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CONTENTS

Trend detection in weather parameters using Mann-Kendall test for *Tarai* region of Uttarakhand

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ABSTRACT: The trend analysis of the different weather parameters had been assessed for the *Tarai* region of Uttarakhand namely, maximum temperature, minimum temperature, rainfall, sunshine hours and evaporation by using non-parametric test i.e., Mann-Kendall test together with Sen's slope estimator for assessing actual change in the magnitude which has already occurred and this will further help in future predictions. The present study focuses on detecting the trend in different weather parameters from 1981-2021 on an annual and seasonal basis and comparison being made with the last 5 years trend i.e., from 2017-21.

Key words: Mann-Kendall, Pettitt, Sen's slope, *Tarai*

There was an increasing trend in the Tmax & Tmin of about 0.003^0C and 0.02^0C respectively and decreasing trend in the rainfall, sunshine hours and evaporation of about 2.12 mm, 0.04 hr & 0.02mm respectively, on the annual basis. The study also indicated that there is a decrease in the rainfall during monsoon season while increase in the rainfall during all other seasons due to the occurrence of certain extreme events in the last 5 years and range of temperature had been also decreased during most of the seasons.

Climate variability refers to the natural variations in climate parameters such as temperature, precipitation, wind patterns, and other atmospheric conditions over a period of time, ranging from weeks to decades (Ghodhke, 2014). Climate change has a marked and lasting change in the distribution of weather statistics from time to time ranging from millions of years to tens of millions. Weather conditions can vary due to factors such as changes in temperature, precipitation, and wind patterns. Climate change is primarily driven by alterations in ocean currents, fluctuations in solar radiation, and human-induced modifications to the natural environment. These human activities, including pollution and the release of greenhouse gases, are exacerbating global warming. Climate change is often used to describe a particular impact of human activities as indicated by Singh *et al.* (2014).

As climate variations affect the climatic pattern in short and long term the requirement of plant species which is the function of climate parameters also tends to change over time, so there is a need to acknowledge these variations in the climatic parameters. For this reason, Mann Kendall test is performed to detect the trend in these weather parameters for the management of water as the total rainfall in the monsoon season is decreasing which has adverse effect on the growth of the water loving crops especially Rice as indicated by Sandhu *et al.* (2024). In the last 5 years, there have been substantial changes in the climate as in some parts of country, flood like situation prevails and in the other part drought like situation could be seen so there is a need to detect these changes and according to that we can plan some mitigation and management practices.

The study area is located in the Kumaon region of Uttarakhand. The study area falls under sub-humid subtropical climate and *Tarai* belt located in the foothills of Himalayas at 29.02^0N & 79.48^0E and at the altitude of 244.0 m above the mean sea level as presented in the Figure 1. The geographical area of the town is 3055 km^2. The Tarai belt is 8–25 kms wide, with a general slope of 1% to the south.

MATERIALS AND METHODS

The weather data collected from the Agrometeorological Observatory (29.02^{0}N & 79.48^{0}E, altitude of 244.0 m) at N.E. Borlaug Crop Research Centre, G.B. Pant University of Agriculture and Technology, Pantnagar, from 1981 to 2021, were gathered on a daily basis (Fig. 1). Subsequently, averages were calculated on an annual, monthly, and seasonal basis as required. The trend analysis was done to detect the presence of increasing or decreasing trend using the non-parametric Mann-Kendall test and magnitude of trend was determined by Sen's slope estimator test as well as change point detection done by Pettitt's test. The trend analysis is done on the annual, monthly, weekly and seasonal basis. Climate normals (Weekly, Monthly, Seasonal and annual) have been calculated from the data collected.

