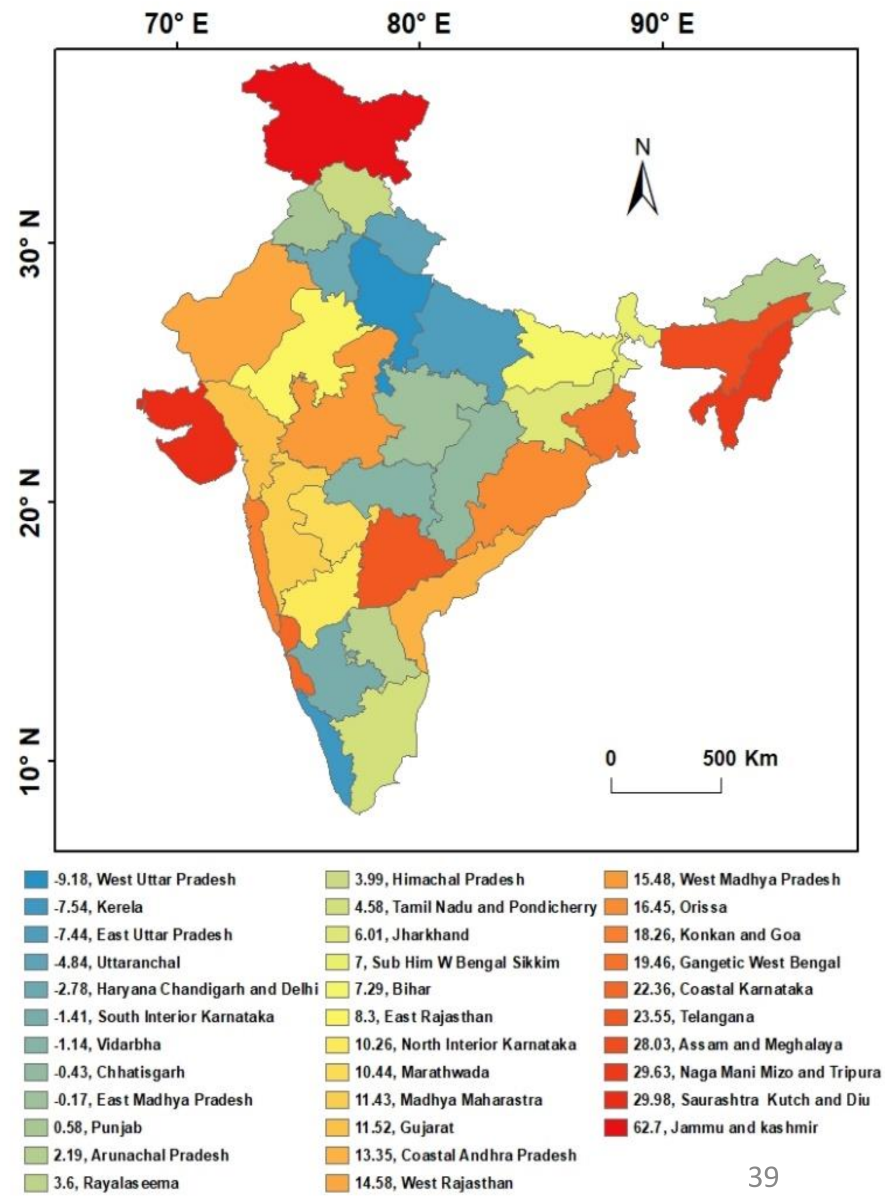
- Change percentages have to be been computed

