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Long term rainfall trend over meteorological sub divisions and districts of India

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सार – इस शोध पत्र में विभिन्न जिलों, मौसम उपखंड्रें और समूचे भारत में वार्षिक और ऋतुकालिक वर्षा की दीर्घकालिक प्रवृत्ति का अध्ययन किया गया है जिसके लिए 1901 - 2013 तक की अवधि के दीर्घकालिक वर्षा आँकड़ों का उपयोग किया गया है। वर्षा की मात्रा और पैटर्न में परिवर्तन कृषि, जल संसधन प्रबंधन और देश की सम्पूर्ण अर्थव्यवस्था को प्रभावित करती है। इस प्रवृत्ति की विशेषता की जांच करने के लिए मैनकैंडल टैस्ट का अनुप्रयोग किया गया है। अंडमान और निकोबार द्वीप समूह और लक्षद्वीप को छोड़कर देश के मुख्य भू - भाग में ग्रिडिड वर्षा आँकड़ा (0.25º × 0.25º) का उपयोग करते हुए भारत के 632 जिलों और 34 उपखंड़ों का अध्ययन किया गया है। बहुत से लेखकों ने यह अध्ययन किया कि वर्षापात की चरम घटनाएं बढ़ रही है परन्तु पैन इंडिया में वर्षा का कोई ट्रेंड नहीं है। जिला स्तर पर, वार्षिक वर्षा विश्लेषण से यह रिकॉर्ड किया गया है कि 10% जिलों में बढ़ोत्तरी देखने को मिली है और 13% में कमी (मुख्य रूप से उत्तर प्रदेश में) देखने को मिली है। कम या अधिक वर्षा क्षेत्रों के निरपेक्ष रहते हुए यह देखा गया है कि देश के 10% क्षेत्र में वर्षा में महत्वपूर्ण बढ़ोतरी की प्रवृत्ति है एवं 8% क्षेत्रों में महत्वपूर्ण नकारात्मक प्रवृत्ति पाई गई है। विशेष रूप से पूर्वी और पश्चिमी उत्तर प्रदेश मौसम उपखंडों में नकारात्मक प्रवृत्ति को दर्शाते हैं और कुछ तटीय उपखंडों में सकारात्मक प्रवत्ति को दर्शाते हैं। यह भी देखा गया है कि संपूर्ण देश की वर्षा किसी प्रकार की कोई महत्वपूर्ण प्रवृत्ति नही दिखा रही है।

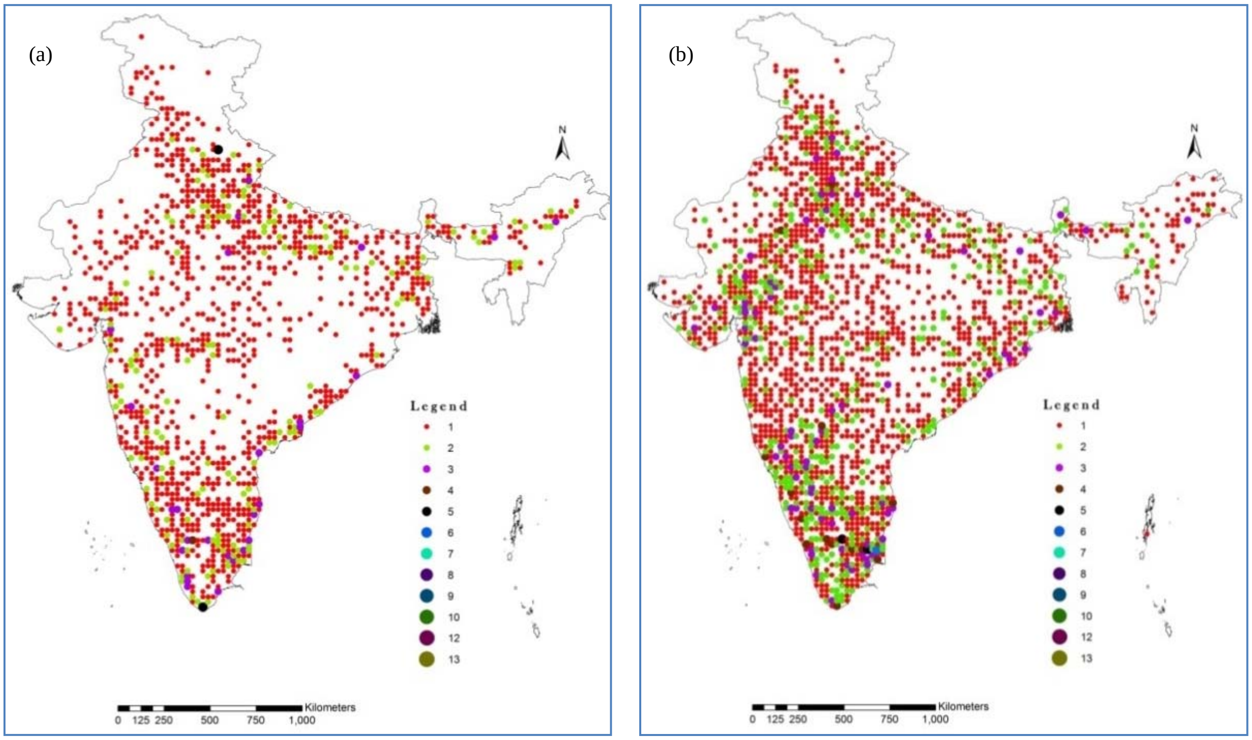
ABSTRACT. In this paper the long term trend of annual and seasonal rainfall over different districts, Meteorological (Met.) sub-divisions and whole India have been studied using the long term rainfall data for the period from 1901 to 2013. The changes in amount and pattern of rainfall have a significant impact on agriculture, water resources management and overall economy of the country. Mann-Kendall test is applied to check the significance of the trend. Linear Regression and Theil-Sen's non parametric test has been applied to estimate the trend. The study is carried out for 632 districts and 34 sub divisions of India by utilizing the gridded rainfall data (0.25° × 0.25°) over the main land except Andaman & Nicobar and Lakshadweep islands. Many authors have studied that extreme events are increasing but there is no trend in Pan India's rainfall. It is observed from the annual rainfall analysis 10% of the number of districts are showing significant increasing trend and 13% significant decreasing (mainly in Uttar Pradesh) trend whereas irrespective of high and low rainfall regions, 10% area of the country is showing significant increasing trend and 8% of the area of the country showing significant decreasing trend in annual rainfall. In Meteorological Sub divisions, east & west UP are showing significant negative trend and some of the coastal sub divisions are showing positive trend. It is also observed that the country's rainfall is not showing any trend.

