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Trend Analysis of Climate Variables Using Non-Parametric Tests

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Abstract: Changes in climatic parameters like rainfall and temperature has increased in last few decades. These changes have impact on daily life. So, assessing the change in trend of climate variables will help to take measures to overcome these problems. In this paper annual and seasonal trend of climate variables like rainfall, minimum and maximum temperature of India from year 1901 to 2021 have been analysed using non-parametric tests like Mann-Kendall, Modified Mann-Kendall and Sen's Slope Estimator. To detect the change point Pettit homogeneity test has been used. Results revealed that there is increasing trend in both annual and seasonal temperatures. There is decreasing trend in rainfall except pre-monsoon rainfall. This indicates that there will be increase in temperature and decrease in rainfall in future days.

Keywords: Trend, Precipitation, Agriculture, Climate Change, Temperature.

I INTRODUCTION

Changes in climate over the India region which mainly depends on agriculture, would have a significant impact agriculture production, water resource management and overall Indian economy (Jain and Kumar, 2012). Temperature and Rainfall are the important factors that causes climate change (Verma and Ghosh,2019). Increase in temperature can causes heat waves and water scarcity. Increase in temperature during flowering stage will damage the crops which results in reduction of crop yield and caused delay in harvesting. Increase in rainfall causes flood while decrease in rainfall causes drought. Sudden climate change can induce diseases to humans and crop and it will increase the pest incidences. A complete understanding of rainfall and temperature patterns will help to make better decisions and helps to adapt the people for extreme climate changes (Bora et al, 2022).

Many researchers have done trend analysis in climate variables for many regions (Ahmad et al, 2017; Choudry and Salini, 2023; Kamal and Pachurai, 2019; Kessabi et al, 2022; Verma and Ghosh, 2019). Other than climate variables researcher analysed trend for runoff of river (Achite et al, 2022), groundwater (Vousoughi et al, 2013) and yield of crops (Wansik et al, 2022).

This paper is an attempt to analyze the trend of India's rainfall, minimum and maximum temperature and to detect the change point of these climate variables.

II MATERIALS AND METHODS

2.1 Data description

The data used for the study is annual and seasonal climate variables like rainfall, minimum temperature and maximum temperature of India from year 1901 to 2021. Data was collected from indiastat. Seasons used for the study are pre-monsoon (March-May), monsoon (June-September), winter (January, February) and post-monsoon (October-December). To analyse trend of climate variables non-parametric tests like Mann-Kendall test, Modified Mann-Kendall and Sen's Slope estimator have been used. Mann-Kendall and Modified Mann-Kendall tests shows whether there is trend or not while Sen's slope estimator identifies the change per unit time of climate variables. To detect the change point of trend Pettit homogeneity test has been used.

2.2 Mann-Kendall test

The purpose of the Mann-Kendall test (Mann,1945; Kendall,1975; Gilbert,1987) is to statistically assess if there is a monotonic upward or downward trend of the variables over time. A monotonic upward (downward) trend means that the variable consistently increases (decreases) through time, but the trend may or may not be linear.

the test statistic S is defined as,

$$S= \sum_{i=2}^{n} \sum_{j=1}^{i-1} sign(x_i - x_j) \qquad (2.1)$$

Where, n is length of data, x_i and x_j are sequential data in the series and

$$sign(x_i - x_j) = \begin{cases} -1 \; if(x_i - x_j) < 0 \\ 0 \; if(x_i - x_j) = 0 \\ 1 \; if(x_i - x_j) > 0 \end{cases} \quad (2.2)$$

Mean of S, E(S)=0 and Variance is

$$\text{Var(S)} = \frac{n(n-1)(2n+5) - \sum_{p-1}^{q} tp\,(tp-1)(2tp+5)}{18} \quad (2.3)$$

where, tp is number of ties of p value

Standardized test statistics Z is

$$Z = \begin{cases} \frac{S-1}{\sqrt{Var(S)}} \; if \; S > 0 \\ 0 \; if \; S = 0 \\ \frac{S+1}{\sqrt{Var(S)}} \; if \; S < 0 \end{cases} \quad (2.4)$$

To test for monotonic trend at α significance level, the null hypothesis of no trend is rejected if the absolute value of Z is greater than Z1–α/2, which is obtained from the standard normal cumulative distribution tables.

