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Trend assessment of rainfall, temperature and relative humidity using non-parametric tests in the national capital region, Delhi

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सार — जल संसाधन उपयोग की योजना और सिंचाई संबंधी निर्णय लेने के लिए स्थानीय, क्षेत्रीय और वैश्विक पैमानों पर वर्षा और तापमान की स्थानिक-अस्थायी विविधताओं को समझना महत्वपूर्ण है। वर्तमान जाँच में भारत के राष्ट्रीय राजधानी क्षेत्र (एनसीआर), दिल्ली, में 31 **वर्षों** (1990-2020) **में आईएआरआई मौसम विज्ञान केंद्र, पूसा, नई दिल्ली से प्राप्त वर्षा, तापमान और सापेक्ष आर्द्रता की प्रवृत्तियों और विविधताओं की पहचान करने का प्रयास किया गया है। समय के साथ परिवर्तन की प्रवृत्ति दिशा और परिमाण का आकलन करने के लिए वार्षिक, मासिक और ऋतुनिष्ठै विश्लेषण हेतु थेइल सेन ढलान परीक्षण के बाद मान-कंडेल** (MK) **परीक्षण का उपयोग करके सांख्यिकीय प्रवृत्ति विश्लेषण किया गया। चर की समय श्रृंखला में विभक्ति बिंदु का पता लगाने के लिए पेटीट परीक्षण किया गया है। वार्षिक अधिकतम तापमान** (*T*max), **न्यूनतम तापमान** (*T*min) **और वर्षा के डेटा में कोई प्रवृत्तियाँ नहीं पाई गई जबकि, वार्षिक सापेक्ष आर्द्रता में सकारात्मक वृद्धि की प्रवृत्ति दिखाई दी। जनवरी और दिसंबर के सर्दी के महीनों में अधिकतम तापमान** (*T*max) **में सांख्यिकीय रूप से महत्वपूर्ण गिरावट की प्रवृत्ति का पता चला है। इसका तात्पर्य जनवरी और दिसंबर के सर्दी के महीनों में तापमान में गिरावट से है। साथ ही, अधिकतम तापमान** (*T*max) **के ऋतुनिष्ठ विश्लेषण से शीत ऋतु में कमी की प्रवृत्ति का पता चला है। इसी तरह, न्यूतनतम तापमान** (*T*min) **से जनवरी और दिसंबर के सर्दी के महीनों में कमी की प्रवृत्ति का पता चला है। हालांकि, अप्रैल में न्यूनतम तापमान** (*T*min) **में सांख्यिकीय रूप से वृद्धि की प्रवृत्ति देखी गई, जो बढ़ते तापमान के कारण जायद मौसम की फसलों की खेती के लिए प्रतिकूल वातावरण पैदा कर सकती है। इसके अलावा, न्यूनतम तापमान** (*T*min) **के ऋतुनिष्ठद विश्लेषण से मॉनसून, शरद ऋतु और शीतऋतु के दौरान कमी की प्रवृत्ति का पता चला है। सापेक्ष आर्द्रता ने फरवरी, जून, जुलाई, अगस्त, सितंबर और मॉनसून ऋतु को छोड़कर वार्षिक, मासिक और ऋतुनिष्ठ आधार पर सकारात्मक वृद्धि की प्रवृत्ति दर्शाई। प्रवृत्ति परिवर्तन विश्लेषण में वार्षिक अधिकतम तापमान और न्यूनतम तापमान के डेटा श्रृंखला में कोई परिवर्तन बिंदु नहीं दिखाई दिया। यह देखा गया कि** 2005 **के अगस्त में न्यूनतम तापमान के डेटा में परिवर्तन की प्रवृत्ति है। साथ ही, न्यूनतम तापमान** (*T*min) **डेटा श्रृंखला के लिए मॉनसून और शीतऋतु में परिवर्तन बिंदु का पता चला है। वार्षिक औसत वर्षा डेटा में परिवर्तन बिंदु को** 2012 **में चिह्नित किया गया। सापेक्ष आर्द्रता में भी अप्रैल, नवंबर में वार्षिक और मॉनसून ऋतु के पैमाने पर डेटा श्रृंखला में परिवर्तन बिंदु दिखे। इस शोध पत्र में जल विज्ञान डिजाइन और फसल सिंचाई निर्णयों पर इन परिवर्तनों के शिक्षाप्रद प्रभाव पर चर्चा की गई है।**

ABSTRACT. Understanding rainfall and temperature spatio-temporal variations at the local, regional, and global scales is vital for water resource utilization planning and making irrigation decisions. The present investigation attempts to identify trends and variations in the rainfall, temperature and relative humidity over 31 years (1990-2020) in the National Capital Region (NCR), Delhi, India, obtained from IARI meteorological station, Pusa, New Delhi. The statistical trend analyses were carryout using Mann-Kendall (MK) test followed by Theil Sen slope test for annual, monthly and seasonal analysis to assess the trend direction and magnitude of the change over time. Pettitt's test employed to detect the inflection point in the variable's time series. The annual *T*max, *T*min and rainfall showed an absence of trends in the data. While, annual relative humidity showed a positive increasing trend. *T*max indicated a statistically significant decreasing trend in the winter months of January and December. This implies a dip in the temperature in the winter months of January and December. Also, *T*max seasonal analysis revealed a decreasing trend during winter season. Similarly, *T*min revealed a decreasing trend for the winter months of January and December. Although, a statistically increasing trend for *T*min was seen in April, which may cause a harsh environment for cultivating the Zaid season crops due to increased warming. In addition, *T*min seasonal analysis revealed a decreasing trend during monsoon, autumn and winter seasons. Relative humidity showed positive increasing trends on annual, monthly, and seasonal basis except during February, June, July, August, September and Monsoon season. The trend change analysis showed no change point in the annual *T*max and *T*min data series. It was observed that *T*min in August showed a change point in the data trend in 2005. Also, the change point was detected in monsoon and winter seasons for *T*min data series. The change point in the annual average rainfall data was marked in 2012. Relative humidity also showed change points in data series in April, November, Annual and Monsoon season scales. A didactic implication of these changes on hydrologic design and crop irrigation decisions was discussed in this paper.

Key words – Trend analysis, Man-Kendall test, Pettitt test, Theil-sen's slope, Climate analysis, India.