Key words – Rainfall trend, CV, Meteorological sub-division, Theil-Sen, Mann-Kendall test.

1. Introduction

The annual rainfall over India is highly variable in space and time. More than 75% of rainfall received during southwest (SW) monsoon period (June to Sept) which results in scarcity of water in many parts of the country during the non-monsoon periods, although large number, around 5000 large hydraulic structures have been constructed to store the water to use for drinking and irrigation purposes. The water requirement in India is increasing; it will be almost double from the year 2000 to 2050. The problem may be aggravated due to global climate changes which may influence long-term rainfall patterns impacting the availability of water, along with the increasing number of extreme rainfall events results in occurrences of droughts and floods. Changes in climate over the Indian region, particularly during the SW monsoon, would have a significant impact on agricultural production, water resources management and overall economy of the country.

Water resource has become a prime concern for any development and planning including food production, flood control and effective management of water resource. IPCC (2007) reported that global surface warming is occurring at a rate of 0.74 ± 0.18 °C in period 1906-2005. Parry *et al.* (2007) has also reported that the IPCC has estimated that even if the concentration of all greenhouse



Figs. 1(a&b). Map showing no. of stations per Grid for year (a) 1901 & (b) 2013

gases and aerosols will be kept constant at the year 2000 levels, a further warming of about 0.1 °C per decade would be expected. The impact would be particularly severe in the tropical areas, and mainly in developing countries, including India. Pant and Kumar (1997) have reported an increase in mean annual temperature in India at the rate of 0.57 °C in the last century.

The impact of climate change in the future is quite severe as given by IPCC reports which signify that there will be reduction in the freshwater availability because of climate change. This has also been revealed that by the middle of the twenty-first century, decrease in annual average runoff and availability of water will project up to 10-30%.

Many authors have studied trend in precipitation over different parts of India in different seasons and the results shows some places it is increasing and some places decreasing or no trend. Guhathakutha and Rajeevan (2007) have studied the rainfall trend over India and concluded that Indian monsoon rainfall as a whole does not show any significant trend but trends are observed over some specific areas. During the southwest monsoon season, three subdivisions *viz*., Jharkhand, Chhattisgarh, Kerala show significant decreasing trend and eight subdivisions *viz*., Gangetic WB, West UP, Jammu & Kashmir, Konkan & Goa, Madhya Maharashtra, Rayalseema, Coastal AP and North Interior Karnataka show significant increasing trends. Gajbhiye *et al.* (2016) have studied trend analysis over Sind basin and found increasing trend in seasonal and annual series during 1901-2002. Various studies have been carried out over Himalayan region. Pant *et al.* (1999) have found that seasonal and annual rainfall did not show any significant trend over Western Himalaya during the period 1893-1990. Archer and Fowler (2004) found a non-significant trend (10% per 100 years) over Srinagar. Kumar *et al.* (2005) have found a slight downward trend in monsoon rainfall and a slight upward trend in winter rainfall over Himachal Pradesh during 1964-1992. Preethi *et al.* (2016) have studied the recent trends over South and East Asian summer monsoons. They have identified two regions over India namely northeast India showing decreasing trend and increasing over the northern part of the West coast of India during SW monsoon.

As mentioned above, many authors have studied trend in precipitation over different parts of India or Pan India on a state, sub divisional or river basin scale. In this paper, the long term trend in precipitation has been studied on a district scale for the whole India using the data from 1901 to 2013. There are significant developments in recent years, so the trend analysis is also carried out for the recent period 1961-2013.

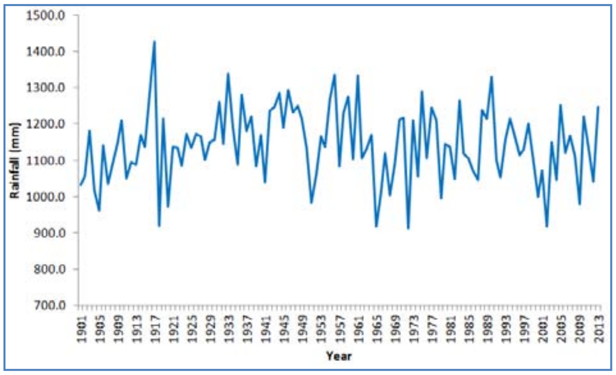


Fig. 2. The India's rainfall for the period 1901-2013

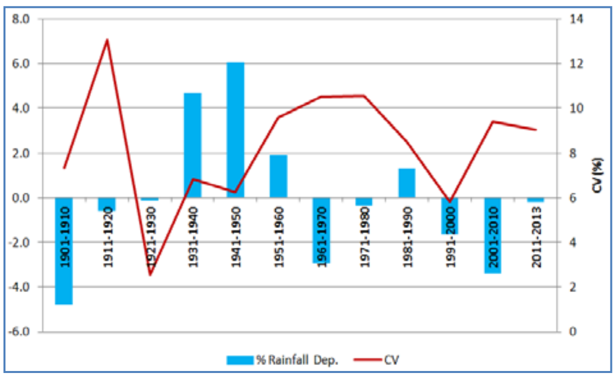


Fig. 3. Decadal % rainfall departure and CV of India's rainfall.

2. Data Used

The daily gridded rainfall data Pai *et al.* (2014) at a high spatial resolution (0.25° × 0.25) of a longer period of 113 years (1901-2013) over the Indian main land has been used in this study. The gridded data has been prepared by IMD using the daily rainfall records from 6995 rain gauge stations in India after making quality control of basic rain-gauge stations. The gridded rainfall is computed for main land area excluding Andaman & Nicobar (AN) and Lakshadweep (LK) islands. For the preparation of the gridded data for each day of the data period, on an average, about 3500 stations that varied between 1450 & 3900 were used. For the interpolation, inverse distance weighted interpolation (IDW) scheme of Shepard (1968) was used. The districts rainfalls have been computed for 632 districts from the gridded rainfall data by simple average over the rainfall at the grids lying in the district. The sub divisional rainfall has been computed for 34 sub divisions using the weighted average rainfall of the districts and the country's rainfall by the weighted rainfall of the sub divisions. The number of stations per grid used in preparation of gridded rainfall is given in Figs. 1(a&b).