2.3 Modified Mann-Kendall Test

From the name itself Modified Mann-Kendall test is a modification of Mann-Kendall test. Serial correlation is an issue in time-series data. The Modified Mann-Kendall test is used to detect trends in climatic data, and addresses the issue of serial correlation using a variance correction approach. The modified variance of S statistic V*(S) is as follows

$$V^*(S) = V(S)\frac{n}{n^*} \quad (2.5)$$

Where, $\frac{n}{n^*}$ is a correction factor. V(S) is calculated in same as Mann-Kendall test.

2.4 Sen's slope Estimator

The Mann-Kendall test shows whether there is a positive or negative trend. Sen's slope calculates the strength of a trend and is given by

$$b_{sen} = Median\left[\frac{y_i - y_j}{i-j}\right] \quad \text{for all j<i} \quad (2.6)$$

Where, y_i and y_j are data at time i and j respectively.

The positive and negative sign of the test statistic indicates increasing and decreasing trends respectively.

2.5 Pettit homogeneity test

The Pettit test is a non-parametric test used for detecting abrupt changes in a time series. Here, it is used to detect the change point of climate variables. Pettit test is given by the hypothesis

H_0: There is no abrupt change in the data
H_1: There is a change at some point in the data.

The test statistic is calculated by the formula,

$$U = max_{1 \le t \le n-1} \left[\sum_{i=1}^{t} sign(x_i - x_t) + \sum_{i=t+1}^{n} sign(x_t - x_i)\right] \quad (2.7)$$

Where, n is the number of observations

x_i represents the value of the time series at time *i*

sign(x) is the sign function, which returns -1 if *x*<0, 0 if *x*=0 and 1 if *x*>0

if *U* exceeds the critical value null hypothesis is rejected.

III RESULTS AND DISCUSSION

3.1 Descriptive Statistics of Climate Variables

Table 1 shows the descriptive statistics of climate variables such as rainfall, minimum temperature and maximum temperature of India from year 1901 to 2021.

Table 1: Descriptive Statistics

Season	Climate Variables	Min	Max	Mean	Standard Deviation
Annual	Rainfall(mm)	920.8	1463.9	1176.4	106.52
	Minimum Temperature(°C)	18.62	20.90	19.52	0.55
	Maximum Temperature(°C)	28.11	31.54	29.37	0.82
Pre-Monsoon	Rainfall(mm)	83.5	210.7	128.4	22.42
	Minimum Temperature(°C)	19.72	22.98	20.83	0.7
	Maximum Temperature(°C)	29.92	34.84	31.77	10.8
Monsoon	Rainfall(mm)	674.3	1084.3	885.5	85.94
	Minimum Temperature(°C)	22.51	24.66	23.42	0.46
	Maximum Temperature(°C)	30.24	32.67	31.29	0.52
Winter	Rainfall(mm)	11.60	86.30	41.53	14.01
	Minimum Temperature(°C)	12.70	15.57	13.98	0.61
	Maximum Temperature(°C)	22.25	28.09	24.87	1.2
Post-Monsoon	Rainfall(mm)	52.6	206.0	120.5	32.96
	Minimum Temperature(°C)	15.52	18.58	16.71	0.71
	Maximum Temperature(°C)	25.74	29.88	27.42	0.95

From table 1 the mean of annual rainfall, minimum and maximum temperature is 1176.4mm, 19.52°C and 29.37°C respectively. Mean of pre-monsoon season rainfall, minimum and maximum temperature is 128.4mm, 20.83°C and 31.77°C respectively. Similarly, mean of monsoon season rainfall, minimum and maximum temperature is 885.5mm, 23.42°C and 31.29°C respectively. Mean of winter season rainfall, minimum and maximum temperature is 885.5mm, 23.42°C and 31.29°C respectively. Mean of post monsoon season rainfall, minimum and maximum temperature is 120.5mm, 16.71°C and 27.42°C respectively.

3.2 Converting Monthly variables to season and annual variables

The monthly data of rainfall, minimum temperature and maximum temperature are converted to annual and seasonal data. Here, four seasons such as pre-monsoon (March-May), monsoon (June-September), winter (January, February) and post-monsoon (October-December) have been used. To calculate annual and seasonal temperatures, mean of monthly temperature have been used. To calculate annual and seasonal rainfall, sum of monthly rainfall has been used.