1. Introduction

Recent years have indicated a severe challenge to global food production due to alterations in climatic behavior besides others. Hindrances posed by climate change at various scales to agricultural sustainability attracted scientific intellect to pursue intensive efforts to understand their pattern and behavior to offset its effects (Kushwaha *et al*., 2016). Climate change has caused several impacts on land, water, and the environment at the global level. It threatens human existence due to food insecurity, water scarcity, farming failures, extreme events, infectious diseases, biodiversity loss and displacement due to the availability of deprived resources (Kushwaha *et al*., 2022). Rainfall and temperature are commonly utilized to explain climate change impacts water resources. Different studies have indicated that temperatures and rainfall have consistently registered monotonous changes to their trends in the past decades (Pingale *et al*., 2014). New *et al*. (2001) retrieved rainfall data from a different nation to detect rainfall trends and they reported an increasing trend during the 20^{th} century. A 150 years study led by authors Jones *et al*. (1999) on surface temperatures showed that the average temperature increased by 0.37 °C and 0.32 °C during 1925-1944 and 1978-1997 at the global scale. Several studies have been performed in India to assess the spatio-temporal variability of rainfall at various scales. According to Lal (2001), the random variability in rainfall in India during the past 100 years has no systematic shift either on a yearly or seasonal scale. However, rainfall fluctuation was noticed in India on temporal and spatial scales (Pattanaik, 2005). The rainfall trend analysis of 45 districts in Madhya Pradesh, India, was conducted, and 1978 was determined the most likely year of change in yearly rainfall (Duhan and Pandey, 2013). Researchers (Rajani *et al*., 2020) applied discrete wavelet transform (DWT) based Mann-Kendall test in the central Gujarat region for long-term trend analysis of rainfall. They reported a significant decrease in the rainfall amount across the stations. District level climate variables trend assessment helps develop proper agriculture plans to safeguard the crops and achieve better crop production (Khavse and Chaudhary. 2022). Extreme long-term records tend to absorb the trends due to a possible cyclic trend acquaintance. At the same time, a short-term, especially a decadal change, is likely to exhibit a seasonal tendency in variations as reported by Mahapatra and Mohanty (2006), found that the seasonal rainfall variation was more significant from 1980 to 1999 than from 1901-1990. Another authors (Phukan and Saha, 2022) analyzed rainfall trends in the rainfall over Tripura. They reported increasing and decreasing trends at the different stations within the state, which shows the spatial variability in the rainfall. Though, there was no significant trend was seen in the mean seasonal rainfall but substantial increase in the heavy rainfall events-based hazards over the central India would occur (Goswami *et al.*, 2006). The rainfall data sources (resolutions of products) also affect the trend assessment (Li *et al.*, 2022).

Most temperature trend analyses in India or elsewhere focus on analyzing seasonal and yearly temperature trends considering a single station or a cluster of stations. The study by Srivastava *et al*. (1992) on decadal climate trends over India offered the first clear signs that the diurnal discrepancy of surface temperatures over India is quite distinctive from that over most world regions. Pant and Kumar (1997) researchers examined yearly and season-wise air temperature data from 1881 to 1997 and discovered a significant temperature increase of 0.57°C per century. Author Jaswal (2010) evaluated India's monthly maximum and minimum temperature and found variability in the warmer months across the northern and southern India. Sharma and Chaudhary, 2014 reported a cooling trend in the winter temperature in the Bastar plateau agro-climatic zone of Chhattisgarh. Rupa Kumar *et al*. (1994) found a rising trend in the Tmaxdata and no trend for *T*min at 121 stations in India from 1901 to 1987, causing an increase in average and diurnal temperature spectrum. Relative humidity is a crucial climatic variable that governs the aerodynamics portion of the atmospheric evaporating needs (Wang and 40 Dickinson, 2012). According to Talaee *et al*. (2012), the yearly relative humidity in Iran's southern and northern coastal regions risen by 1.03%/decade. Kaur *et al*. (2022) concluded that relative humidity was trending upward, while wind speed, pan evaporation and sunlight hours were trending downward, suggesting that overcast and damp weather conditions were becoming more common in the Punjab state. The non-parametric Mann-Kendall test (MK test) is frequently used for trend assessment in meteorological variables (Gellens 2000; Das *et al*., 2008; Das *et al*., 2020; Shadmani *et al*., 2012; Pingale *et al*., 2014; Korade and Dhorde 2016). The possible explanation for using this non-parametric statistical test is that it can see monotonic trends (both increasing and decreasing) in the variable's data. Many studies employed Theil-Sen

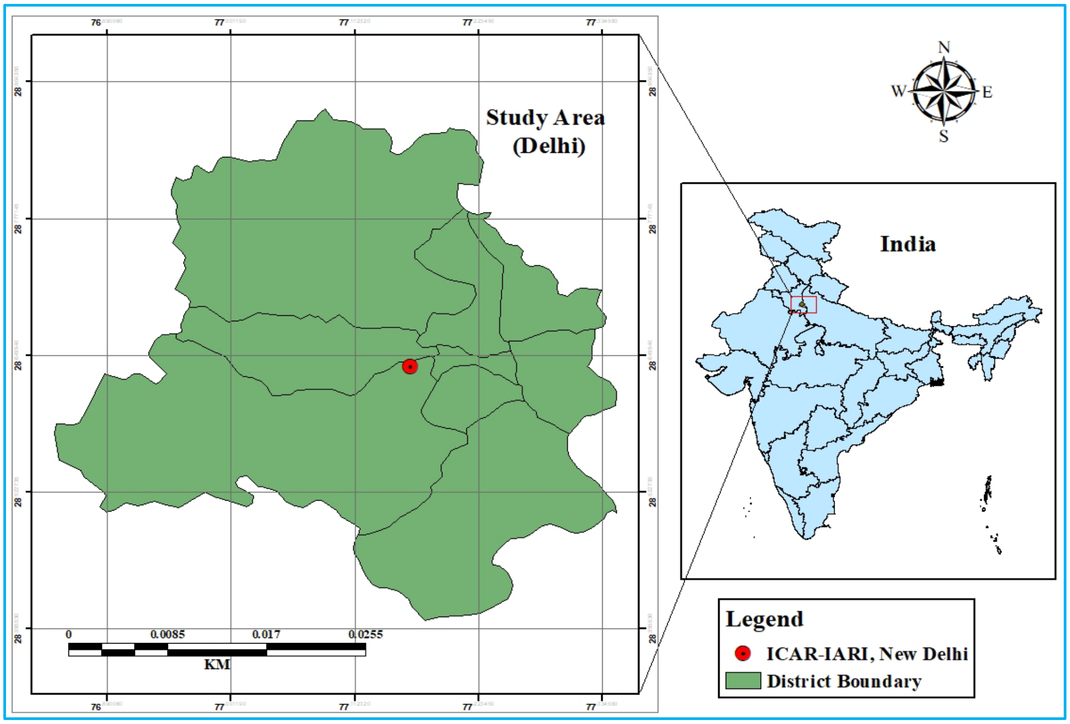


Fig. 1. Study area and IARI meteorological station map

approach for calculating the actual magnitude of slope (Hirsch *et al*., 1982; Gallego *et al*., 2006; Chen & Grasby 2009; and Shadmani *et al*., 2012). Pettitt's (1979) test identifies shifting points in data series (Zhang *et al*., 2008; Gebremicael *et al*., 2013).

In a motivation derived from the above studies, the present study utilized 31 years of rainfall, temperature and relative humidity (average) data to investigate trends in a sub-tropical climate region of Delhi, India. The MK and Theli-Sen slope tests were employed to identify trend identification and rate estimation in the variables data. At the same time, the Pettitt technique was followed to see the inflection point describing the shifting in the time-series data.