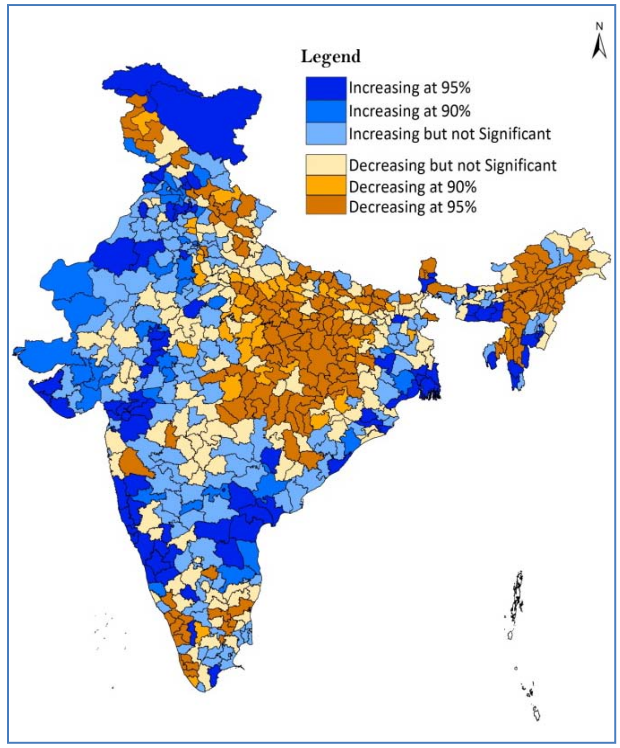


Fig. 4. District wise annual rainfall trend for the period 1901-2013

3. Methodology

The Mann-Kendall and Sen's slope estimator has been used for the determination of the trend.

3.1. *Significance of trend*

The Mann-Kendall test [Burn *et al.*, 2004; Douglas *et al.*, 2000; Libiseller and Grimval, 2002; Singh *et al.*, 2008a; Yu *et al.*, 1993; Yue and Hashino, 2003] is used to detect monotonic (increasing or decreasing) trends and is widely used for detecting trends in time series, because it is simple and robust accommodates missing values and the data need not conform to any statistical distribution. Since there are chances of outliers to be present due to extreme rainfall events, the non-parametric Mann-Kendall test is useful, because its statistic is based on the (+ or −) signs, rather than the values of the random variable and therefore, the trends determined are less affected by the outliers [Birsan *et al.*, 2005; Helsel & Hirsch, 1992].

Trend analysis using the MK test to detect trend in the rainfall time series, we proceeded as follows:

Assuming that the rainfall time series was independent, and then the Mann-Kendall statistic S was computed as:

TABLE 1

State wise number of districts showing increasing and decreasing trend

S. No.	State & UT	Total no. of Districts	No. of Districts (1901-2013)		No. of Districts (1961-2013)	
			Increasing trend	Decreasing trend	Increasing trend	Decreasing trend
1.	Arunachal Pradesh	16	0	8	1	7
2.	Andhra Pradesh	13	6	0	4	0
3.	Assam	27	1	15	2	9
4.	Bihar	38	1	13	4	2
5.	Chandigarh	1	0	1	0	0
6.	Chhattisgarh	18	1	12	1	0
7.	Delhi	8	0	0	0	8
8.	Dadra & Nagar Haveli and Daman & Diu	3	2	0	0	1
9.	Goa	2	1	0	2	0
10.	Gujarat	26	7	0	4	0
11.	Haryana	22	2	0	0	5
12.	Himachal Pradesh	12	3	3	0	1
13.	Jammu & Kashmir	14	3	4	6	2
14.	Jharkhand	24	0	7	3	1
15.	Karnataka	30	8	2	6	1
16.	Kerala	14	0	9	1	3
17.	Madhya Pradesh	52	5	12	0	3
18.	Maharashtra	35	8	6	1	0
19.	Manipur	10	3	0	4	0
20.	Meghalaya	7	5	1	1	2
21.	Mizoram	8	2	4	5	0
22.	Nagaland	11	0	10	0	0
23.	Odisha	30	4	4	12	0
24.	Puducherry	4	0	1	0	1
25.	Punjab	21	5	0	2	0
26.	Rajasthan	33	2	0	0	0
27.	Sikkim	4	1	3	1	2
28.	Tamil Nadu	32	2	5	1	1
29.	Telangana	10	2	0	0	0
30.	Tripura	4	1	2	0	0
31.	Uttarakhand	13	0	6	0	4
32.	Uttar Pradesh	72	0	27	0	32
33.	West Bengal	18	7	2	3	0
	Total	632	82 (13%)	156 (24.7%)	64 (10.1%)	85 (13.4%)

$$S = \sum_{\substack{1\leq i\leq n-1 \\ i+1<j<n}} \text{sign}(X_j\text{-}X_i) \quad (1)$$

where, X_i and X_j are sequential data for the i^{th} and j^{th} terms; n is the sample size; and

$$\text{sign}(X_j\text{-}X_i) = \begin{cases} +1; & \text{if } X_j\text{-}X_i>1 \\ 0; & \text{if } X_j\text{-}X_i=0 \\ -1; & \text{if } X_j\text{-}X_i<1 \end{cases} \quad (2)$$

The statistic S is approximately Gaussian when n = 18 with the mean E(S) and variance Var (S) of the statistic S is given by:

$$E(S) = 0 \text{ and } Var(S) = \frac{n(n-1)(2n+5)}{18} \quad (3)$$

However, if ties exist in the dataset, then the expression for Var(S) has to be adjusted and becomes :

$$Var(S) = \frac{n(n\text{-}1)(2n\text{+}5)\text{-}\sum_{p=1}^{q} t_p\,(t_p\text{-}1)\,(2t_p\text{+}5)}{18} \quad (4)$$

The variable q and t_p are number of tied group's and number of data values in the p^{th} group, respectively. The standardized statistic (Z) for one-tailed test of the statistic S is given as follows:

TABLE 2

Districts with increasing trend ↑ in annual rainfall during the period 1961-2013

State	Name of Districts	Area (sq. km)	%
Arunachal Pradesh	West Kameng	5510.0	0.1683
Andhra Pradesh	Guntur, Krishna, Prakasam, Vishakhapatnam	49634.9	1.5161
Assam	Baksa, Barpeta	4725.6	0.1443
Bihar	Bhagalpur, Katihar, Munger, Purnia	10255.9	0.3133
Chhattisgarh	Dantewara	8598.0	0.2626
Goa	North Goa, South Goa	3718.2	0.1136
Gujarat	Ahmedabad, Junagarh, Rajkot, Surendra Nagar	38704.6	1.1823
Jammu And Kashmir	Baramula, Mirpur, Punch, Riasi, Udhampur	35030.4	1.0700
Jharkhand	Purbi Singbhum, Sahebganj, Saraikela	8441.9	0.2579
Karnataka	Chikmagalur, Chitradurga, Davangere, Kolar, Mandhya, Uttar Kannada	41002.9	1.2525
Kerala	Idukki	4384.9	0.1339
Maharashtra	Pune	15728.0	0.4804
Manipur	Bishnupur, Churachandpur, Imphal East	5807.1	0.1774
Meghalaya	South Garo Hills	1929.7	0.0589
Mizoram	Aizawl, Champhai, Kolasib, Lawngtlai, Serchhip	11624.1	0.3551
Orissa	Baragarh, Cuttack, Kalahandi, Kendujhar, Khordha, Koraput, Malkangiri, Mayurbhanj, Nabarangapur, Nayagarh, Puri, Subarnapur	68846.9	2.1030
Punjab	Patiala, Sas Nagar	3731.6	0.1140
Sikkim	East Sikkim	957.7	0.0293
Tamil Nadu	Teni	2882.5	0.0880
West Bengal	Bankura, Darjeeling, Puruliya	16326.4	0.4987
	Total		10.3197

TABLE 3

Districts with decreasing trend ↓ in annual rainfall during the period 1961-2013

State	Name of Districts	Area (sq. km)	%
Arunachal Pradesh	Dibang Valley, East Siang, Lohit, Lower Dibang Valley, Tirap, Upper Siang, West Siang	37673.1	1.1508
Assam	Dhemaji, Dibrugarh, Golaghat, Kamrup Metro, Karbi Analog, Lakhimpur, N.C. Hills, Tinsukia	34098.7	1.0416
Bihar	Kishanganj, Siwan	4222.7	0.1290
Delhi	Central Delhi, East Delhi, North Delhi, Ne Delhi, Nw Delhi, South Delhi, Sw Delhi, West Delhi	1489.6	0.0455
Daman & Diu	Diu	28.2	0.0009
Harayana	Gurgaon, Jhajjar, Karnal, Panipat, Sonipat	9048.4	0.2764
Himachal Pradesh	Shimla	5138.0	0.1569
Jammu And Kashmir	Kathua, Tribal Territory	5202.1	0.1589
Jharkhand	Palamu	4408.8	0.1347
Karnataka	Dharwad	4281.2	0.1308
Kerala	Kozikod, Palakkad, Thiruvanathpuram	9039.4	0.2761
Madhya Pradesh	Datiya, East Nimar, Hoshangabad	16873.6	0.5154
Meghalaya	Jaintia Hills, Ri Bhoi	6233.1	0.1904
Pondicherry	Yanam	38.0	0.0012
Sikkim	North Sikkim, West Sikkim	5481.7	0.1674
Tamil Nadu	Kanyakumari	1692.8	0.0517
Uttarakhand	Dehradun, Nanital, Pauri Garhwal, Uttarkashi	20438.1	0.6243
Uttar Pradesh	Agra, Aligarh, Auraiya, Baghpat, Ballia, Balrampur, Barabanki, Bulandsahar, Etah, Etawah, Farrukhabad, Fatehpur, Firozabad, Gautam Budh Nagar, Gazipur, Gonda, Gorakhpur, Jalaun, Kannauj, Kanpur, Kanpur Dehat, Kanshiram Nagar, Kushinagar, Mahamaya Nagar, Maharajganj, Mainpuri, Mathura, Muzafarnagar, Pratapgarh, Raibeareli, Siddharthnagar, Unnao	97663.9	2.9832
	Total		8.0352

TABLE 4

% area of the country showing increasing and decreasing trend in annual rainfall

Region	Period (1961-2013)	
	Increasing trends ↑	Decreasing trends ↓
India*	14%	8%
India* except Leh & Ladakh district	10%	8%

*India except Andaman & Nicobar and Lakshadweep Island

TABLE 5

Mann-Kendall test parameters of some districts showing increasing trend in annual rainfall

Parameters	Aizawl	Bhagalpur	Dantewara	Kolar	Mayurbhanj	North Goa	Patiala	Prakasam
n	53	53	53	53	53	53	53	53
Z	3.61	3.01	2.01	2.35	1.8	3.96	2.24	2.64
S	471	405	263	307	235	517	293	345
OLS (Regression Line)								
Slope	18.55	11.41	5.37	3.53	5.28	36.21	4.93	4.08
Intercept	1858	1148	1317	665	1441	2946	780	759
Theil-Sen Trend Line								
Slope	20.25	10.93	5.15	3.43	5.13	34.86	4.07	5.07
Intercept	1865	1206	1261	636	1383	3035	787	717

TABLE 6

Mann-Kendall test parameters of some districts showing decreasing trend in annual rainfall

Parameters	East Nimar	Etawah	Gorakhpur	Jalaun	Kozikod	Nainital	Tinsukia	Tirap
n	53	53	53	53	53	53	53	53
Z	-2.03	-4.22	-1.87	-3.54	-2.79	-3.1	-3.64	-2.22
S	-265	-551	-245	-463	-365	-405	-475	-291
OLS Regression Line								
Slope	-3.99	-9.07	-4.92	-8.5	-20.3	-10.14	-19.92	-4.35
Intercept	1090	895	1261	1066	3426	1667	3149	2449
Theil-Sen Trend Line								
Slope	-4.69	-9.67	-4.69	-8.46	-17.89	-12.27	-22.82	-6.69
Intercept	1086	917	1254	971	3372	1740	3023	2495

$$Z = \begin{cases} \frac{S-1}{\sqrt{(Var(S)}}, & \text{if } S > 0 \\ 0, & \text{if } S = 0 \\ \frac{S+1}{\sqrt{Var(S)}}, & \text{if } S < 0 \end{cases} \qquad (5)$$

If Z is positive, then the trend is increasing, and if Z is negative, then the trend is decreasing.