$$Percentagechange(\%) = \frac{\beta * lengthofperiod}{mean} * 100$$

- β is linear trend, estimated by Theil and Sen's median slope

Change magnitude as Percentage of Mean

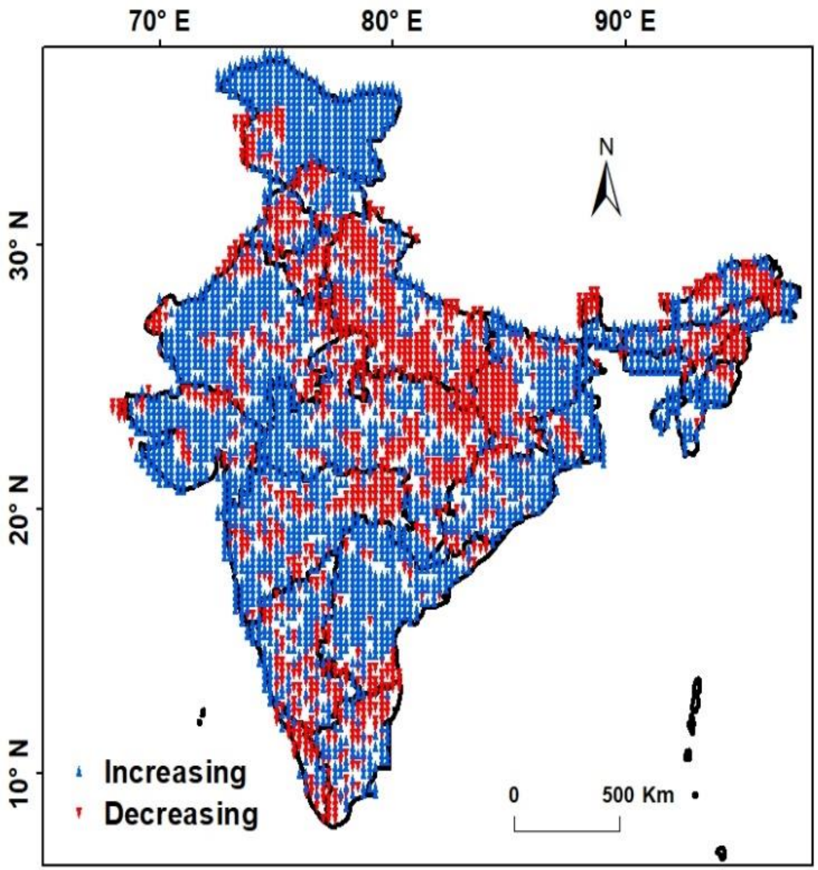




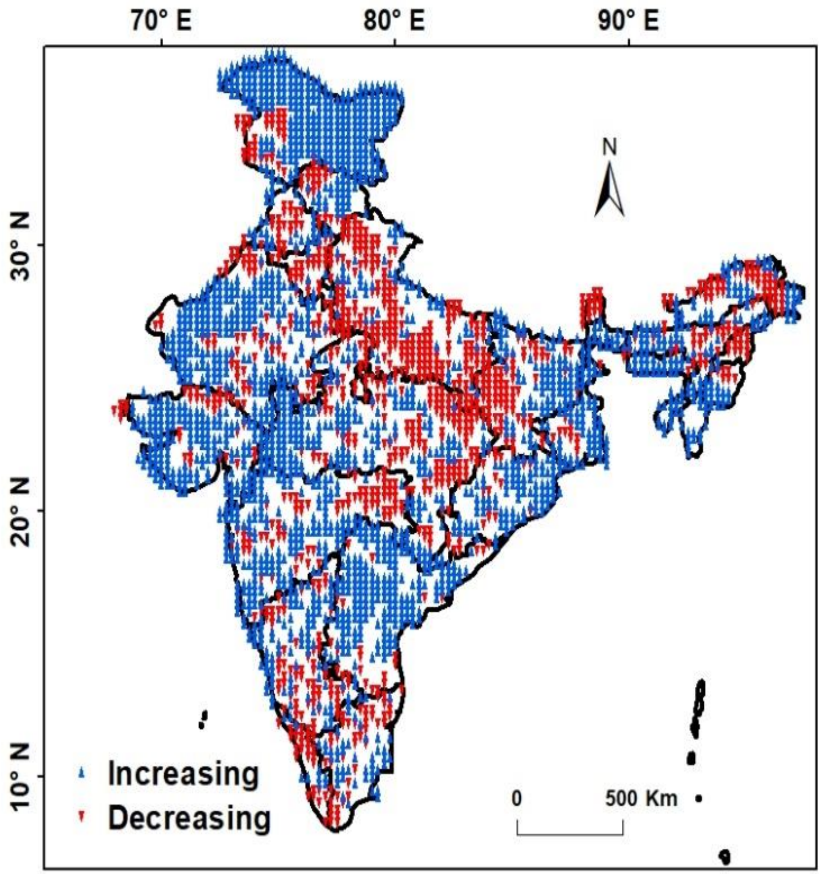
Change magnitude as Percentage of Mean

- **For Gridded Data over India: Percentage (%) Change over 110 years**

5 % Significance level



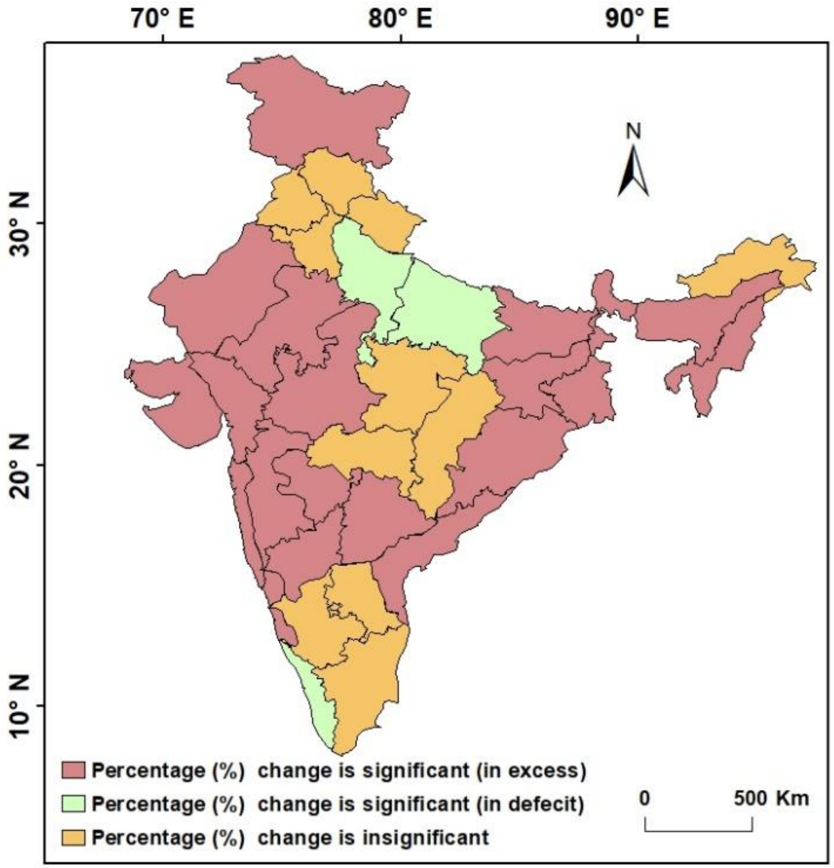
10 % Significance level