3.3 Trend analysis using non-Parametric tests

3.3.1 Results of Annual Rainfall and Temperature trend

To analyze trend of climate variables like rainfall, minimum temperature and maximum temperature non parametric tests like Mann Kendall, Modified Mann Kendall and Sen's Slope estimator have been used and the result is presented in table 2 and 3. Mann Kendall and Modified Mann Kendall shows whether there is trend or not by given hypothesis

H_0: There is no trend
H_1: There is an increasing (decreasing) trend

Sen's slope estimator has been used to identify change per unit time of climate variables.

Table 2: Annual temperature and precipitation trends in India

Climate Variables	Mann-Kendall Test		Modified Mann-Kendall Test		Sen's Slope
	Z test	Result	Z test	Result	
Minimum Temperature(°C)	4.95	S	2.35	S	0.006
Maximum Temperature(°C)	11.16	S	5.32	S	0.016
Rainfall(mm)	-0.28	S	-0.32	S	-0.06

S=Significant

From table 2 it is clear that all annual climate variables are significant. So, by rejecting null hypothesis it is concluded that there is increasing (decreasing) trend of all variables. The sign in Z test shows whether there is increasing or decreasing trend. There is increasing trend in both minimum and maximum temperature which indicate that temperature of India has been increased in the past decades. Also, there is decreasing trend in rainfall which indicates that the rainfall has been gradually decreased in India annually. Sen's slope estimator shows that there will be increase of 0.006°C minimum temperature, 0.016°C maximum temperature in India. There will be decrease of 0.06mm annual rainfall in India.

3.3.2 Results of Seasonal Rainfall and Temperature trend

Similarly, Trend of seasonal climate variables have been calculated using non parametric tests like Mann Kendall, Modified Mann Kendall and Sen's slope estimator and the result is presented in table 3.

Table 3: Seasonal temperature and precipitation trends in India

Season	Climate Variables	Mann-Kendall Test		Modified Mann-Kendall Test		Sen's Slope
		Z test	Result	Z test	Result	
Winter	Minimum Temperature(°C)	4.19	S	2.92	S	0.007
	Maximum Temperature(°C)	9.33	S	6.57	S	0.02
	Rainfall(mm)	-1.54	S	-4.33	S	-0.05
Pre-Monsoon	Minimum Temperature(°C)	4.45	S	2.88	S	0.009
	Maximum Temperature(°C)	8.46	S	5.42	S	0.02
	Rainfall(mm)	0.98	S	1.71	S	0.05
Monsoon	Minimum Temperature(°C)	4.05	S	2.04	S	0.004
	Maximum Temperature(°C)	9.19	S	7.11	S	0.01
	Rainfall(mm)	-0.78	S	-1.04	S	-0.16
Post Monsoon	Minimum Temperature(°C)	6.16	S	3.89	S	0.01
	Maximum Temperature(°C)	10.21	S	6.33	S	0.02
	Rainfall(mm)	-0.08	S	-0.17	S	-0.005

S=Significant

From table 3, p value is significant for all variables. Therefore, by rejecting null hypothesis it is clear that there is increasing (decreasing) trend in seasonal climate variables. From the sign it is clear that the temperatures have been rising. From the table 3, all seasonal rainfall except pre monsoon rainfall is decreasing while pre monsoon rainfall is increasing. Sen's slope estimator shows the change of unit like there will be increase of 0.007°C winter season minimum temperature, increase of 0.02°C winter season maximum temperature. There will be decrease of 0.05mm of winter season rainfall.

3.3.3 Time series plots of climate variables

Time series plot of annual and seasonal climate variables of India with the trend line have been presented in figure 1 to 15.