3.2. *Magnitude of trend*

In addition to identifying whether the trend exists, the magnitude of the trend was also estimated by a slope estimator β, which was extended by Hirsch *et al.* (1982) that was proposed by Sen (1968). β is the robust estimate of the trend magnitude. In other words, the slope estimator β is the median of overall possible combinations of pairs for the whole dataset. A positive value of β indicates an 'upward trend' (increasing values with time), while a negative value of β indicates a 'downward trend' (Karpouzos *et al.*, 2010; Xu *et al.*, 2007). The magnitude of trend was predicted by the Sen's slope estimator with the slope (T_i) of all data pairs was computed as follows:

$$T_i = X_j - X_i \,/\, j\text{-}i \qquad (6)$$

where, X_j and X_i are considered as rainfall values at time j and i ($j > i$). The median of these N values of T_i is

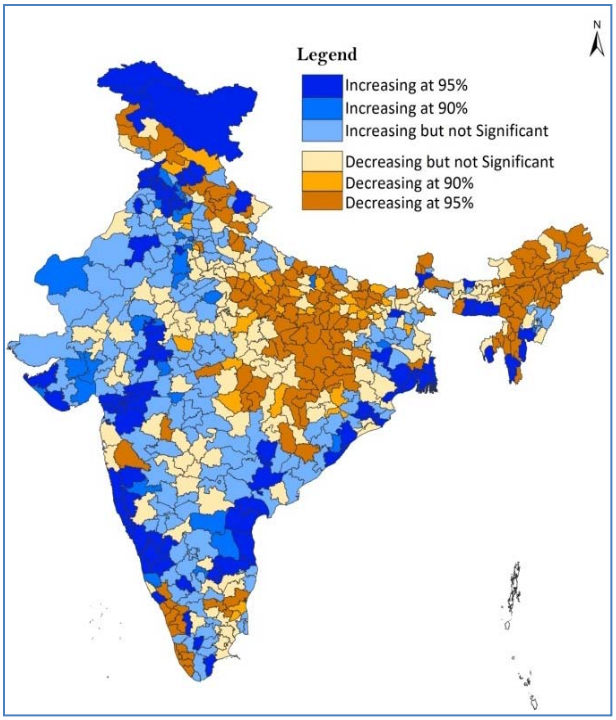


Fig. 5. District wise trend in monsoon rainfall for the period 1901-2013

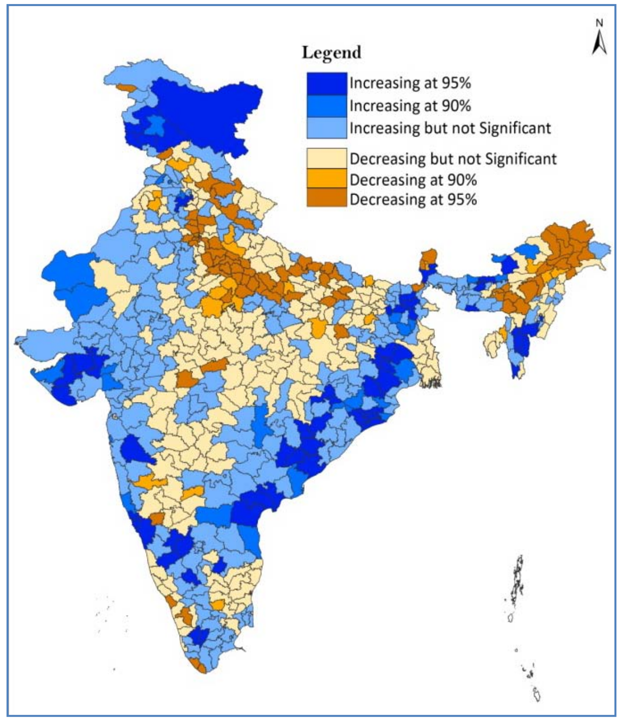


Fig. 6. District wise trend in annual rainfall for the period 1961-2013

represented as Sen's estimator of slope. Sen's estimator is computed as $Q_{med}=T(N+1)/2$ if N is odd and it is considered as $Q_{med}=[T(N/2) +T(N+1)/2]/2$ if N is even. At the end, Q_{med} is tested at 100 $(1-\alpha)$% confidence interval, and then a true slope can be obtained by the non-parametric test. A positive value of Q_i indicates an upward or increasing trend, and a negative value gives a downward or decreasing trend in the time series.

4. Results and discussion

4.1. *Mean, CV and % departure from normal of annual rainfall*

The year wise India's rainfall from 1901 to 2013 is given in Fig. 2. The maximum and minimum rainfall received in the years 1917 and 1972 as 1426 and 912 mm (excluding Andaman & Nicobar and Lakshadweep Island) respectively. The years 1905, 1920, 1951, 1965, 1972, 1979, 2002 and 2009 have received less than 1000 mm rainfall. The decadal % rainfall departure and CV of India's rainfall are given in the Fig. 3. The annual decadal % departure rainfall is showing a pattern of 30 years cycle with positive and negative departures upto 1980 but it is showing a positive departure in the decade 1981-1990 different from the pattern. From 1991 onwards it is showing negative departures till 2013. The years 2014 & 2015 are also having negative departure of -12% and -9% respectively. The value of CV is high in case of negative decadal annual rainfall % departure and low in case of positive decadal annual rainfall % departure.

