



Impact of temperature and rainfall variability on agriculture and horticulture crops in the North-Western Indian Himalaya

HARISH BHARTI¹ and RANBIR SINGH RANA^{2*}

¹State Centre on Climate Change O/o H.P. Council for Science, Technology and Environment (HIMCOSTE),

Vigyan Bhawan, Bemloe, Shimla-171001, H.P., India

²Department of Agronomy, CSK Himachal Pradesh Krishi Vishvavidyalaya, Palampur, H.P. India,

(Received 5 April 2025, Accepted 7 August 2025)

*Corresponding author's email: ranars66@gmail.com

सार – जलवायु परिवर्तनशीलता, विशेष रूप से तापमान और वर्षा में उतार-चढ़ाव ने कृषि क्षेत्र पर महत्वपूर्ण प्रभाव दिखाया, विशेष रूप से खाद्य सुरक्षा सुनिश्चित करने के लिए महत्वपूर्ण फसल प्रणालियों पर। एक व्यापक अध्ययन ने हिमाचल प्रदेश के सिरमौर जिले में कृषि और बागवानी पर सकारात्मक और नकारात्मक दोनों जलवायु परिवर्तनशीलता के प्रभाव का आकलन किया। इस जांच ने 27 वर्षों (1995-2021) में जलवायु चरों और फसल उत्पादकता के बीच जटिल संबंधों का विश्लेषण किया, जो जलवायु-अनुकूल खेती की रणनीति विकसित करने के लिए महत्वपूर्ण अंतर्दृष्टि प्रदान करता है। प्रमुख जलवायु चरों में दीर्घकालिक प्रवृत्तियों का मूल्यांकन करने के लिए सांख्यिकीय उपकरणों और मॉडलों को नियोजित किया गया था, जिसमें देखे गए परिवर्तनों की सार्थकता और दर निर्धारित करने पर ध्यान केंद्रित किया गया था। अध्ययन की अवधि के दौरान, खरीफ (गर्मी) के मौसम में अधिकतम और न्यूनतम दोनों तापमानों में क्रमशः $-0.080^{\circ}\text{C}/\text{वर्ष}$ और $-0.090^{\circ}\text{C}/\text{वर्ष}$ की दरों से महत्वपूर्ण गिरावट देखी गई। खरीफ फसलों के प्रवृत्ति विश्लेषण ने धान (0.046 टन/हेक्टेयर/वर्ष) और दालों (0.020 टन/हेक्टेयर/वर्ष) की उत्पादकता में महत्वपूर्ण वृद्धि का संकेत दिया, जबकि मक्के की उत्पादकता में महत्वहीन वृद्धि देखी गई। बागवानी क्षेत्र में, समशीतोष्ण क्षेत्र (Temperate zone) में फल लगने की अवस्था के दौरान अधिकतम और न्यूनतम दोनों तापमानों में महत्वपूर्ण गिरावट देखी गई, जो कई फेनोलॉजिकल चरणों में जलवायु-प्रेरित परिवर्तनों का सुझाव देती है। इसके अलावा, उप-उष्णकटिबंधीय (Sub-tropical) क्षेत्र में, फल लगने की अवस्था के दौरान अधिकतम तापमान में महत्वपूर्ण कमी दर्ज की गई थी। ये निष्कर्ष इंगित करते हैं कि पिछले 27 वर्षों में, सिरमौर जिले में जलवायु परिवर्तनों का अमरुद को छोड़कर, अधिकांश फलों की फसलों की उत्पादकता पर आम तौर पर सकारात्मक प्रभाव पड़ा है, जिसकी पैदावार में गिरावट देखी गई थी। इस विश्लेषण ने क्षेत्र में कृषि उत्पादकता को बनाए रखने और बढ़ाने के लिए बदलते जलवायु प्रतिरूपों के सामने अनुकूलन रणनीतियों की महत्वपूर्ण आवश्यकता पर प्रकाश डाला।