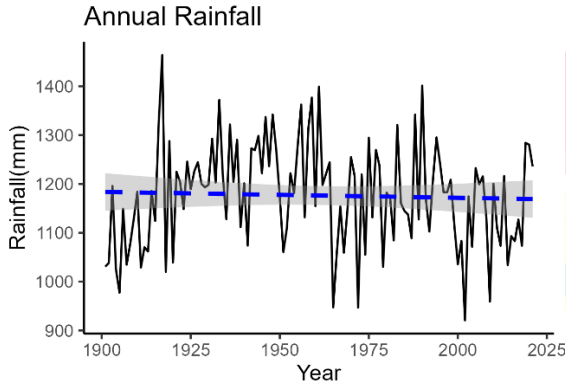

Figure 1: Plot of Annual Rainfall

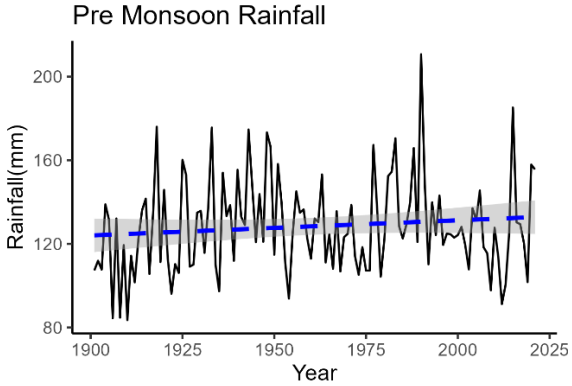

Figure 2: Plot of Pre-Monsoon Rainfall

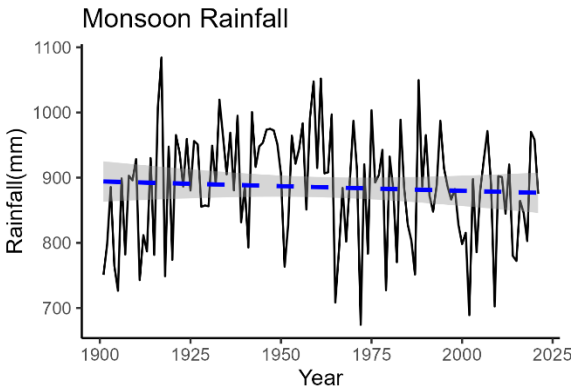

Figure 3: Plot of Monsoon Rainfall

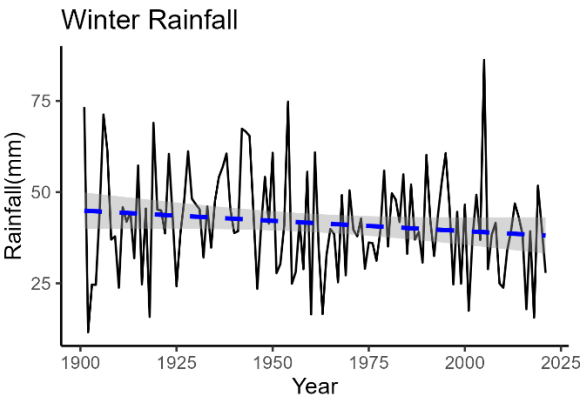

Figure 4: Plot of Winter Rainfall

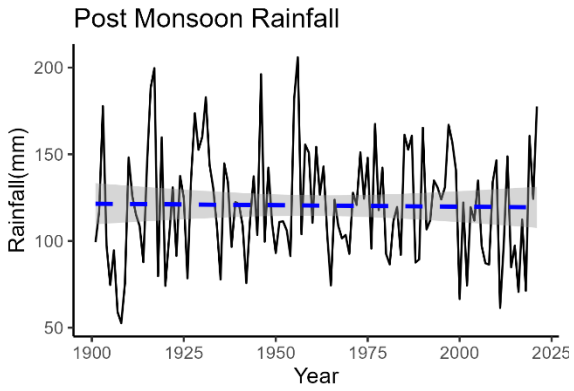

Figure 5: Plot of Post Monsson Rainfall

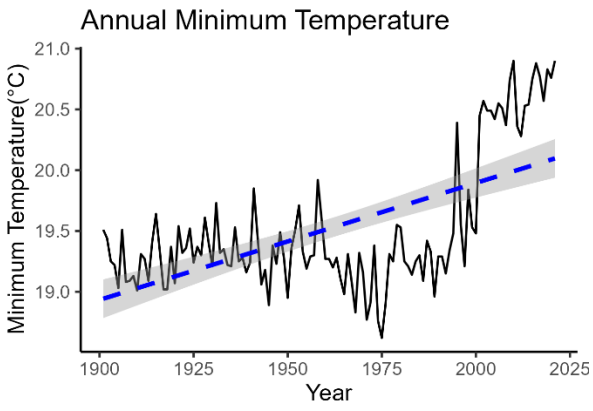

Figure 6: Plot of Annual Min Temperature

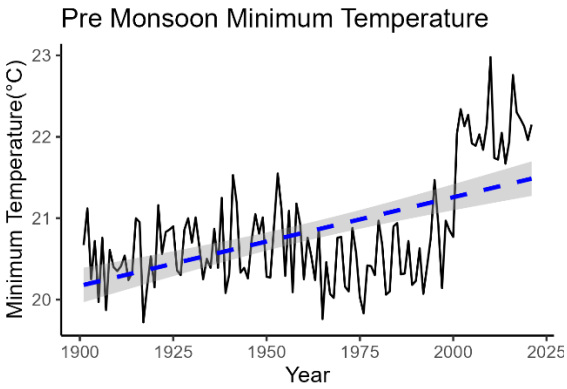

Figure 7: Plot of Pre-monsoon min temp