The Mann-Kendall test- It is a non-parametric test, which means it works for all distributions (i.e. your data doesn't have to meet the assumption of normality), but the data should not have serial correlation as if the data follows a normal distribution, we can run simple linear regression instead. The Mann-Kendall test is a rank-based method for detecting trends in rainfall, temperature, sunshine hours, and evaporation that has been used in many previous researches. This is one of the most effective approaches for determining rainfall and temperature trends. The trend analysis for the historical period, i.e., from 1981 to 2021, was carried out in this work on an annual, monthly, weekly & seasonal basis and again these 41 years data were compared with last 5 years data i.e., from 2017-21.

The Mann-Kendall statistic, S, was considered to have a value of 0 at the beginning (i.e., no trend). The S statistic was increased by one if a data value from a later period was higher than a data value from an earlier period. The S statistic was decremented by 1 if the data value from a later time period was lower than the data value sampled earlier. The net result of all such increments and decrements yielded the final value of S (Ghadekar, 2013). The Mann Kendall Trend Test (also known as the M-K test) is used to observe, the consistently increasing or decreasing (monotonic) patterns in Y values in data gathered over time. For performing Mann Kendall test and Pettit's test R Studio software has been used.

Sen's Slope Estimator Test- The trend magnitude is calculated by slope estimator methods. The positive sign shows an increasing trend whereas the negative

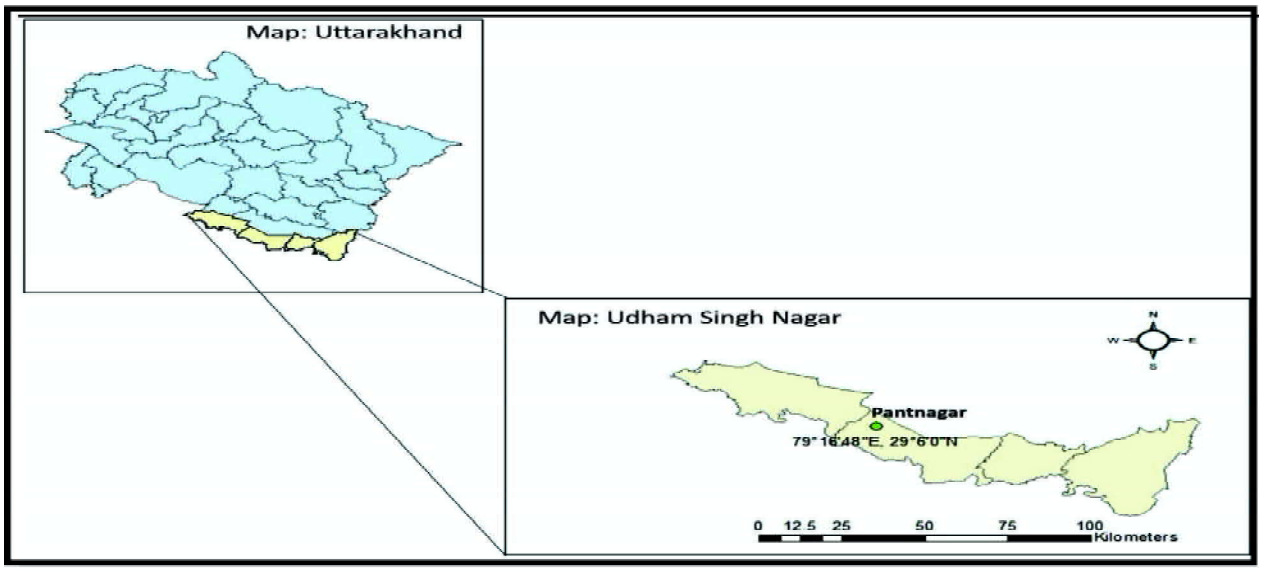

Fig. 1: The map depicting the study area i.e., *Tarai* region of Uttarakhand

sign shows a decreasing trend.