ABSTRACT. Climate variability, particularly fluctuations in temperature and rainfall, showed significant impacts on the agricultural sector, especially on cropping systems critical to ensuring food security. A comprehensive study assessed the influence of both positive and negative climate variability on agriculture and horticulture in the Sirmour district of Himachal Pradesh. This investigation analyzed the complex relationship between climate variables and crop productivity over 27 years (1995–2021), providing insights crucial for developing climate-resilient farming strategies. The statistical tools and models were employed to evaluate long-term trends in key climatic variables, with a focus on determining the significance and rate of observed changes. Over the study period, a significant decline in both maximum and minimum temperatures during the Kharif (summer) season was observed, with rates of $-0.080^{\circ}\text{C}/\text{year}$ and $-0.090^{\circ}\text{C}/\text{year}$, respectively. Trend analysis of Kharif crops indicated a significant increase in the productivity of rice (0.046 t/ha/year) and pulses (0.020 t/ha/year), while maize showed a non-significant increase in productivity. In the horticulture sector, significant declines in both maximum and minimum temperatures were observed during the fruit-setting stage in the temperate zone, suggesting climate-induced alterations across multiple phenological stages. Furthermore, in the sub-tropical region, a significant decrease in maximum temperature was recorded during the fruit-setting stage. These findings indicate that over the past 27 years, climatic changes in the Sirmour district have had a generally positive impact on the productivity of most fruit crops, except guava, which exhibited a decline in yield. This

analysis highlighted the critical need for adaptive strategies in the face of evolving climate patterns to sustain and enhance agricultural productivity in the region.

Key words – Climate variability, Crop productivity, Long-term trends, Horticulture, Agriculture.

1. Introduction

The phenomenon of climate change is already affecting food security by raising temperatures, altering precipitation patterns, and increasing the occurrence of extreme events (Mbow, *et al.*, 2019). Increased temperatures have been shown to cause heat stress in important crop species, which can impair photosynthesis, disrupt critical growth stages, and impede plant development as a whole (Ruchel, *et al.*, 2020). In addition, elevated temperatures have been linked to an increase in pests and diseases, which in turn results in reduced crop quality and yield (Getahun, *et al.*, 2022). The crop productivity is expected to reduce when rainfall patterns change and hot spells become more unpredictable, (Gora, *et al.*, 2019).

Himachal Pradesh is an important part of the Himalayas, and the mountain ecosystem is highly sensitive to climate change (KC, *et al.*, 2022). Local studies on climatic trends conducted in several agroclimatic zones in Himachal Pradesh Himalayas have shown declining trends in rainfall while increasing maximum and lowest temperatures in the mountain state of Himachal Pradesh (Rana *et al.*, 2012). Similarly, the farmers' perceptions across different Agroclimatic zones on weather cycles with climate change in Himachal Pradesh also clearly described the validated change in climatic parameters causing a shift in crop production from crops that require high to low water. The study concludes that climate variability has a clear impact on crop productivity and increases in vulnerability in climate-dependent agricultural systems. (Rana, *et al.*, 2013). Similarly, drastic climate change alters the progressive stages of pathogens in the agriculture sector, severely affecting crop growth and yields, as well as potentially increasing pest and insect populations, ultimately destroying overall productivity (Rao, *et al.*, 2019b). Also, the changes in climatic parameters in Himachal have indicated a decrease in water resources in the mountains during the past three decades impacting the assured irrigation channel (Rana, *et al.*, 2014). Weather parameter forecasts were proven to be useful and profitable for agricultural decision-making, particularly rainfall and temperature forecasts proved to be advantageous in conserving irrigated crops (Rana *et al.*, 2013).

The current study region contains a substantial component of the Himalayan ecosystem, and entirely

Himalayan region is considered to be highly vulnerable to climate change (Gopirajan, *et al.*, 2022). To examine the effect of major climate drivers *i.e.*, temperature and rainfall, a study was conducted in the Sirmour district of Himachal Pradesh to investigate the impact on agriculture and horticulture crops. The study conducted for climate vulnerability in the Agricultural sector for the region concluded that the shift toward off-season vegetable production better control of diseases, insects, and pests and the implementation of adaptation measures to offset climate change can enhance climate resilience in mountain regions. (Rana, *et al.* 2021).

2. Data and methodology

2.1. Study area

Sirmour is the southernmost district of Himachal Pradesh, in northern India. It is largely mountainous and rural, with 90% of its population living in villages. The district is headquartered in Nahan and lies between North latitude 31° 01'00" to 30° 22'00" and East longitude 77° 01'00" to 77° 50'00". The district has an inter-state boundary in the south with the states of Haryana and Uttar Pradesh and in the east with Uttarakhand (Fig. 1).