2. Materials and methods

2.1. *Study area description*

Study area IARI Pusa is located in the semi-arid region of the National Capital Region (NCR), Delhi, India. Delhi has a semi-arid, subtropical climate with hot, dry summers and cold winters and is located in the Agro-ecoregion-IV. The annual average temperature is 25.5° C. May, and June is the warmest months, with an average maximum temperature of 39° C in the range of 43.9 to 45.0° C for the last 30 years. The winter season lasts from December through February. January's average temperature of 14° C is regarded as the coldest. On the other hand, the lowest temperature falls below 1° C. 75% of the annual rainfall (710 mm) occurs during the monsoon season (June to September). The location map of the selected study area is shown in Fig. 1.

2.2. *Dataset*

Long-term rainfall, temperature and relative humidity data (observed daily for 31 years) were investigated to detect trends during 1991 to 2020 in National Capital Region, Delhi, India. The data were acquired from the meteorological station, Division of Agricultural Physics, IARI, Pusa, Delhi, India. Tables 1, 2, 3 and 4 summarizes central tendency and dispersion measures for *T*max, *T*min, rainfall and relative humidity (average). The annual rainfall was maximum with the value of 1524.3 mm in 2013 and yearly minimum rainfall amounting to 452.7 mm was obtained in 2002. The analysis of the present investigation is the monthly and annual minimum temperature (*T*min) and the maximum temperature (*T*max) during 1990-2020. Annually maximum temperature observed was 42.60 °C in 2012, whereas the minimum temperature was found in 2005. Relative humidity (RHaveg.) analysis showed that monthly average minimum and maximum values were found as 46.35 and 77.35 % in May and August, respectively.

TABLE 1

Monthly values of measures of central tendency and dispersion for *T*max

Parameter	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
Mean	19.51	23.27	29.15	36.26	39.65	38.78	34.89	33.44	33.51	32.66	27.76	22.20
Median	19.60	23.10	29.20	36.00	39.75	38.90	34.30	33.50	33.60	32.70	27.80	22.60
Mode	18.60	23.10	29.90	35.40	40.10	40.30	34.30	33.60	33.40	32.60	26.90	22.6
Std. Deviation	1.52	1.51	1.79	1.61	1.34	2.06	1.55	1.01	1.15	1.14	0.85	1.51
Variance	2.30	2.29	3.19	2.59	1.79	4.26	2.39	1.02	1.32	1.29	0.72	2.29
Skewness	0.04	0.94	0.47	0.40	-0.35	-0.40	1.24	0.47	-0.27	-1.20	-0.51	-1.75
Kurtosis	-0.10	2.34	-0.37	0.30	0.76	-0.02	1.73	-0.08	0.36	2.91	0.90	3.31
Range	6.60	7.40	6.50	7.50	6.40	8.80	6.90	4.20	5.00	5.80	3.80	6.20
Minimum	16.30	20.80	26.80	32.80	36.10	33.80	32.50	31.60	30.90	28.90	25.30	17.70
Maximum	22.90	28.20	33.30	40.30	42.50	42.60	39.40	35.80	35.90	34.70	29.10	23.90
25th percentile	18.45	22.25	27.60	35.40	38.80	37.35	33.90	32.60	32.89	32.24	27.30	21.75
50th percentile	19.60	23.10	29.20	36.00	39.75	38.90	34.30	33.50	33.60	32.70	27.80	22.60
75th percentile	20.55	24.35	30.00	37.30	40.60	40.30	35.50	33.95	34.10	33.40	28.23	23.20

TABLE 2

Monthly values of measures of central tendency and dispersion for *T*min

Parameter	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
Mean	6.48	9.14	13.58	19.28	24.19	26.77	26.70	25.95	23.93	17.41	11.49	6.84
Median	6.70	9.20	13.40	19.10	24.00	26.80	26.60	25.90	24.00	17.50	11.60	6.80
Mode	5.50	8.40	13.70	19.10	23.90	27.10	25.70	25.70	24.00	18.70	10.60	6.10
Std. Deviation	1.11	1.11	0.96	1.18	1.05	1.04	1.07	0.62	0.78	1.29	1.38	1.24
Variance	1.23	1.23	0.92	1.40	1.11	1.08	1.14	0.38	0.60	1.67	1.90	1.55
Skewness	-0.01	0.10	0.64	0.13	0.29	0.05	1.23	-0.57	0.38	-0.26	1.26	-0.13
Kurtosis	-0.56	-0.11	0.64	-0.30	0.59	-0.21	3.96	0.88	1.27	-0.88	3.46	-0.50
Range	4.67	4.80	4.20	4.70	5.10	4.40	6.00	2.80	3.70	4.90	7.20	5.20
Minimum	4.30	6.90	11.60	17.10	21.80	24.60	24.40	24.20	22.30	14.90	9.00	4.10
Maximum	8.97	11.70	15.80	21.80	26.90	29.00	30.40	27.00	26.00	19.80	16.20	9.30
25th percentile	5.50	8.40	13.00	18.65	23.50	26.05	26.14	25.65	23.55	16.40	10.60	6.10
50th percentile	6.70	9.20	13.40	19.10	24.00	26.80	26.60	25.90	24.00	17.50	11.60	6.80
75th percentile	7.25	9.80	13.85	20.10	24.90	27.34	27.15	26.45	24.34	18.46	12.10	7.90

[a] More than one mode exists, only the first is reported

2.3. *Methodology*

Trend analysis, a technique for determining the spatio-temporal variations in several climate parameters, is the simplest procedure to detect the variation of variables in the data time series. This is indeed a critical problem for a country such as India, as our economy relies primarily on agriculture, heavily reliant on monsoon rainfall. Hence, any shift in that time of the year can devastate the nation's farming prospects, therefore, the

TABLE 3

Monthly values of measures of central tendency and dispersion for rainfall

Parameter	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
Mean	19.73	24.21	24.03	9.15	33.39	79.74	217.43	236.52	121.99	16.76	4.87	8.78
Median	11.40	13.00	8.00	4.00	27.20	72.80	181.20	219.10	105.90	0.00	0.00	0.20
Mode	0.00	0.00	0.00	0.00	0.00	4.60	7.20	66.30	5.40	0.00	0.00	0.00
Std. Deviation	22.37	28.91	46.70	12.72	35.30	60.95	149.12	108.73	85.35	28.14	9.07	18.27
Variance	500.36	835.51	2181.24	161.80	1246.19	3714.34	22238.00	11822.83	7284.81	791.96	82.25	333.82
Skewness	1.08	1.42	3.13	2.07	1.35	1.29	0.83	0.50	0.39	1.86	2.26	2.49
Kurtosis	0.05	1.49	9.69	4.24	1.56	2.05	0.13	0.18	-0.90	3.10	4.96	5.63
Range	72.90	109.40	201.80	51.80	136.60	266.40	571.40	455.60	308.80	109.00	37.00	68.00
Minimum	0.00	0.00	0.00	0.00	0.00	4.60	7.20	66.30	5.40	0.00	0.00	0.00
Maximum	72.90	109.40	201.80	51.80	136.60	271.00	578.60	521.90	314.20	109.00	37.00	68.00
25th percentile	1.90	1.70	1.10	0.90	5.40	34.05	122.65	162.95	50.75	0.00	0.00	0.00
50th percentile	11.40	13.00	8.00	4.00	27.20	72.80	181.20	219.10	105.90	0.00	0.00	0.20
75th percentile	33.20	31.20	21.35	11.80	46.35	104.60	294.45	307.35	191.00	27.50	5.40	6.30