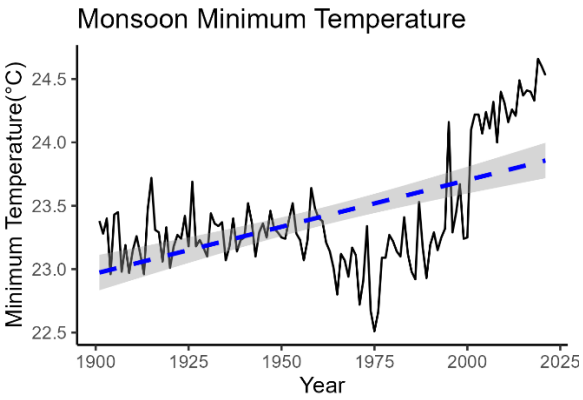

Figure 8: Plot of monsoon min temp

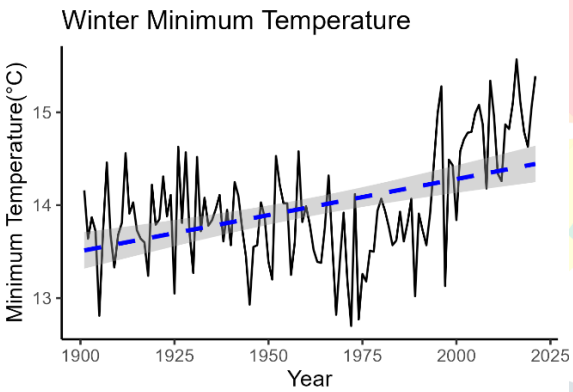

Figure 9: Plot of Winter Min Temperature

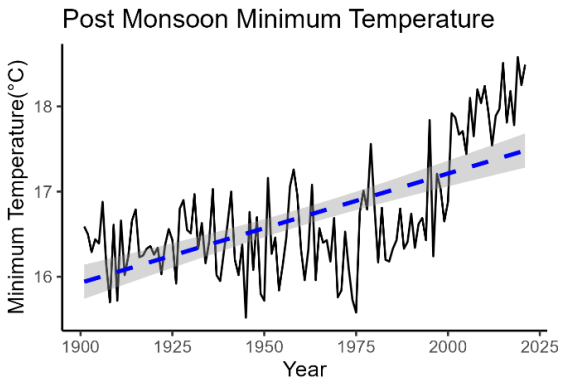

Figure 10: Plot of Post-Monsoon Min Temperature

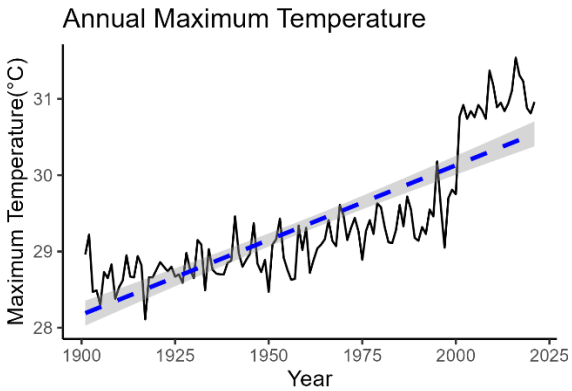

Figure 11: Plot of Annual Max Temperature

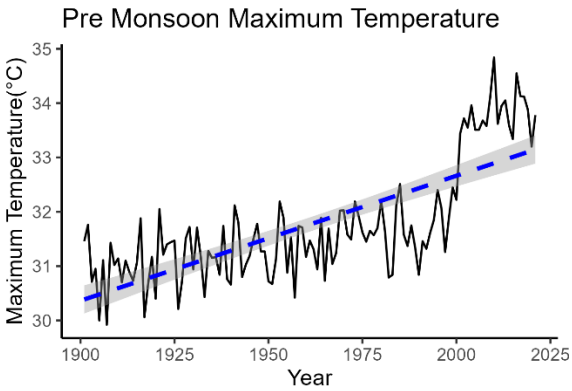

Figure 12: Plot of Pre-Monsoon Max Temperature

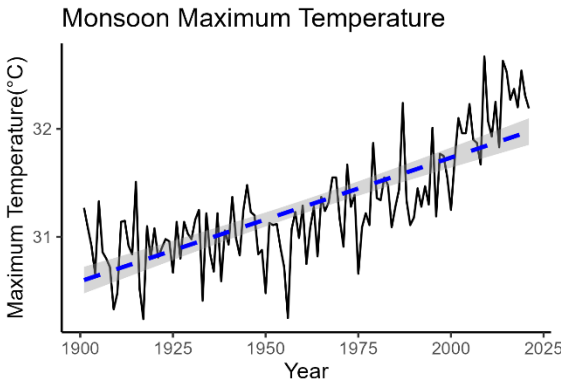

Figure 13: Plot of Monsoon Max Temperature

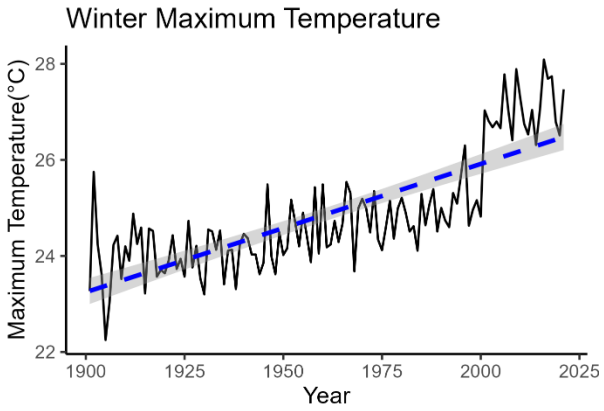