Pettitt's test- The change point detection is an important aspect to assess the period from where significant change has occurred in a time series. The Pettitt's test for change detection, developed by Pettit (1979), is a non-parametric test, which is useful for evaluating the occurrence of abrupt changes in climatic records. The Pettitt's test is the most commonly used test for change point detection because of its sensitivity to breaks in the middle of any time series. The Pettitt's test is a method that detects a significant change in the mean of a time series when the exact time of the change is unknown (Shankar, 2019).

RESULTS AND DISCUSSION

There is an increasing trend in the maximum and minimum temperature over the period from 1981-2021 on the annual basis as stated by the Z value of Mann Kendall test performed, as per Table 1. The rate of increase in the minimum temperature is more than the maximum temperature as per the calculated Sen's slope, the increase in maximum temperature is not significant but in case of Tmin, it is significant (0.013^0C), which is much more and the trend is incompatible, as p value is very much less than 1. If we plot a graph also, we can observe those changes or break in the series of Tmax in the year 2008, while that in Tmin during 1997 as depicted in the Table 1.

If we compare this 41-year data with the last 5-year data i.e., from 2017-21 as shown in the Table 2, a non- significant decrease in Tmax could be observed of about 0.138^0C and the reason behind this is, in the last 5 years, Indian subcontinent was hit by strong cyclones every year. For example, in 2020 & 2021 there was a strong cyclone i.e., Amphan and Tauktae due to which there was very high rainfall in almost all the parts of the country as well as, we all are aware of the impact of Janta Curfew on the air quality during Covid pandemic situation. According, to the report given by the CPCB (Central Pollution Control Board, MOEFCC, Government of India) there was the significant reduction in the $PM_{2.5}$, PM_{10}, and NO_x

Table 1: Descriptive analysis of Mann Kendall test and change point detection for the different weather parameters on annual basis from 1981-2021

Weather Parameters	Trend Analysis				Change point		
	Mann-Kendall statistic (Z)	Sen's Slope (β)	p value	Trend Significance at 95% confidence level	Pettitt's test Statistic(U^*)	Year of change	Change Significance at 95% confidence level
Tmax(^{0}C/year)	0.34	0.00	0.74	NS Increasing	114	2008	NS
Tmin (^{0}C/year)	4.48	0.02	0.03	S* Increasing	336	1997	S
Rainfall (mm/year)	-0.39	-2.12	0.69	NS Decreasing	108	2001	NS
Sunshine hours (hr./year)	-5.17	-0.04	0.00	S* Decreasing	350	2007	S
Evaporation (mm/year)	-3.98	-0.02	0.05	S* Decreasing	2.716	1992	S

*: indicates significance at $p< 0.05$ (5% level of Significance)

Table 2: Descriptive analysis of Mann Kendall test and change point detection for the different weather parameters on annual basis from 2017-21

Weather Parameters	Trend Analysis				Change point		
	Mann-Kendall statistic (Z)	Sen's Slope (β)	p value	Trend Significance at 95% confidence level	Pettitt's test Statistic(U^*)	Year of change	Change Significance at 95% confidence level
Tmax(^{0}C/year)	-0.25	-0.14	0.81	NS Decreasing	4	2017	NS
Tmin (^{0}C/year)	0.00	0.00	1.00	NS Increasing	3	2017	NS
Rainfall (mm/year)	-0.74	-47.10	0.46	NS Decreasing	6	2018	NS
Sunshine hours (hr./year)	0.00	-0.02	1.00	NS Decreasing	4	2017	NS
Evaporation (mm/year)	0.00	-0.01	1.00	NS Decreasing	4	2018	NS

*: indicates significance at $p< 0.05$ (5% level of Significance)

Table 3: Descriptive analysis of Mann Kendall test and change point detection for the maximum temperature on seasonal basis from 1981-2021