[a] More than one mode exists, only the first is reported

TABLE 4

Monthly values of measures of central tendency and dispersion for relative humidity

Parameters	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
Mean	73.25	68.15	60.39	47.87	46.35	55.35	73.40	77.32	72.58	62.65	63.72	69.45
Median	72.60	67.80	60.24	47.37	47.31	54.48	75.00	79.19	72.90	61.50	63.50	68.77
Mode	62.60	70.39	50.19	38.65	42.82	36.32	52.53	65.36	70.38	53.84	52.73	54.90
Std. Deviation	5.94	7.13	7.42	7.11	6.93	9.33	6.65	5.53	7.21	5.52	5.70	5.65
Variance	35.23	50.87	55.10	50.48	47.99	87.03	44.16	30.55	51.96	30.52	32.54	31.93
Skewness	-0.08	0.54	0.51	0.10	0.00	-0.18	-1.51	-0.50	-0.35	0.46	0.11	-0.13
Kurtosis	-1.17	0.54	-0.72	-1.39	-0.64	-0.30	2.64	-0.16	-0.44	-0.57	-0.32	0.47
Range	19.81	30.41	26.27	22.27	26.86	37.90	29.50	23.29	28.53	21.39	23.78	26.29
Minimum	62.60	54.40	50.19	37.75	33.24	36.32	52.53	65.36	57.25	53.84	52.73	54.90
Maximum	82.40	84.80	76.47	60.02	60.10	74.22	82.03	88.65	85.78	75.23	76.52	81.20
25th percentile	68.48	63.82	55.13	41.49	41.70	50.67	70.43	73.33	68.81	58.63	59.58	66.69
50th percentile	72.60	67.80	60.24	47.37	47.31	54.48	75.00	79.19	72.90	61.50	63.50	68.77
75th percentile	78.23	70.25	64.84	54.61	50.21	61.86	77.56	80.55	77.38	66.77	68.33	73.32

economy. So, trend analysis is capable of resolving global climate change challenges. The main objective of this trend investigation is to analyse changes in meteorological parameters (rainfall temperature and relative humidity). Thirty-one years of meteorological observations were analyzed to examine rainfall and temperature data patterns. The MK test was employed to detect the trend, and the magnitude of slopes was analyzed employing the Theli-Sen technique.

Additionally, the Pettitt test was employed to determine the time series' change point (Pettitt 1979).

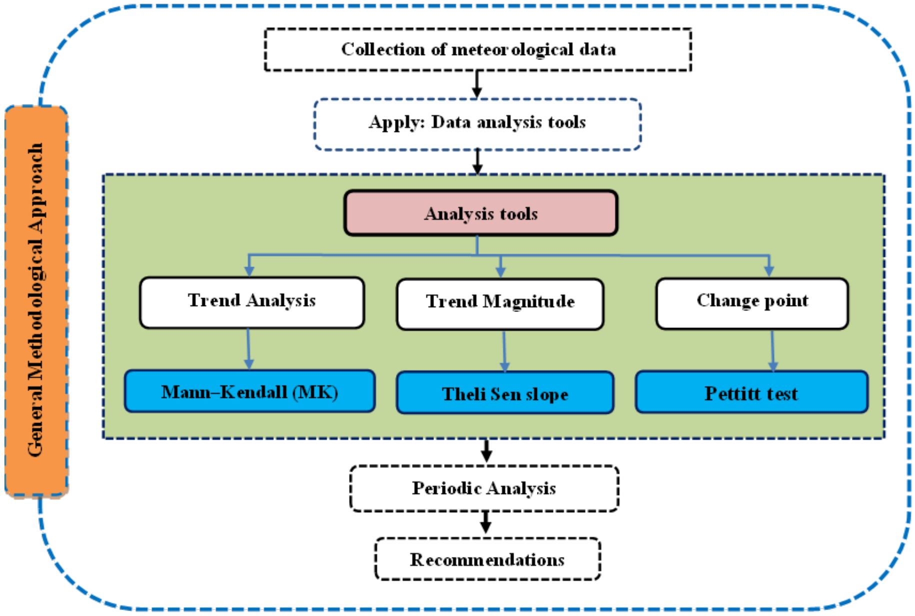


Fig. 2. Flow diagram of the methodology

The flow methodology diagram followed in this investigation has displayed in Fig. 2.

2.3.1. *Mann-Kendall test*

The MK is a popular technique to identify trends in a time series dataset. This method finds a monotonic trend in the investigation parameter during the intended period. A monotonic upward (downward) trend indicates that the variable continuously rises (falls) over the period. Also, the null hypothesis H0 and alternative hypothesis Ha denote the absence and presence, respectively. The MK test is assessed as per the Shadmani *et al*. (2012):

$$\text{sgn}(x_i - x_j) = \begin{cases} +1 \text{ if } x_j > x_i \\ 0 \text{ if } x_j = x_i \\ -1 \text{ if } x_j < x_i \end{cases}$$

$$S = \sum_{i=1}^{n-1} \sum_{j=i+1}^{n} \text{sgn}(x_i - x_j)$$

where x_i and x_j show the data at times i and$j$, respectively and n is the data period of the data. If S is +, means the variable continuously rises in time; $a - S$ value means a declining trend. The following equation is utilized in cases where n is more significant than 10.

$$\text{Var}(S) = \frac{n(n-a)(2n+5) - \sum_{i=1}^{p} t_i(t_i - 1)(2t_i + 5)}{18}$$

where p means the number of tied groups, t_i is the number of data values in the pth group. When the variance of time is provided in the preceding equation, the standard Z can be expressed by the following equation:

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

2.3.2 *Theil-Sen approach*

This approach is utilized to compute the slope magnitude after the trend tests. The Theil-Sen techniqueis shown by the equation (Shadmani *et al*., 2012) is as follows:

$$\beta = \text{median}\left(\frac{X_j - X_i}{j - i}\right) \quad \text{for all } i < J$$

where X_i and X_j means the sequential data values of the time series in the years i and j, respectively, the estimated β is estimated slope trend magnitude in the data series.