Figure 14: Plot of Winter Max Temperature

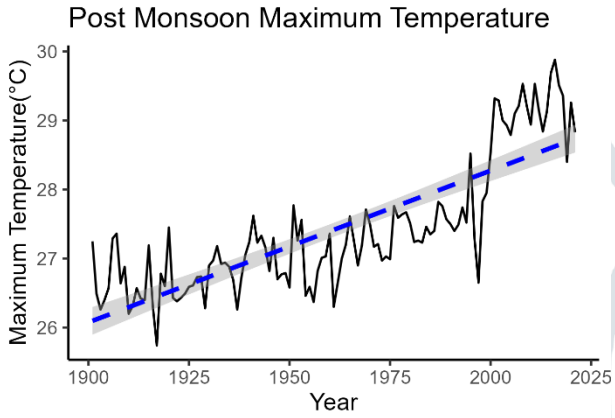

Figure 15: Plot of Post Monsoon Max Temperature

Figure 1 to 15 shows the time series plot of annual and seasonal Rainfall, Minimum Temperature and Maximum Temperature of India with the trend line. From the plots it is clear that there is decreasing trend in annual and seasonal Rainfall except Pre-Monsoon season. There is increasing trend in all annual and seasonal Minimum temperature and Maximum temperature.

Trend equation for the plots with the Adjusted R^2 is given in the table 4.