2.2. Database

The meteorological variables, *i.e.*, temperature and rainfall, were collected from the India Meteorological Department (IMD), Shimla for the Sirmour district for the years 1995 to 2021. The data on acreage and production of horticulture and agriculture crops over the past three decades (1995–2021) was obtained from the Department of Economics and Statistics, Government of Himachal Pradesh. The agriculture data was categorized as Rabi (winter) and Kharif (summer) seasons, *i.e.*, November to April and May to October, respectively. For horticultural crops, datasets were categorized into different phenological stages: pre-flowering, flowering, and fruit setting. The study examined thirteen fruit crops to assess the effects, including apple (*Malus domestica*), plum (*Prunus domestica*), peach (*Prunus persica*), apricot (*Prunus armeniaca*), pear (*Pyrus communis*), various dry fruits, guava (*Psidium guajava*), mango (*Mangifera indica*), orange (*Citrus reticulata*), malta (*Citrus sinensis*), galgal (*Citrus medica*), kagzi lime (*Citrus limon*), litchi (*Litchi chinensis*), and five agriculture crops *viz.*, maize (*Zea mays*), rice (*Oryza sativa*), wheat (*Triticum vulgare*),

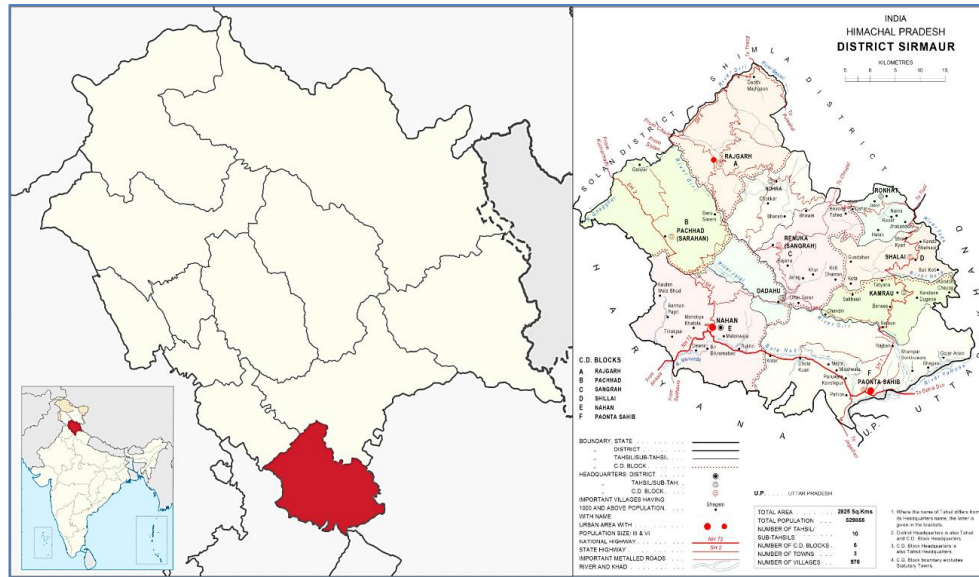


Fig. 1. Geographical representation of the study area situated in Sirmour district, Himachal Pradesh, India

barley (*Hordeum vulgare*), and pulses also included for the study of the impacts.

2.3. Methodology

Trend analysis: The Mann-Kendall Test (Mann, 1945; Kendall, 1975), a statistical test for trend analysis in climatologic and hydrologic time series, was used to examine seasonal patterns in climatic variables like minimum, maximum, and diurnal temperatures, as well as rainfall (quantity and days) (Pohlert, 2018). The Mann-Kendall Test compares the basic null hypothesis of no trend, which claims that the data is independent and in random order, to the alternative hypothesis, H₁. The test is performed on a time series of n data points, using T_i and T_j as two subsets of data (i = 1, 2, 3, n-1) and j = i+1, i+2, i+3, ..., n.