2.3.3. *Pettitt's test*

Pettitt's method is widely utilized to identify shifting points in variables time series values. For a time series

TABLE 5

Trend analysis of temperature, rainfall and relative humidity

Tests	*T*max			*T*min			Rainfall			RHaveg		
	M-K Test Value (S)	Theli Sen slope	Trend	M-K Test Value (S)	Theli Sen slope	Trend	M-K Test Value (S)	Theli Sen slope	Trend	M-K Test Value (S)	Theli Sen slope	Trend
Jan	-112	-0.05	-	-100	-0.0381	-	42	0.18	N	133	0.3035	+
Feb	21	0.0061	N	-4	0	N	-71	-0.3077	N	70	0.124	N
Mar	62	0.0286	N	36	0.01	N	102	0.48	+	105	0.3109	+
Apr	41	0.0271	N	153	0.05	+	102	0.1833	+	142	0.3476	+
May	20	0.0059	N	-75	-0.0292	N	45	0.4571	N	144	0.3407	+
Jun	4	0	N	-53	-0.0222	N	-3	-0.02	N	81	0.2264	N
Jul	14	0	N	-92	-0.0261	N	107	5.1529	+	85	0.1718	N
Aug	41	91	N	-79	-0.2	N	31	0.85	N	29	0.0436	N
Sep	50	0.0211	N	-57	-0.0125	N	-11	-0.5238	N	40	0.1024	N
Oct	49	0.0167	N	3	0	N	1	0	N	157	0.2648	+
Nov	-67	-0.02	N	-31	-0.015	N	-25	0	N	101	0.2188	+
Dec	-117	-0.04	-	-109	-0.0556	-	6	0	N	113	0.2032	+
Annually average	-20	-0.0026	N	-61	-0.0094	N	97	6.47	N	201	0.2546	+
Spring	57	0.0286	N	1	0	N	49	1.9983	N	105	0.237	+
Summer	23	0.0095	N	7	0.0014	N	37	1.2083	N	161	0.2905	+
Monsoon	53	0.0159	N	-108	-0.0235	-	71	5.6	N	91	0.1568	N
Autumn	-8	-0.0015	N	-100	-0.032	-	-14	-0.159	N	137	0.2507	+
Winter	-148	-0.0577	-	-146	-0.0375	-	-11	-0.1167	N	170	0.2727	+

(*Note* : N= No statistically significant trend, + = Increasing trend, - = Decreasing trend, α = 5 %, Spring-February to March, Summer: April to June, Monsoon: July to September, Autumn: October to November, and Winter: December to January)

like *X*1, *X*2, …, *Xn* with a length *n*, let *t* be the time of the change point. Then, the samples (X1, *X*2, ..., *Xt*) and (X_{t+1}, X_{t+2}….X_n) can be obtained by changing the time series at time *t*. The test statistic U_t was given by (Chen *et al*., 2009) and calculated as follows:

$$U_t = \sum_{i=1}^{t} \sum_{j=i+1}^{n} \operatorname{sgn}\left(x_i - x_j\right)$$

$$\operatorname{sgn}(x) = \begin{cases} +1 & \text{if } x > 0 \\ 0 & \text{if } x = 0 \\ -1 & \text{if } x < 0 \end{cases}$$

At time *t*, the greatest *jU*ₜ*j* can be regarded as the most important change point. The following equation may be used to estimate the significant change probability *P*(*t*) at the change point (Chen *et al*., 2009):

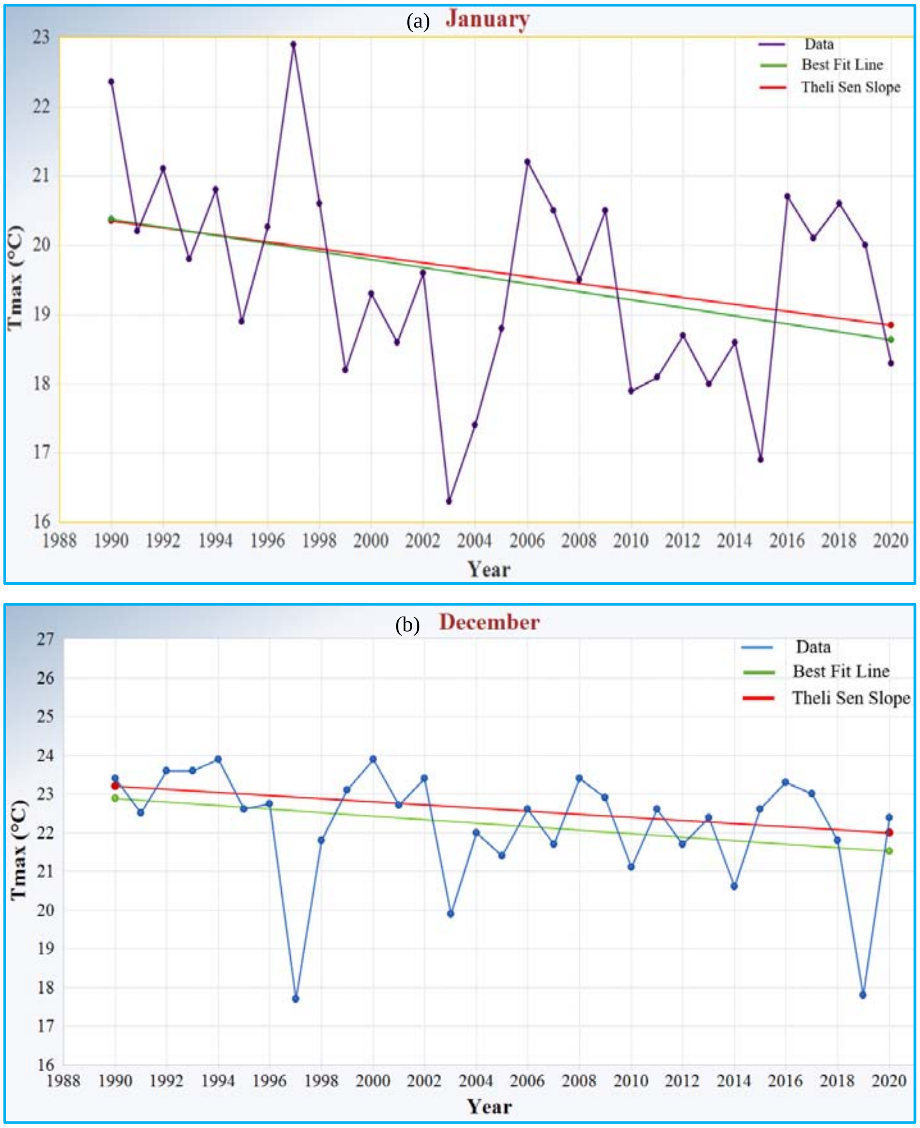
$$P(t) = 1 - \exp\left(\frac{-6U^2}{n^3 + n^2}\right)$$

When the approximated probability exceeds (1-α), the change point is taken at a statistically significant level of α.