4.2. *Trend in districts rainfall (1901-2013)*

The Mann-Kendall (MK) trend test is applied to district wise annual rainfall series (1901-2013) to check the trend. The state wise number of districts showing increasing and decreasing trend are given in Table 1. It is found that 82 districts are showing significant increasing trend and 156 districts are showing significant negative trend at 95%. Out of the 632 districts, 13% of the districts are showing increasing trend, 25% of the districts are showing decreasing trend and 62 % of the districts are not showing any trend or the trend is not significant at 5% level of significance. It can be seen from the Table that Andhra Pradesh (6), Gujarat (7), Karnataka (8), Maharashtra (8), W. Bengal (7) districts are showing an increasing trend whereas Assam (15), Bihar (12), Chhattisgarh (12), Kerala (9), Madhya Pradesh (12), Nagaland (10), Uttar Pradesh (27) are showing decreasing trend. The district wise information of annual rainfall showing significant increasing trend at 95% & 90%, decreasing trend at 95% & 90% and increasing & decreasing trend but not significant are shown in Fig. 4. The district wise trend in monsoon rainfall is also studied and results are shown in Fig. 5. It is found that the pattern of increasing and decreasing trend is similar to annual

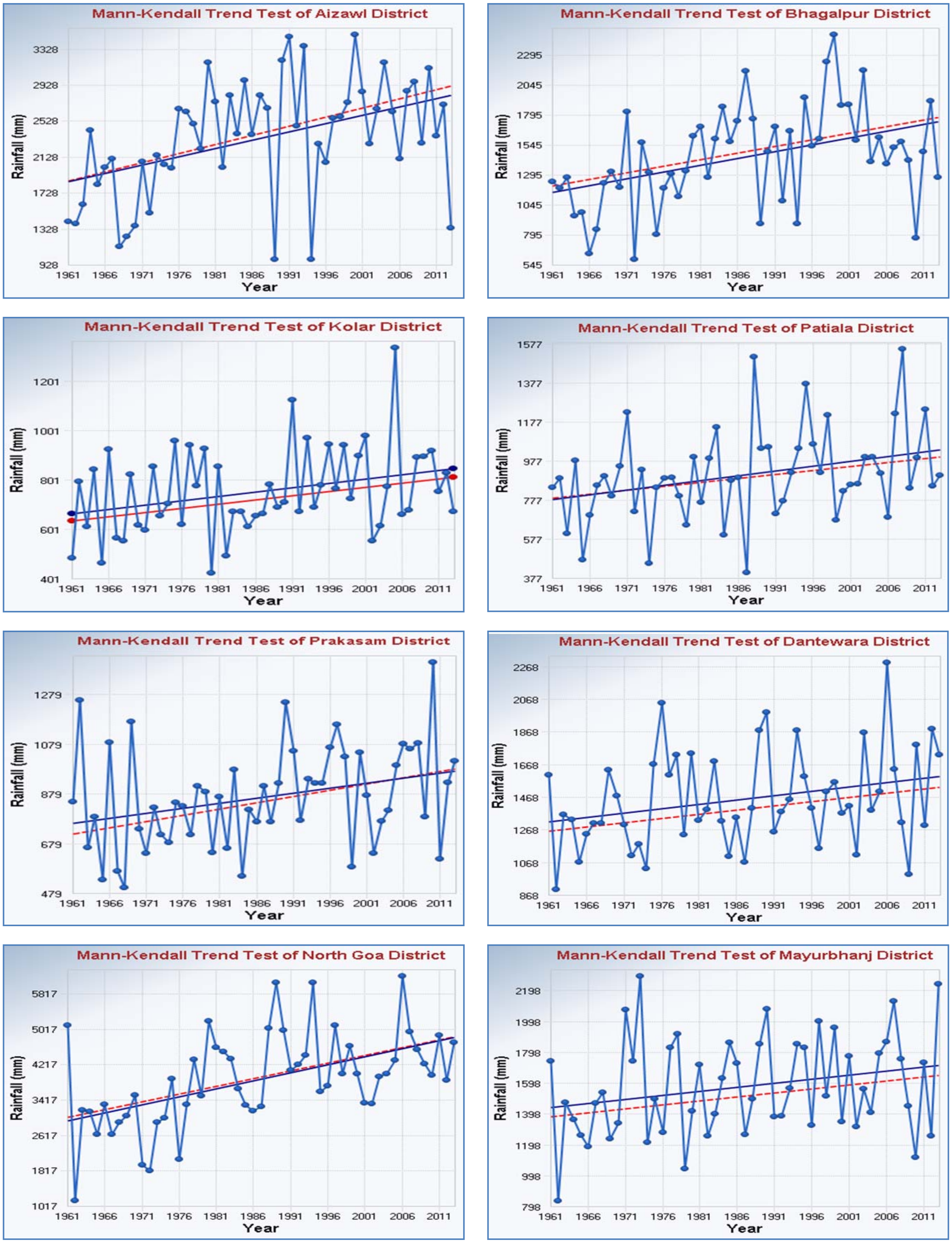


Fig. 7. Mann-Kendall trend test of some districts showing increasing trends
(Note: *Red line denotes Theil-Sen trend line and blue line denotes OLS regression line*)