Seasons (^{0}C/year)	Trend Analysis				Change point		
	Mann-Kendall statistic (Z)	Sen's Slope (β)	p value	Trend Significance at 95% confidence level	Pettitt's test Statistic(U*)	Year of change	Change Significance at 95% confidence level
Monsoon	-0.37	-0.00	0.71	NS Decreasing	141	1995	NS
Post Monsoon	0.53	0.01	0.60	NS Increasing	119	2014	NS
Winter	-1.36	-0.02	0.17	NS Decreasing	176	1996	NS
Summer	0.08	0.00	0.94	NS Increasing	92	1983	NS

Table 4: Descriptive analysis of Mann Kendall test and change point detection for Maximum Temperature on seasonal basis from 2017-21

Weather Parameters (^{0}C/year)	Trend Analysis				Change point		
	Mann-Kendall statistic (Z)	Sen's Slope (β)	p value	Trend Significance at 95% confidence level	Pettitt's test Statistic(U*)	Year of change	Change Significance at 95% confidence level
Monsoon	-1.19	-0.08	0.27	NSDecreasing	4	2017	NS
Post Monsoon	0.00	0.01	1.00	NSIncreasing	4	2017	NS
Winter	-1.36	-0.02	0.17	NSDecreasing	4	2017	NS
Summer	0.08	0.00	0.94	NSIncreasing	6	2018	NS

Table 5: Descriptive analysis of Mann Kendall test and change point detection for Minimum Temperature on seasonal basis from 1981-2021

Weather Parameters (^{0}C/year)	Trend Analysis				Change point		
	Mann-Kendall statistic (Z)	Sen's Slope (β)	p value	Trend Significance at 95% confidence level	Pettitt's test Statistic(U*)	Year of change	Change Significance at 95% confidence level
Monsoon	5.28	0.03	0.00	S* Increasing	314	2008	S
Post Monsoon	1.92	0.03	0.09	NS Increasing	192	2020	NS
Winter	2.36	0.02	0.02	S* Increasing	199	2002	S
Summer	1.67	0.02	0.09	NS Increasing	211	1999	NS

*: indicates significance at p< 0.05 (5% level of Significance)

Table 6: Descriptive analysis of Mann Kendall test and change point detection for Minimum Temperature on seasonal basis from 2017-21

Weather Parameters	Trend Analysis				Change point		
	Mann-Kendall statistic (Z)	Sen's Slope (β)	p value	Trend Significance at 95% confidence level	Pettitt's test Statistic(U*)	Year of change	Change Significance at 95% confidence level
Monsoon	1.52	0.06	0.13	NSIncreasing	6	2019	NS
Post Monsoon	0.25	0.21	0.81	NSIncreasing	4	2018	NS
Winter	0.00	0.06	1.00	NSIncreasing	4	2017	NS
Summer	-0.74	-0.27	0.46	NSDecreasing	4	2020	NS

levels in the atmosphere and it seems to be rejuvenated and clean, so there was less Tmax comparatively, especially in the year 2020 as per Nanda *et al.* (2021). But an increasing trend in the Tmin had been observed and there is a steady increase in Tmin as p value is exactly 1, which means range of temperature is decreasing (Tmax-Tmin) which would adversely affect the photosynthetic rate of the crops.

There is a non-significant decrease in the rainfall trend over the period from 1981-2021 as well as in

Table 7: Descriptive analysis of Mann Kendall test and change point detection for Rainfall on seasonal basis from 1981-2021

Weather Parameters	Trend Analysis				Change point		
(mm/year)	Mann-Kendall statistic (Z)	Sen's Slope (β)	p value	Trend Significance at 95% confidence level	Pettitt's test Statistic(U^*)	Year of change	Change Significance at 95% confidence level
Monsoon	-0.19	-1.08	0.85	NSDecreasing	110	1998	NS
Post Monsoon	-0.20	0.00	0.84	NSDecreasing	65	2009	NS
Winter	-0.84	-0.67	0.40	NSDecreasing	118	2003	NS
Summer	0.62	1.78	0.54	NSIncreasing	158	1998	NS

Table 8: Descriptive analysis of Mann Kendall test and change point detection for Rainfall on seasonal basis from 2017-21