3. Results and discussion

3.1. *Temperature trend analysis*

The annual, monthly temperature data (maximum and minimum) showed no significant trend, implying no considerable variation in the annual minimum and maximum temperature during the investigation period. After the MK test had identified the trends, Theli Sen slope was estimated to quantify the slope magnitude. The MK Test value and Theli Sen slope for maximum temperature are shown in Table 5. A statistically decreasing trend was observed for the maximum temperature (*T*max) during January and December (Fig. 3). The MK test value for January was -112 and Theli Sen slope magnitude of -0.0500 during the period, while for December month, the MK test value obtained was -117 and Theli Sen slope magnitude of -0.04. Results indicated a decreasing *T*max during the winter, affecting

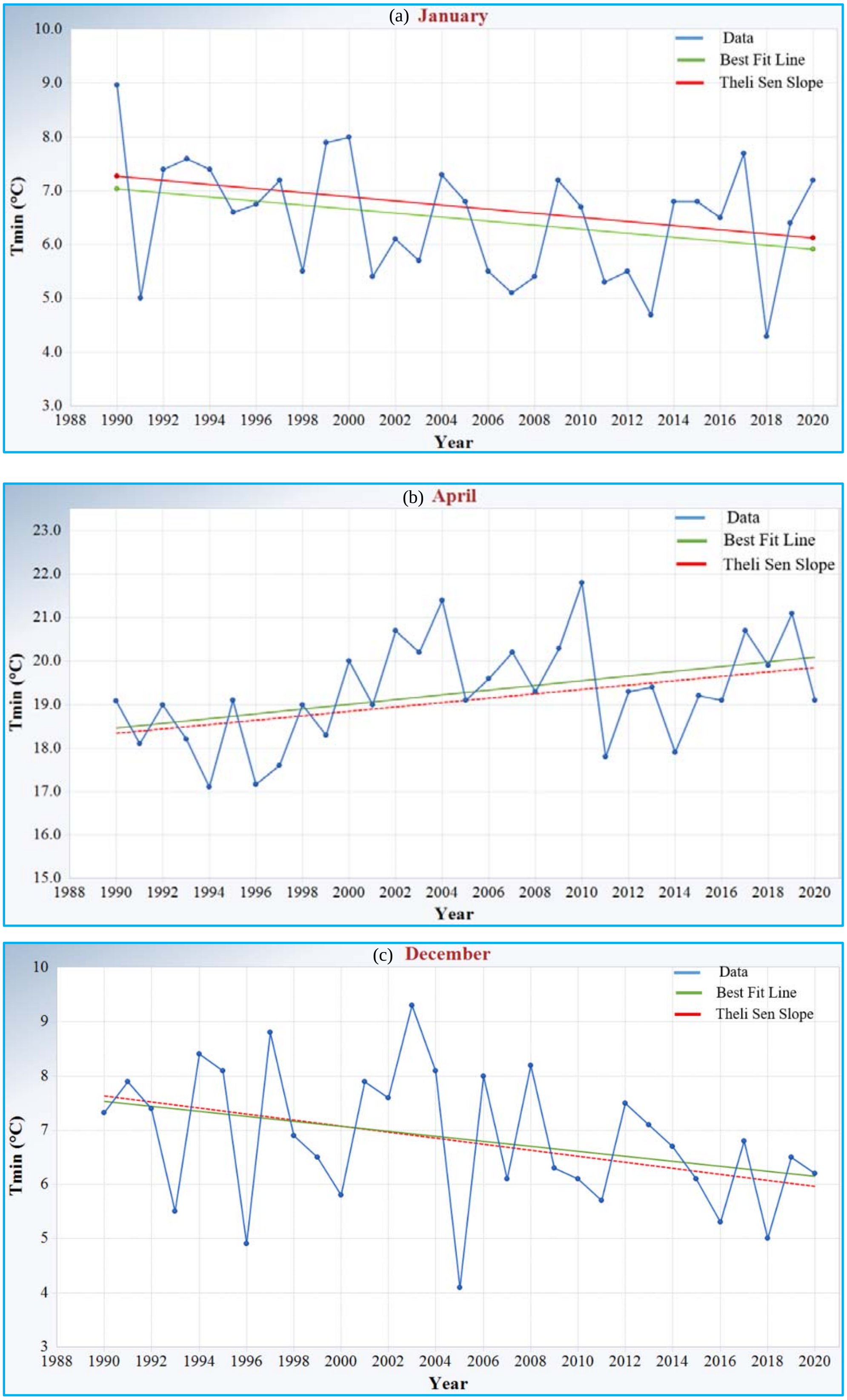


Figs. 3(a&b). The significant trend observed in monthly *T*max time series data in (a) January and (b) December

agriculture crop yield. Trend analysis of *T*min revealed a significant declining trend for January with an MK test value of -100 and Theli Sen slope of -0.0381. A statistically positive increasing trend was seen in April. The MK test value of 153 and Theli Sen slope of 0.050 for April was observed. A statistically decreasing trend was identified for December. The MK test value of -109 and Theli Sen slope of -0.0556 was found for December. For the remaining months, no trend was seen for *T*max and *T*min. Seasonal analysis of *T*max time series data showed that there has been a statistically decreasing trend for winter season. This downward temperature trend may affect vegetables which are sensitive to lower temperatures. Similarly, for *T*min, seasonal analysis showed statistically decreasing trend during monsoon, autumn and winter seasons. Though decreasing temperatures could lower the crop water demands but may affect the crop development by hampering the growing degree days requirements to achieve biological crop maturity. Another negative effect associated with lower temperatures is extension of crop durations. Fig. 4 shows the significant trends observed in the monthly *T*max data series.

3.2. *Trend change point analysisof temperature data*

The change point analysis of temperature (maximum and minimum) data was performed using the Pettitt test. The Pettitt test showed no change point for annual *T*max



Figs. 4(a-c). The significant trend observed in monthly *T*max time series data in (a) January, (b) April and (c) December