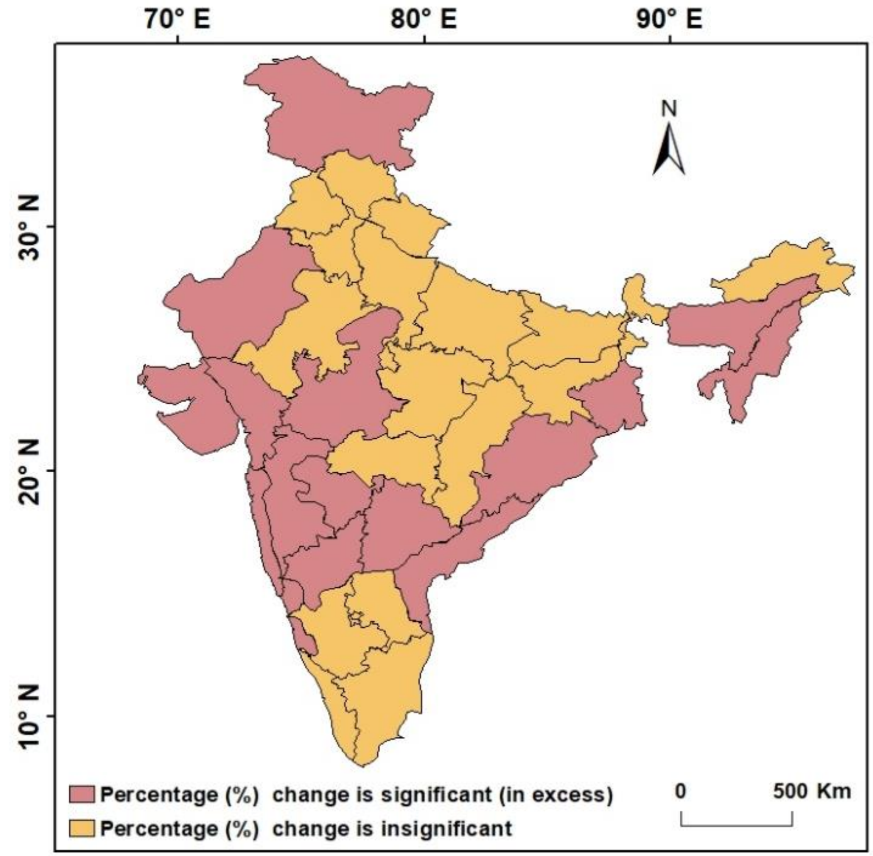
Change magnitude as Percentage of Mean

- **For Meteorological Sub-division over India**

5 % Significance level



10 % Significance level



Change magnitude as Percentage of Mean

- **Conclusion**

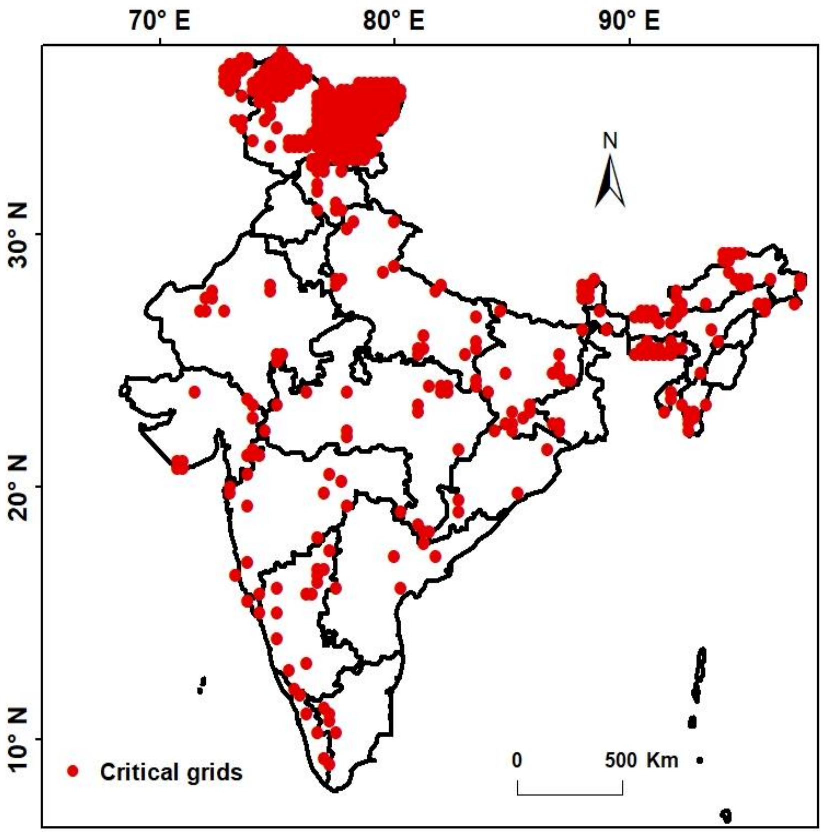
- Change In magnitude of Annual Maximum rainfall series indicated a significant change in nearly 82.60 % (4088 out of 4949) , 65.52 % (3243 out of 4949) grids at 5% & 10% significance level respectively