Weather Parameters	Trend Analysis				Change point		
(mm/year)	Mann-Kendall statistic (Z)	Sen's Slope (β)	p value	Trend Significance at 95% confidence level	Pettitt's test Statistic(U^*)	Year of change	Change Significance at 95% confidence level
Monsoon	-1.72	-196.48	0.09	NSDecreasing	6	2018	NS
Post Monsoon	1.01	18.50	0.31	NSIncreasing	4	2020	NS
Winter	0.25	18.50	0.81	NSIncreasing	4	2020	NS
Summer	1.23	40.13	0.22	NSIncreasing	6	2019	NS

Table 9: Descriptive analysis of Mann Kendall test and change point detection for Sunshine Hours on seasonal basis from 1981-2021

Weather Parameters	Trend Analysis				Change point		
(hr./year)	Mann-Kendall statistic (Z)	Sen's Slope (β)	p value	Trend Significance at 95% confidence level	Pettitt's test Statistic(U^*)	Year of change	Change Significance at 95% confidence level
Monsoon	-2.94	-0.03	0.00	S*Decreasing	254	2006	S
Post Monsoon	-5.14	-0.06	0.00	S*Decreasing	366	2003	S
Winter	-6.16	-0.07	0.00	S*Decreasing	395	2002	S
Summer	-2.51	-0.02	0.01	S*Decreasing	249	2005	S

*: indicates significance at $p< 0.05$ (5% level of Significance)

Table 10: Descriptive analysis of Mann Kendall test and change point detection for Sunshine Hours on seasonal basis from 2017-21

Weather Parameters	Trend Analysis				Change point		
(hr./year)	Mann-Kendall statistic (Z)	Sen's Slope (β)	p value	Trend Significance at 95% confidence level	Pettitt's test Statistic(U^*)	Year of change	Change Significance at 95% confidence level
Monsoon	0.25	0.04	0.81	NSIncreasing	6	2018	NS
Post Monsoon	0.00	0.03	1.00	NSIncreasing	2	2017	NS
Winter	-0.74	-0.19	0.46	NSDecreasing	6	2018	NS
Summer	-0.25	-0.14	0.81	NSDecreasing	4	2020	NS

the last 5 years for the *Tarai* region of Uttarakhand. In the year 2021 there was more rainfall and flood like situation occurred in the post monsoon season due to Western Disturbances during the post monsoon period (October and November) and during the winter season (December to February) and weather over the Himalayas is determined by the eastward passage of low-pressure systems.

The rate of decrease in the magnitude of rainfall is about 2.12 mm as depicted in the Table 1 and break in the rainfall trend was observed during 2001 in the time series. There is a significant decrease in

Table 11: Descriptive analysis of Mann Kendall test and change point detection for Evaporation on seasonal basis from 1981-2021

Weather Parameters	Trend Analysis				Change point		
(mm/year)	Mann-Kendall statistic (Z)	Sen's Slope (β)	p value	Trend Significance at 95% confidence level	Pettitt's test Statistic(U^*)	Year of change	Change Significance at 95% confidence level
Monsoon	-1.93	-0.02	0.05	NSDecreasing	266	2002	NS
Post Monsoon	-3.40	-0.02	0.00	S*Decreasing	306	2002	S
Winter	-3.32	-0.11	0.00	S*Decreasing	283	2002	S
Summer	-3.68	-0.05	0.00	S*Decreasing	300	2001	S

*: indicates significance at $p< 0.05$ (5% level of Significance)

Table 12: Descriptive analysis of Mann Kendall test and change point detection for Evaporation on seasonal basis from 2017-21