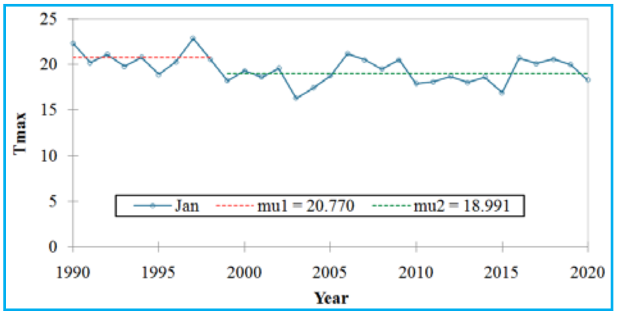


Fig. 5. Trend change point identification in *T*max monthly time-series data

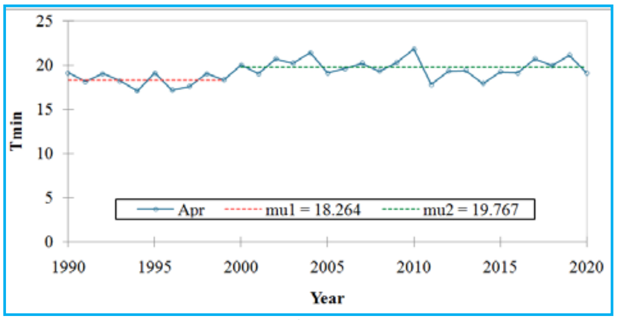


Fig. 6. Trend change point identification in *T*min monthly time-series data

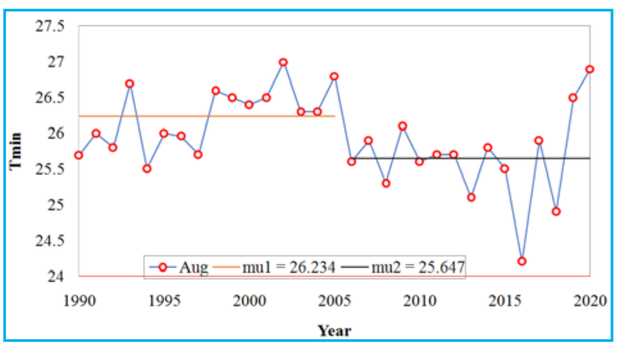


Fig. 7. Trend change point identification in *T*min monthly time-series data

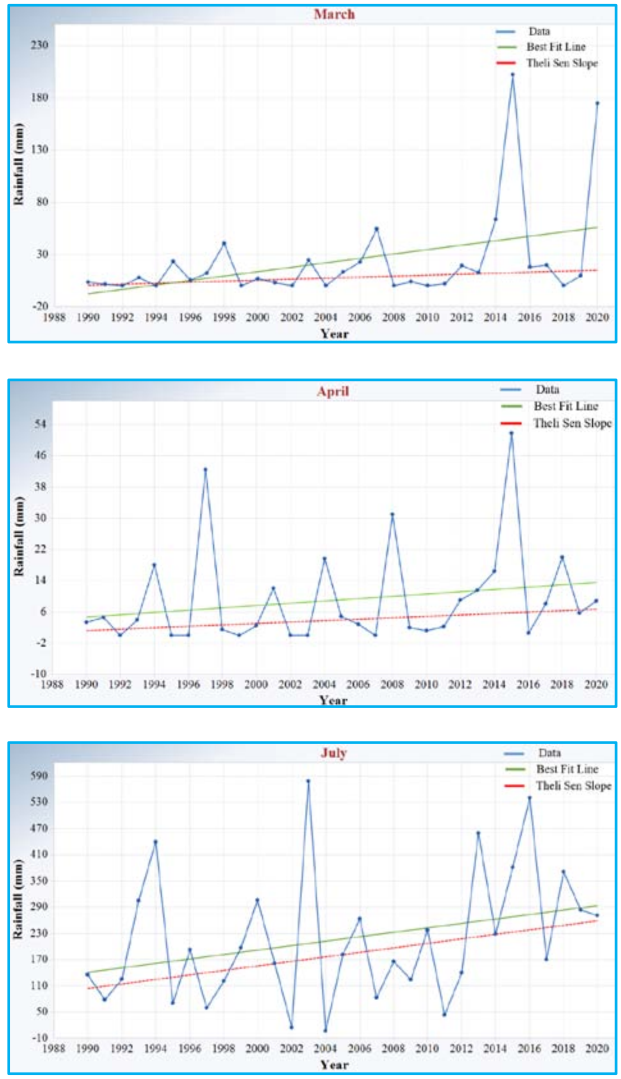


Fig. 8. The significant trend observed in monthly rainfall time series data in (a) March, (b) April and (c) July

and *T*min. However, monthly *T*max and *T*min showed a shifting point in the time series trend. For the *T*max, a trend change point was observed for January 1998 (Fig. 5). The average *T*max value before the change point (1990-1998) was 20.770 (°C), while the average *T*max value post the change point (1999-2020) was found as 18.991 (°C). This finding showed a 1.78 (°C) decline in the time series trend. This result indicated that the *T*max during January is on decreasing trend. This finding agreed with the MK test results, which showed a decreasing trend for *T*max in January. Pettitt was then applied to monthly *T*min values and it was observed that *T*min showed a change point in 1999 (Fig. 6) for April. The average *T*min value before the trend change point (1990-1999) and post-change point (2000-2020) were found as 26.23 (°C) and 25.64 (°C), respectively. This demonstrates a decline in the *T*min of 0.59 (°C) in the time series trend. Also, *T*min showed a changed point in 2005 for August. The mean value of data series before and after changed points were 26.234 and 25.647 °C, respectively as depicted in Fig. 7. *T*max seasonal analysis showed no change point in data series. However, *T*min seasonal analysis revealed change point for monsoon and winter seasons. The mean value of *T*min data series prior to change point for monsoon season was 25.828 °C which decreased to 25.207 °C, which clearly indicates a declining in the temperature. Similarly, the mean values of *T*min data series during the winter season were 7.108 and 6.258 °C prior and post the change point. This further revealed a declining trend of the *T*min.

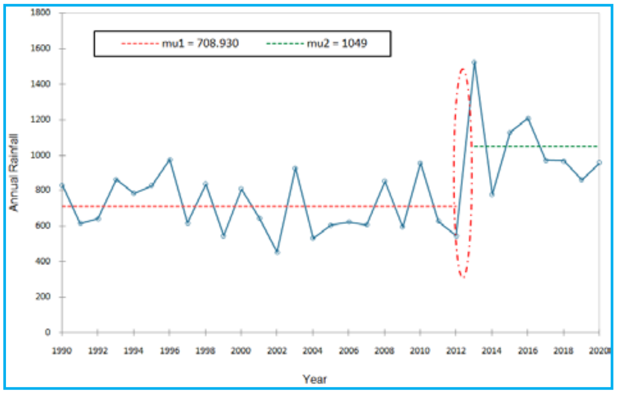


Fig. 9. Change or break point of annual rainfall data series

3.3. *Rainfall trend analysis*

Annual, monthly and seasonal rainfall trends were investigated individually. Annual rainfall showed no statistically significant trend, implying no substantial variation in the chosen station's annual rainfall value. Once the MK test had identified the trends, Theli Sen slope was estimated to quantify the slope magnitude. Monthly and annual MK Test values and Theli Sen slope for rainfall are displayed in Table 5. For the monthly rainfall, a statistically rising trend was found for March and April [Figs. 8 (a&b)]. The MK test value for March was 102 with the Theli Sen slope magnitude of 0.4800. At the same time, April has obtained the MK test value of 102 with a Theli Sen slope magnitude of 0.1833. Only July showed a statistically increasing trend [Fig. 7(c)] during the monsoon period with a MK test value of 107 and Theli Sen slope of 5.1529. Thus, monthly trend results imply increasing rainfall amounts in March, April and July. The seasonal analysis of rainfall showed no trends in the rainfall time series data.

3.4. *Rainfall Trend Change Identification Analysis*

The change point analysis of data series is vital in designs of hydrologic structures. Average annual rainfall time-series data (1990-2020) were subjected to the Pettitt test for change point identification. The shifting point in the annual average rainfall data was observed in 2012 (Fig. 9). The mean value of average annual rainfall before the change point (1990-2012) was 708.93 mm and a mean value of 1049 mm for the annual rainfall data series was found post the change point (2013-2020). The difference in the magnitude of these two data series means values is 340.07 mm. This indicates that there has been arise in the rainfall amount during the last decade temperature for January. Pettitt test was also applied to monthly data and revealed no trend change point in the monthly data series. No change point was reported by the seasonal analysis of the rainfall data.