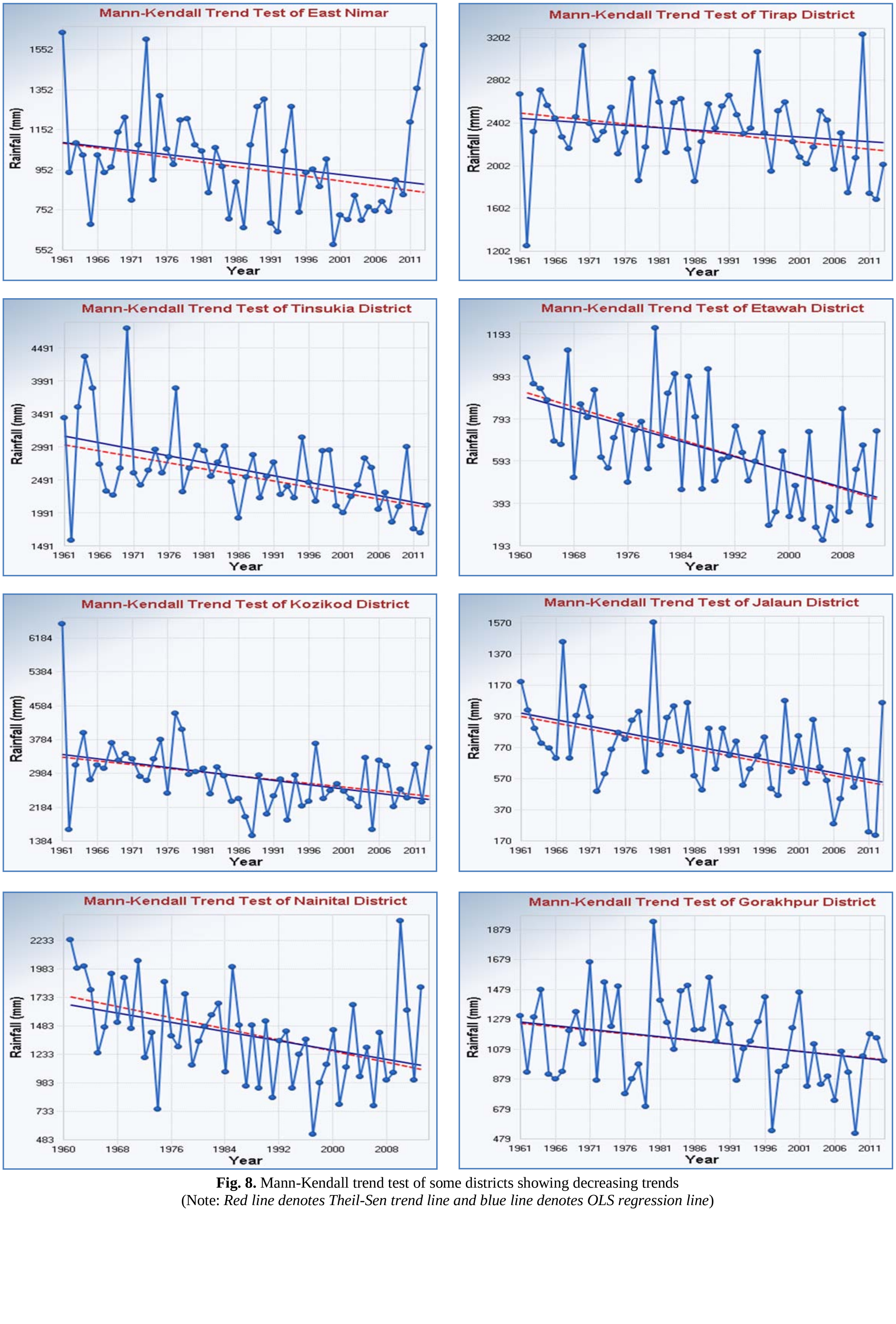
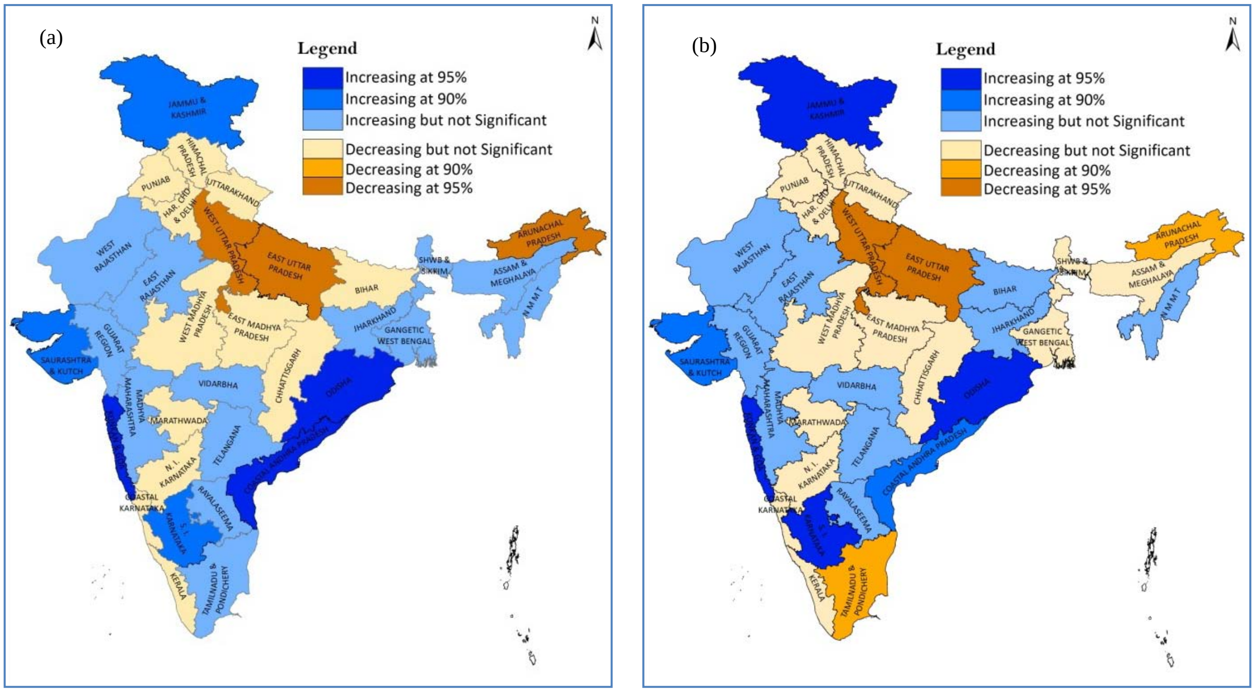


Fig. 8. Mann-Kendall trend test of some districts showing decreasing trends
(Note: *Red line denotes Theil-Sen trend line and blue line denotes OLS regression line*)



Figs. 9(a&b). Meteorological (Met.) sub-division wise (a) Annual and (b) Monsoon rainfall, trend for the period (1961-2013)

rainfall. However, the number of districts for significant increasing and decreasing trend is less in the monsoon rainfall as compared to annual rainfall. This may be due to less variability in monsoon rainfall because more than 75% of rainfall occurs during the monsoon period (June-September).

4.3. *Trend in districts rainfall (1961-2013)*

The Mann-Kendall (MK) trend test is applied to district wise annual rainfall series for the recent period (1961-2013) to check the trend. The state wise number of districts showing increasing and decreasing trend are given in Table 1. It is found that 64 districts are showing significant increasing trend and 85 districts are showing significant negative trend at 95%. Out of the 632 districts, 10% of the districts are showing increasing trend 13% of the districts are showing decreasing trend and 77 % of the districts are not showing any trend or the trend is not significant at 5% level of significance. It can be seen from the table that Andhra Pradesh (4), Bihar (4), Gujarat (4), Manipur (4), Jammu & Kashmir (6), Karnataka (6), Mizoram (5) and Odisha (12) districts are showing an increasing trend whereas Arunachal Pradesh (7), Assam (9), Delhi (8), Haryana (5) and Uttar Pradesh (32) are showing decreasing trend. The districts with significant increasing trend at 95% & 90%, decreasing trend at 95% & 90% and increasing & decreasing trend but not significant are shown in Fig. 6. It is observed that there is decreasing trend over NE India and Indo-Gangetic plains. It is also observed that in the coastal areas there is increasing trend over northern part of western coast and eastern coast except Tamil Nadu. Preethi *et al.* (2016) mentioned that the decrease in rainfall may be due to intensification and expansion of the South Asian High (SAH) in recent times.