Weather Parameters	Trend Analysis				Change point		
(mm/year)	Mann-Kendall statistic (Z)	Sen's Slope (β)	p value	Trend Significance at 95% confidence level	Pettitt's test Statistic(U^*)	Year of change	Change Significance at 95% confidence level
Monsoon	-0.25	-0.09	0.81	NSDecreasing	4	2020	NS
Post Monsoon	1.23	0.19	0.22	NSIncreasing	6	2019	NS
Winter	1.72	0.14	0.09	NSIncreasing	6	2018	NS
Summer	-0.74	-0.04	0.46	NSDecreasing	6	2019	NS

the trend for sunshine hours and evaporation, over the period from 1981-2021 for the *Tarai* region of Uttarakhand because aberrations in the values of these two parameters could be observed. A non-significant decrease in the trend for the sunshine hours and evaporation had been depicted in the last 5 years (Table 2).

The non- significant decreasing trend in the Tmax had been observed during monsoon and winter season due to presence of more relative humidity during these two seasons as compared to post monsoon and summer season (Table 13). There is a significant increase in the Tmin during monsoon season and winter season (Table 5) because during these two seasons characterized by the presence of sufficient water vapor, minimal disparity was observed in the Tmax (maximum temperature) and Tmin (minimum temperature). Conversely, a non-significant increasing trend in Tmin was noted during the post-monsoon and summer seasons. A non- significant increase in the trend of Tmin during all the seasons in the last 5 years (Table 6) has been observed except in the summer season, during which, there is a decreasing trend especially in 2020 because of the cyclone as studied by Liu *et al.* (2021).

There is a non-significant decrease in the trend of rainfall during all the seasons except during the summer season (Table 7) due to the certain natural disaster as discussed before had been observed in this region, while an increasing trend in the rainfall during all the seasons had been observed in the last 5 years for the *Tarai* region of Uttarakhand as depicted in Table 8 due to the late onset of monsoon and increase in the western disturbances event, during the last 5 years (Hunt, 2024).

A significant decrease in the trend of sunshine hours during all the season had been observed as per the Table 9 over the period from 1981-2021 due to increase in the pollutant as discussed above but during the last 5 years, an increasing trend in the sunshine hours during monsoon and post monsoon season has been observed in the *Tarai* region due to decrease in the no. of rainy days during monsoon season as shown in the Table 10 and though there is a slight increase in the no. of rainy day, but this increase is due to extreme event that occurred around 17-19 October in most parts of the Uttarakhand in the post monsoon season (IMD , October 2021) and the reason behind this was, the deep depression

which originated around the Bay of Bengal & Western Disturbances. Generally, the post monsoon season is considered as dry month for the *Tarai* region of Uttarakhand but in the year 2021 there was total rainfall of about 427.5 mm (Table 15).

There is a non-significant decrease in the trend of sunshine hours during summer and winter season due to increase in the no. of rainy day as per the Table 14. A significant decrease in the rate of evaporation during all the seasons has been observed except in the monsoon season, during which there is a non-significant decrease in the evaporation because of the presence of sufficient moisture as depicted in Table 11. A non-significant increase in the trend of evaporation in the last 5 years during post monsoon and winter season has been calculated due to increase in western disturbances event in these two seasons while, a decreasing trend in the evaporation had been observed during monsoon and summer season due to less availability of moisture comparatively during these two seasons as presented in the Table 12.

Table 13: The average Relative Humidity data on seasonal basis for Tarai region of Uttarakhand over the period from 1981-2021