In an ordered time, series, every data point is compared to the next data point. If the next data point is greater than the current one, the statistic S is increased by 1, and if it is less than the current one, S is decreased by 1. The net results of all iterations are used to determine the final value of S, also known as the Mann-Kendall S statistic.

$$S = \sum_{i=1}^{n-1} \sum_{j=i+1}^n \text{sgn}(T_j - T_i) \quad (1)$$

$$\text{Sgn}(T_j - T_i) = \begin{cases} 1 & \text{if } T_j - T_i > 0 \\ 0 & \text{if } T_j - T_i = 0 \\ -1 & \text{if } T_j - T_i < 0 \end{cases} \quad (2)$$

where T_j and T_i are the annual values in years j and i, j > i, respectively.

A trend that is upward or downward is shown by a positive or negative value for S.

Sen's Slope, which indicates the linear rate of change and intercept, measures the magnitude of the pattern. After evaluating a variety of linear slopes, Sen's slope—the median of all linear slopes—is computed to determine the extent of the observed seasonal pattern. The p-value is an additional statistic related to the Mann-Kendall test. The greater the weight of evidence against the null hypothesis of no pattern, the lower the p-value (below 0.05). The statistical Mann-Kendall test is performed on the software XL-STAT, 2024 (Lumivero, 2024) for this analysis. The null hypothesis is tested at a 95% confidence level for rainfall (amount and days) and minimum, maximum, and diurnal temperate conditions for the years 1995–2021. Additionally, the trends in agricultural and horticultural crop productivity were examined.

Standardized Anomaly Index: This was used to measure deviations in climate variables (like temperature, precipitation, etc.) from their historical mean, to identify anomalies in a standardized way by deducting the long-term average of rainfall and temperature data sets from individual values, then dividing the result by the standard deviation of the values (Koudahe, et al., 2017). This test helps for crop management, and assessing the effects of climate change on agricultural production, as it provides a consistent metric to compare anomalies across different periods or locations.

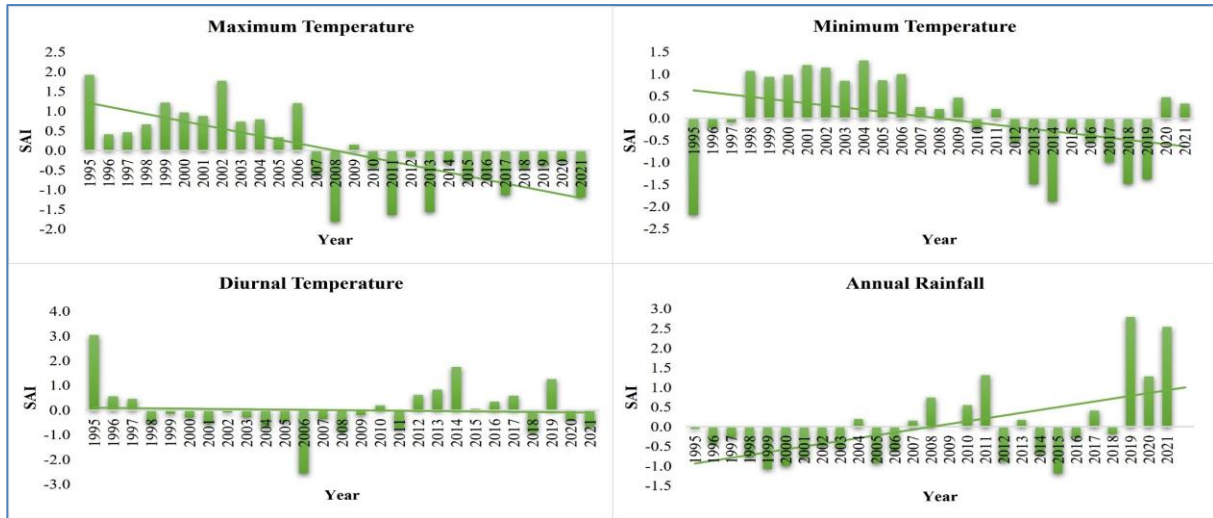


Fig. 2. Standardized Anomaly Index (SAI) of maximum, minimum, diurnal temperature, and rainfall for *Kharif* Season, Sirmour district, 1995–2021, Himachal Pradesh, India