The state-wise name of the districts and their corresponding areas showing increasing and decreasing significant trend in annual rainfall during the period 1961-2013 are given in Table 2 and Table 3 respectively. It can be seen from Table 4, annual rainfall for the period 1961-2013 shows that 10% area of the country is showing significant increasing trend whereas 8% of the area of the country showing significant decreasing trend after excluding the area of the Leh & Ladakh (J & K) district due to its large area and sparse network. It is showing the % area of the country for increasing and decreasing trend irrespective of the magnitude of the rainfall.

After comparing the periods 1901-2013 and 1961-2013 (Table 1), it is found that total numbers of districts are descendants both in increasing and decreasing trend. In Eastern coast there is an increasing trend in more number of districts as we move from coast to inland in the state of Odisha and Andhra Pradesh. It may be due to more intense storm activities and penetrating more in the land areas. It can be also seen that, the states of Bihar, Chhattisgarh, East UP and West MP showing significant decreasing trend to insignificant decreasing trend. There are some changes observed in the North Eastern India and other parts of India. The changes in north eastern India may be due to the increase in rain-gauge network in the recent period which computes more precise rainfall information.

In recent period, 149 districts are showing significant increasing or decreasing trend. Out of these some districts showing significant increasing and decreasing trends are shown in the Fig. 7 and 8 respectively.

The parameters *n*, S, Z and Slope & Intercepts by Ordinary Least Square (OLS) Regression and Theil-Sen Trend line for some districts showing increasing and decreasing trend in annual rainfall during the period 1961-2013 are given in Table 5 and Table 6 respectively.

4.4. *Trend in meteorological sub-division*

4.4.1 *Annual rainfall*

The trend analysis has been carried out on the annual rainfall series from 1961-2013 on the 34 sub-divisions except AN & LK for which gridded data is not available and the results are shown in the Fig. 9(a), it can be seen that the sub-divisions of West UP, East UP and Arunachal Pradesh are showing significantly negative trend in rainfall whereas the sub-divisions Odisha, Coastal AP and Konkan & Goa are showing significantly positive trend at 95%.

4.4.2 *Monsoon rainfall*

From the Fig. 9(b), it can be seen that the sub-divisions of West UP and East UP are showing significantly negative trend in monsoon rainfall whereas the sub-divisions Jammu & Kashmir, Odisha, S.I. Karnataka and Kankan & Goa are showing significantly positive trend in monsoon rainfall at 95%.

4.4.3 *Comparison of trend in Met.sub-division wise monsoon and annual rainfall (1961-2013)*

When we compare the trend in the sub-divisions of Annual and Monsoon Rainfall, it is found that there is difference in the significance of trend for some Met Sub-divisions. In Jammu & Kashmir trend in monsoon rainfall is significant at 95% whereas in annual rainfall it is significant at 90%, In coastal AP trend in monsoon rainfall is significant at 90% whereas in annual rainfall it is significant at 95%, In SI Karnataka trend in monsoon rainfall is significant at 95% whereas in annual rainfall it is significant at 90%, In Arunachal Pradesh trend in monsoon rainfall is significant at 90% whereas in annual rainfall it is significant at 95%. In few subdivisions the trend is changing from negative to positive side or vice-versa. In Tamil Nadu & Puducherry sub-division, significant negative trend in monsoon rainfall at 90% while it is showing positive trend in annual rainfall which indicates that there is a positive trend in the NE monsoon and Bihar subdivision showing positive trend in monsoon rainfall and negative trend in annual Rainfall. In Assam & Meghalaya it is showing negative trend in monsoon rainfall but positive significant trend in annual rainfall. Further study will be carried out in future publication.

5. Conclusions

This paper gives the information on the districts of India giving significant increasing, decreasing and no trend in rainfall which is useful for the state government officials working in the field of management of water resources, agriculture, flood management etc. The salient features are given below:

(*i*) The annual rainfall for the period 1901-2013, it varies from 912 mm to 1426 mm (excluding Andaman & Nicobar and Lakshadweep Island). The years 1905, 1920, 1951, 1965, 1972, 1979, 2002 and 2009 have received less than 1000 mm rainfall.

(*ii*) The decadal average rainfall showing a pattern of 30 years cycle with positive and negative departures from 1901-1980 there after it is showing negative decadal departures except a positive departure in the decade 1981-1990. It shows that if there is high variability in rainfall in the recent decades.

(*iii*) No district is showing increasing trend in the states/UT of Uttar Pradesh, Uttarakhand, Delhi and Puducherry in both the periods.

(*iv*) In the recent period, the maximum number of districts showing decreasing rainfall trend are 32 in Uttar Pradesh.

(*v*) In the recent period, the districts in Odisha, Jammu & Kashmir and Arunachal Pradesh showing increasing trend while Assam, Bihar, Mizoram, Nagaland, Madhya Pradesh, Kerala and Chhattisgarh showing decreasing trend. It is also seen that all the districts of Delhi showing negative trend.

(*vi*) Annual rainfall for the period 1961-2013 shows that the met sub divisions of Arunachal Pradesh, west & east UP are showing negative trend and Konkan & Goa, coastal AP and Odisha are showing significant positive trends.

(*vii*) Monsoon rainfall for the period 1961-2013 shows that the met sub divisions of west & east UP are showing negative trend and Konkan & Goa, SI Karnataka, J&K and Odisha are showing significant positive trends.

(*viii*) When we compare the trends in annual and monsoon rainfall in the met sub-divisions, they are not following the same pattern. In few met sub-divisions, there is negative trend in monsoon rainfall whereas positive in annual rainfall or *vice-versa* (Tamil Nadu & Puducherry, Bihar, Assam & Meghalaya) and in some met sub-divisions there is same pattern of trend but change in the level of significance. In Tamil Nadu & Puducherry, a positive trend is indicated in NE monsoon.

(*ix*) Annual rainfall for the period 1961-2013 shows that 10% area of the country is showing significant increasing trend whereas 8% of the area of the country showing significant decreasing trend irrespective of magnitude of rainfall.

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