- Out of today grids showing significant change in magnitude 63.60% shows an increasing change while 36.39% shows decreasing changes at 5% significance level

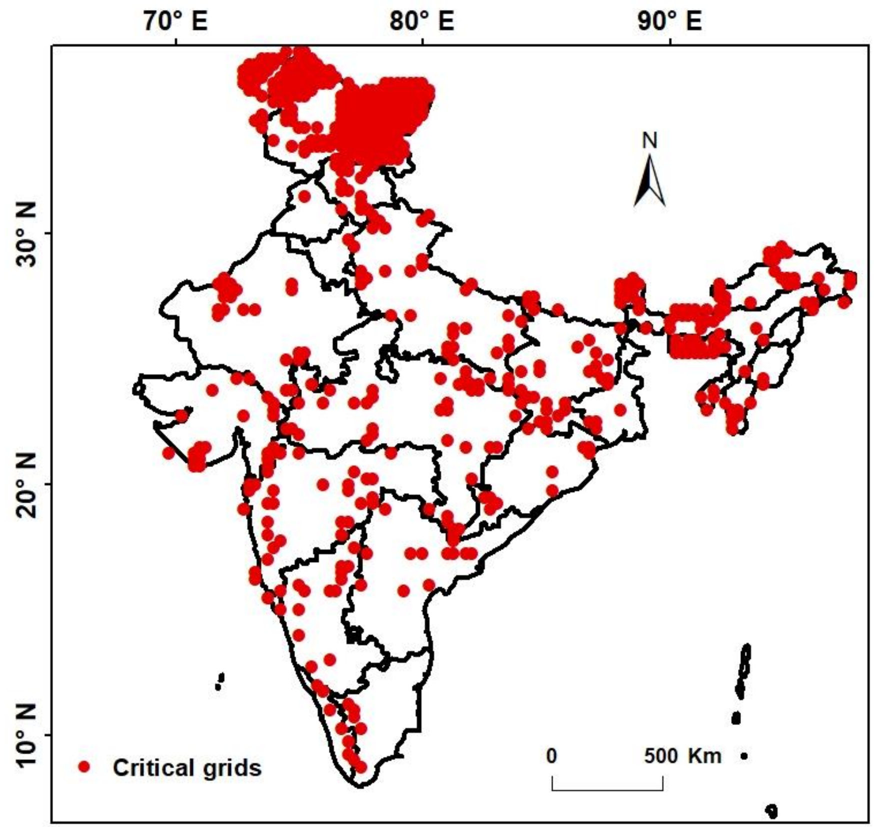
- Out of today grids showing significant change in magnitude 66.32% shows an increasing change while 33.67 % shows decreasing changes at 10% significance level

Critical Grids

5 % Significance level



10 % Significance level



Thank You !!!