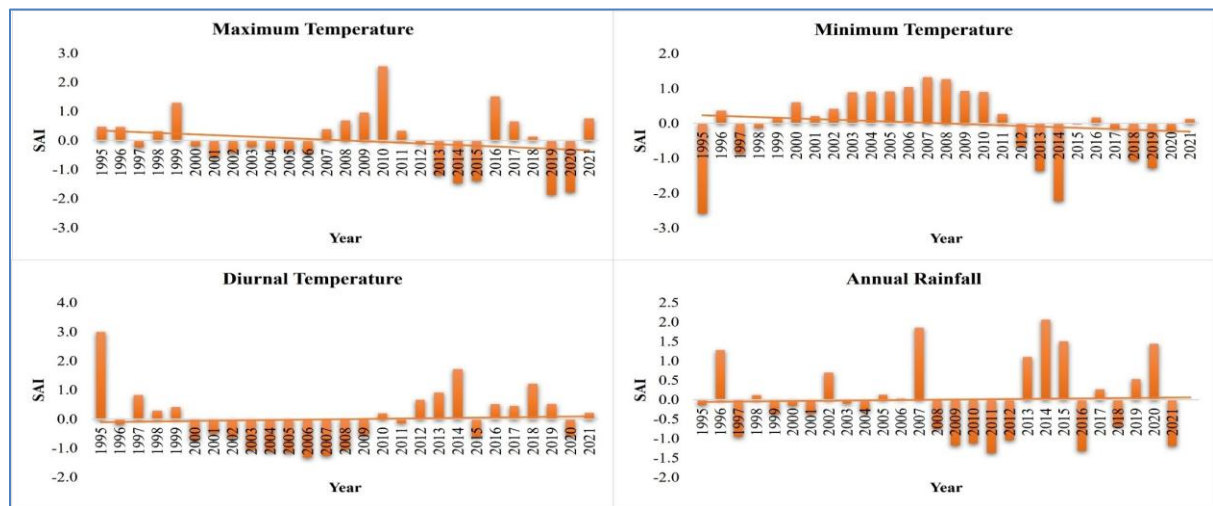


Fig. 3. Standardized Anomaly Index (SAI) of maximum, minimum, diurnal temperature, and rainfall for *Rabi* Season, Sirmour district, 1995–2021, Himachal Pradesh, India

Multivariate Linear Regression Model: The linear multivariate regression (IBM Corp, 2019) a statistical measure is chosen to assess the climate-crop yield relationship. A dependent variable is driven by multiple independent variables in a multivariate linear regression model, and thus multiple coefficients are calculated. In this investigation, the degree of association between agricultural productivity and meteorological variables was assessed using Pearson's correlation coefficient. A correlation coefficient of -1 indicates a perfectly negative linear relationship between the two variables; a correlation coefficient of 0 doesn't indicate a linear relationship between the two variables (but probably a non-linear relationship); and a correlation coefficient of 1 indicates a perfectly positive linear relationship between the two variables. Correlation coefficient values can never be less than -1 or greater than 1. The regression analysis verified

the effect of anomalies in the studied climatic parameters on crop productivity, as demonstrated by the following linear model:

$$\Delta P = \text{constant} + (\alpha \times \Delta T_{\min}) + (\beta \times \Delta T_{\max}) + (\gamma \times \Delta T_{dt}) + (\delta \times \Delta R) + (\epsilon \times \Delta R_d) \quad (3)$$

where, ΔP is the observed change in the productivity due to minimum, maximum, diurnal temperature, and rainfall in the respective phenological stages of the fruit crops and agriculture crops. The symbols for minimum, maximum, rainfall, and diurnal temperature are α , β , γ , and δ , respectively. ΔT_{\min} , ΔT_{\max} , T_{dt} , ΔR and ΔR_d are the observed changes in minimum, maximum, diurnal temperature, rainfall and rainy days respectively for the cropping seasons during the study period.