Year	Monsoon	Post Monsoon	Post Monsoon	Summer
1981	75.3	63.5	70.7	55.8
1982	76.0	65.5	71.2	56.5
1983	72.1	64.8	67.2	56.7
1984	78.4	57.8	69.7	52.8
1985	76.4	68.5	66.7	44.2
1986	76.0	66.5	67.7	50.2
1987	67.8	60.8	68.3	47.7
1988	75.4	63.0	66.3	47.5
1989	78.1	63.0	71.2	44.3
1990	79.8	65.3	73.5	56.0
1991	74.1	60.5	67.3	50.3
1992	71.0	65.0	69.3	44.8
1993	68.3	65.8	67.5	52.7
1994	74.9	62.5	70.8	51.5
1995	76.8	66.3	70.7	48.7
1996	78.4	75.8	74.8	51.5
1997	76.4	69.5	75.2	55.8
1998	75.1	72.5	75.2	58.3
1999	77.6	68.5	74.8	52.3
2000	80.4	68.8	72.3	56.0
2001	77.1	67.5	74.5	53.2
2002	73.8	67.5	71.5	55.5
2003	76.6	64.5	78.7	54.2
2004	80.5	70.0	75.2	53.3
2005	71.3	69.0	72.2	51.2
2006	72.8	70.0	70.7	54.5
2007	76.1	66.8	71.0	55.7
2008	78.6	66.8	69.8	51.5
2009	69.9	67.8	71.8	51.7
2010	72.9	66.5	74.0	50.3
2011	77.4	72.0	74.0	54.8
2012	70.3	64.8	71.5	52.8
2013	77.4	70.8	73.3	53.5
2014	73.1	68.5	79.5	53.0
2015	72.8	67.0	76.3	61.2
2016	76.8	67.2	55.8	53.7
2017	76.5	68.5	74.5	52.8
2018	80.0	73.8	77.7	58.3
2019	72.6	69.5	77.8	53.7
2020	76.9	66.0	78.3	57.5
2021	74.9	68.1	73.7	51.9
Average	75.3	67.0	72.0	52.9

CONCLUSION

The study conducted in the *Tarai* region of Uttarakhand reveals significant shifts in climate patterns over the past five years, with annual maximum temperatures steadily rising while intermittent decrease has been observed. Moreover, there are notable fluctuations in rainfall distribution, including an unprecedented increase in post-monsoon rainfall in 2021, leading to adverse effects on crop growth and necessitating improved management techniques to mitigate damage. Strategies such as implementing the Furrow Irrigated Raised Bed System (FIRBS) for crops like Maize and Groundnut to prevent waterlogging, maintaining proper field drainage systems, and transitioning towards short-duration, low-water requiring crops like Kharif Pulses or employing techniques like Direct Seeded Rice (DSR) are recommended by Upadhyay *et al.* (2015). Additionally, a concerning trend of decreasing maximum temperatures and increasing minimum temperatures has emerged, diminishing the temperature range and potentially impacting crop growth adversely. This trend may lead to accelerated crop maturity and improper grain development due to faster seed germination influenced by higher night temperatures as per Daloz *et al.* (2021). Notably, the rising maximum temperatures pose challenges for apple orchards in higher altitudes around Solan as per the findings of

Table 14: Descriptive analysis of Mann Kendall test and change point detection for no. of rainy day on seasonal basis from 2017-21

Weather Parameters	Trend Analysis				Change point		
(mm/year)	Mann-Kendall statistic (Z)	Sen's Slope (β)	p value	Trend Significance at 95% confidence level	Pettitt's test Statistic(U^*)	Year of change	Change Significance at 95% confidence level
Monsoon	-1.72	-4.63	0.09	NSDecreasing	6	2018	NS
Post Monsoon	0.78	0.75	0.43	NSIncreasing	4	2020	NS
Winter	0.74	1.00	0.46	NSIncreasing	6	2018	NS
Summer	0.74	1.00	0.46	NSIncreasing	6	2019	NS

Table 15: The total seasonal rainfall for the *Tarai* region of Uttarakhand over the period from 2017-21

Year	Monsoon	Post Monsoon	Winter	Summer
2017	1355.4	0	63.2	46.6
2018	1662.9	6.8	11.6	65
2019	1119.4	29.2	127.4	20.6
2020	930.9	0	143.9	178
2021	710.5	427.5	28.2	194.7

Sahu *et al.* (2020), necessitating a shift in cultivation elevations and diversification of crops to peas, potatoes, and plums in lower altitude areas.

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