Table4: Trend equation with Adj R^2

Season	Climate Variables	Equation	Adj R^2
Annual	Rainfall	*Y=1413.95-0.12 X*	0.45
	Minimum Temperature	*Y=0.66+0.009X*	0.25
	Maximum Temperature	*Y=-9.03+0.019X*	0.62
Pre-Monsoon	Rainfall	*Y=-13.98+0.072X*	0.39
	Minimum Temperature	*Y=-0.51+0.01X*	0.33
	Maximum Temperature	*Y=-13.34+0.02X*	0.57
Monsoon	Rainfall	*Y=1169.26-0.14X*	0.08
	Minimum Temperature	*Y=8.97+0.007X*	0.26
	Maximum Temperature	*Y=8.84+0.011X*	0.72
Winter	Rainfall	*Y=152.65-0.06X*	0.58
	Minimum Temperature	*Y=-1.23+0.08X*	0.16
	Maximum Temperature	*Y=-27.49+0.02X*	0.22
Post-Monsoon	Rainfall	*Y=154.24-0.017X*	0.49
	Minimum Temperature	*Y=-8.45+0.012X*	0.81
	Maximum Temperature	*Y=-15.68+0.021X*	0.53

3.4 Change Point detection of climate variables

Detection of change point of climate variables is done by Pettit Homogeneity test and the result is presented in table 5.

Table 4: Change point detection

Season	Variables	Pettit Homogeneity Test		
		p value	Detection	Year
Annual	Rainfall	0.094	NO	-
	Minimum Temperature	<0.05	YES	1991
	Maximum Temperature	<0.05	YES	1963
Winter	Rainfall	0.101	NO	-
	Minimum Temperature	<0.05	YES	1991
	Maximum Temperature	<0.05	YES	1963
Pre-Monsoon	Rainfall	0.204	NO	-
	Minimum Temperature	<0.05	YES	1992
	Maximum Temperature	<0.05	YES	1967
Monsoon	Rainfall	0.085	NO	-
	Minimum Temperature	<0.05	YES	1992
	Maximum Temperature	<0.05	YES	1963
Post-Monsoon	Rainfall	0.716	NO	-
	Minimum Temperature	<0.05	YES	1974
	Maximum Temperature	<0.05	YES	1963

From the table 4, it is clear there is no change point for annual and seasonal rainfall and there is change point for annual and seasonal minimum and maximum temperature. The year where the trend has been changed is given in the table.

Figure 16 and 17 presents the plot of change point detection of annual minimum and maximum temperature.

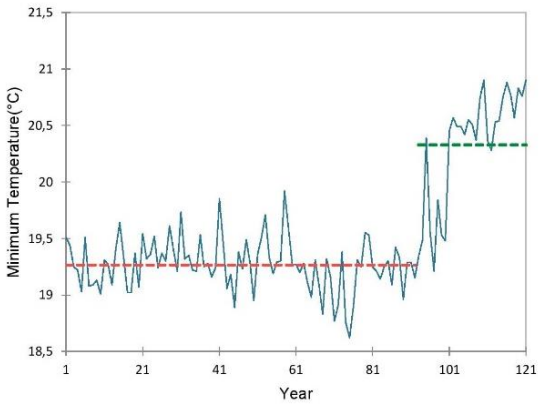

Figure 16: Change point of annual Min temperature

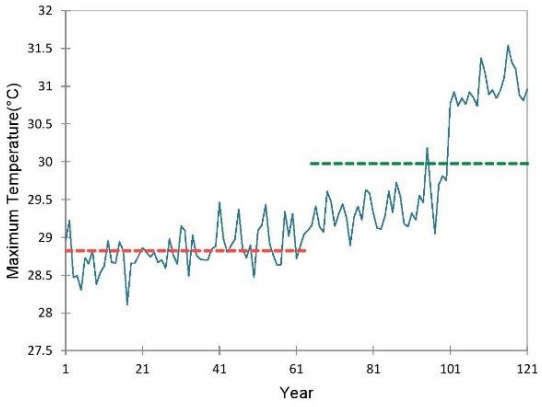

Figure 17: Change point of annual Max temperature

From figure 16 and 17, it is clear that at a certain point there is change of trend of climate variables.

4 Conclusion

The present study is an attempt to analyze the trend and detection of change point of the climatic variables like minimum temperature, maximum temperature and rainfall of India from year 1901 to 2021. Results revealed that there is significantly increasing trend in annual and seasonal maximum and minimum temperature. There is decreasing trend in annual and seasonal rainfall except pre monsoon rainfall which is increasing. This indicates that there is general tendency of rising temperature and decrease in rainfall of India. So, there is possibility of agricultural crop yield reduction, global warming, etc. There are many steps to reduce the climate change like transition to renewable energy, recycle wastes, reducing plastic waste, reducing deforestation, planting plants and trees, etc. So, we individuals should try to follow these steps and reduce the climate change.

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