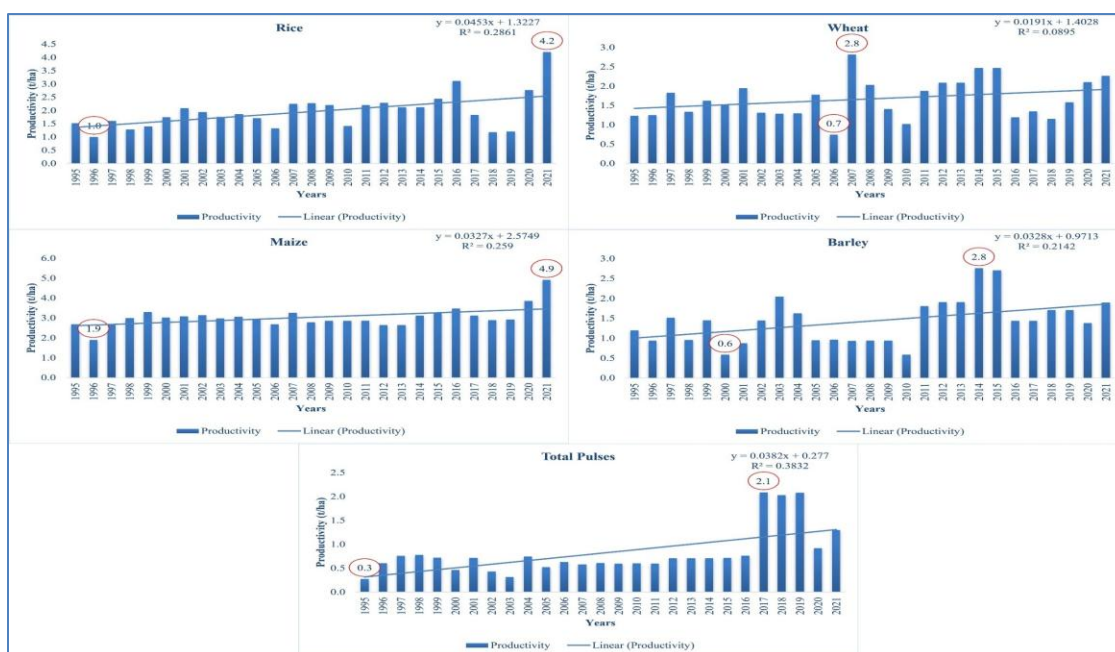


Fig. 4. Productivity of Rice, Wheat, Maize, Barley, and Pulses from 1995–2021 in the Sirmour district of Himachal Pradesh, India

TABLE 1

Mann-Kendall Test Results at 95% confidence level for minimum, maximum, and diurnal temperate, and rainfall for summer and winter Seasons in Sirmour district (1995–2021), Himachal Pradesh, India

Category	Mean	Sen's slope	p-value
<i>Kharif (Summer Season)</i>			
Maximum Temperature	-0.074	-0.080	0.001***
Minimum Temperature	0.084	-0.090	0.002**
Diurnal Temperature	-0.117	0.011	0.628
Rainfall	0.002	0.069	0.009**
<i>Rabi (Winter Season)</i>			
Maximum Temperature	-0.018	-0.028	0.508
Minimum Temperature	0.009	-0.031	0.146
Diurnal Temperature	-0.115	0.035	0.158
Rainfall	0.005	-0.006	0.930

Significance Levels: * $P \leq .05$; ** $P \leq 0.01$; *** $P \leq .001$

3. Results and discussion

The climatic assessment includes phenological stages (pre-flowering, flowering, and fruit setting) for horticultural crops and trend analysis of rainfall and temperature (maximum, minimum, and diurnal temperature), including the Rabi and Kharif seasons for agricultural crops. After analyzing the individual trend analysis, a correlation study was performed to study the climate-crop relationship. The climate assessment comprises a trend analysis of temperature (maximum, minimum, and diurnal variations) and rainfall, for the Rabi and Kharif seasons for crops of the district. It also examines major phenological stages like pre-flowering,

flowering, and fruit setting of horticultural crops. The correlation study was conducted to explore the relationship between climate variables and crop performance.