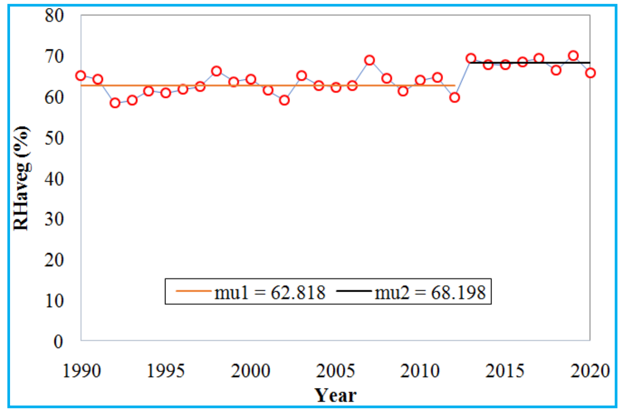


Fig. 10. Change or break point of annual relative humidity data series

3.5. *Relative Humidity Trend Analysis*

The annual average relative humidity (RHaveg.) showed a statistically positive increasing trend with M-K test value (S) of 201 and slope magnitude of 0.2546. The monthly trend analysis revealed that relative humidity is on increasing trend during January, March, April, May, October, November and December. However, no trend was seen in the remaining of the months. The seasonal trend analysis showed positive increasing trend during spring, summer, autumn and winter seasons. However, the monsoon season did not reveal a significant trend. The MK Test value and Theli Sen slope for relative humidity are shown in Table 5. The M-K test value was found highest for annual average data series. While, the highest Theli sen slope was observed for summer season. The corresponding lower values for a statistically significant trend was reported for March (105) and December (0.2032). The analysis revealed that relative humidity has been increasing round the year except monsoon season. Though higher relative humidity is required for plant growth but exceeding a critical value may cause the plant growth development by influencing the atmospheric evaporating demand. It is fact that relative humidity is temperature dependent and cannot be regulated artificially to greater extent under open field conditions. However, relative humidity can be regulated using humidifier and dehumidifier under protected cultivation technologies.

3.6. *Relative Humidity Trend Change Identification Analysis*

The change point analysis of annual average relative humidity revealed a shift point in data time series. The change point was found in year 2012 and the average value of relative humidity prior to change point was 62.818% compared to mean value of 68.198% after the change point (Fig. 10). This clearly shows that there has been an increased in the relative humidity post the change

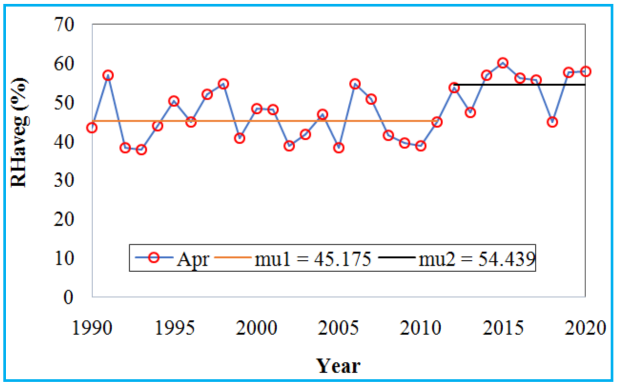


Fig. 11. Change or break point of April relative humidity data series

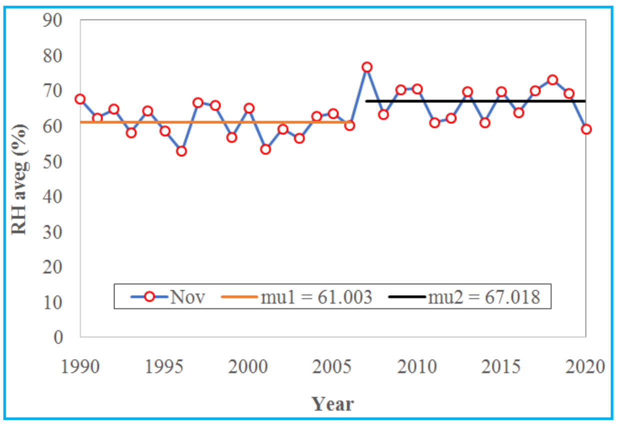


Fig. 12. Change or break point of November relative humidity data series

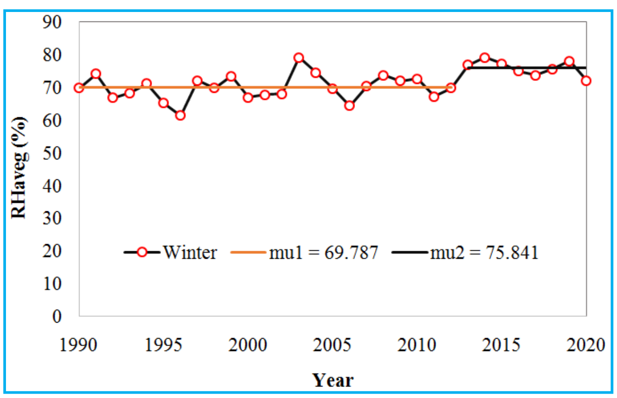


Fig. 13. Change or break point of Winter season relative humidity data series

point by 5.380%. The reason could be in the increased in the relative humidity due to increase in the winter rainfalls events which are associated with the lowering in the temperature. The monthly change point analysis showed change point in the relative humidity trend in April and November and change occurred in 2011 and 2006, respectively (Figs. 11 and 12). The average relative humidity before the change point was 45.175 % while post change point, average relative found to be 54.439 % for April. For November, the value of relative humidity prior to the change point was 61.003 % which was increased to 67.018 % post the change point. The seasonal analysis showed that there has been break in the trend of relative humidity and the change point was observed in 2012 during winter season (Fig. 13). The mean value of the data time series after the change point was 75.841 % compared to mean value (69.787 %) of data time series prior to trend change point. The remaining months and seasons showed no change or shift point in the time series relative humidity data.

4. Conclusion

Based on historical rainfall temperature records (maximum and minimum) and relative humidity the trend change was examined using three tests (Man Kendall, Theli Sen slope and Pettitt) for Annual, monthly and seasonal data. The outcomes of the tests could not find any specific and significant trends magnitude in the time series data of annual rainfall, *T*max and *T*min data. But a positive increasing trend was observed in relative humidity data series. Also, disaggregating the data to monthly and seasonal scale, *T*max indicated a statistically significant downward trend in January and December, unleashing a mixed effect on crop phenology which has both inhibitory and regulatory impact on growth. But this reduced temperature trend could help water saving by reducing the evapotranspiration rate. Also, a declining trend of *T*max during winter season further justified the declining temperature. The *T*min showed a statistically significant declining trend in January and December. This dip in the *T*min could be detrimental to the *Rabi* season crops and cause chilling injuries. In addition, *T*min revealed change declining trend during monsoon, autumn and winter seasons. Notably, the change point for the monthly *T*max data series was detected in January 1998. It was observed that *T*min in April showed an inflection point in the data series trend in 1999. Further, monsoon and winter showed change points for *T*min data. Monthly rainfall indicated a statistically significant increasing trend in March, April and July. This indicated an increase in monsoon and non-monsoon season rainfall magnitude. A typically significant inflection point describing a pattern change in the annual rainfall was detected in 2012. The mean value of average annual rainfall before the change point (1990-2012) was 709 mm and the 1049 mm mean of mean annual rainfall data series was found post-change point (2013-2020). Relative humidity showed positive increasing trends for annual, month and seasonal data series. The implications of such changes to series that exhibited no trend define multiple methods to identify the trends and avoid biased outcomes deciphered from approaches using a single technique.

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Disclaimer : The contents and views expressed in this study are the views of the authors and do not necessarily reflect the views of the organizations they belong to.

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