3.1. Agriculture

The climate data for the Kharif and Rabi seasons were analysed using the Standardized Anomaly Index (SAI) to identify temperature and rainfall anomalies over the long-term dataset (Figs. 2 and 3). Also, the Mann-Kendall trend test was applied to assess the rate of change and determine the statistical significance of observed trends. The Mann-Kendall Test for minimum, maximum, diurnal temperatures and rainfall over the period 1995–2021 revealed distinct seasonal trends in the Kharif (summer) and Rabi (winter) seasons. In the Kharif season, a statistically significant decrease in maximum temperature and an increase in minimum temperature was observed, with p -values of 0.001 and 0.002, respectively, indicating significant warming trends during the night and cooling during the day. The diurnal temperature range showed a nominal decrease. Rainfall in the Kharif season observed a significant increase, indicating a trend towards wetter summer conditions. The Rabi season exhibited no significant changes in maximum and minimum, diurnal temperature range, and rainfall. A non-significant decrease in maximum temperature and diurnal temperature range, as well as a minimal increase in minimum temperature and rainfall, were observed (Table 1). The winter climate during the Rabi season was observed relatively stable, in contrast to the more

TABLE 2

Mann Kendall Test Results: Crop Yields for Summer and Winter Season in Sirmour district (1995–2021), Himachal Pradesh, India.

Crops	Mean	Sen's slope	<i>p</i> -value
Wheat	1.687	0.017	0.152
Barley	1.439	0.029	0.067
Rice	1.974	0.046	0.007**
Maize	3.046	0.014	0.158
Pulses	0.833	0.020	0.008**

Significance Levels: * $P \leq .05$; ** $P \leq 0.01$; *** $P \leq .001$

pronounced shifts observed during the Kharif season. These results indicate that the Kharif season is experiencing more substantial climate variability, particularly in terms of temperature extremes and rainfall patterns (Table 1).

The major food crops of the district were chosen for the trend analysis were rice, maize, wheat, barley and pulses. Fig. 4 shows the productivity of the crops. The trend analysis showed an increasing trend in the productivity of rice, wheat, maize, barley, and pulses in the past 27 years. These results were also analyzed statistically through the Mann-Kendall test to find out the mean values, Sen's slope, and level of significance. The findings also revealed positive trends indicating that rice was increased by 0.046 t/ha/yr (highly significant *i.e.*, p -value $<.001$), followed by barley (0.029 t/ha/yr), pulses (0.020 t/ha/yr) (highly significant), wheat (0.017 t/ha/yr) and maize (0.014 t/ha/yr). The increase in productivity of wheat, barley, and maize crops was not significant as the p -values were higher than that of 0.05, as mentioned in Table 2. The farmers' perceptions of changing climate conditions in different agroclimatic regions of Himachal Pradesh also showed a shift in crop production from high to low water-requiring crops an impact on crop productivity and an increase in vulnerability in climate-dependent agricultural systems. (Rana, *et al.*, 2013).

The relationship between climate and wheat productivity showed a negative correlation with maximum temperature with statistically significant p -values ($p = 0.018$). A decreasing trend in maximum and minimum temperatures was observed to support wheat productivity by extending the crop duration and yield. However, an increase in temperature can elevate respiration rates, leading to a decline in yield reported by Matthews, *et al.*, (1995). Rainfall exhibited a significant positive correlation ($r = 0.349$) with wheat productivity, indicating that increased rainfall positively influenced crop yield. Whereas, minimum temperature and diurnal temperature exhibited weak and non-significant correlations with wheat productivity. The temperature and rainfall accounted for 19.7% of the variability in wheat

productivity, while the remaining 80.3% was attributed to other factors, such as improved seed varieties and enhanced crop management practices/technologies. The analysis for barley revealed a significant negative correlation between average maximum temperature ($r = -0.437$, $p = 0.011$) and productivity and a significant strong negative correlation with minimum temperature ($r = -0.552$, $p = 0.001$). The increase in barley productivity has been supported by declining maximum and minimum temperatures during the winter season reflecting that barley productivity could potentially decrease with a rise in temperature in the region. Similar results for barley and wheat have been revealed by Gammans and Merel Ortiz-Bobea (2017), Mishra *et al.* (2015), and Vaidya *et al.* (2018). Other variables exhibited non-significant weak positive correlations, but the overall contribution of climatic factors to barley productivity was found to be the highest at 36.3% (Table 3).

The climate and crop correlation for the *Kharif* crop showed a significant (.021) moderate negative correlation with the maximum temperature, *i.e.*, -0.393 for pulses only, which means if the maximum temperature increases, the productivity of pulses will decline. The overall impact of the climatic variables on pulses was 15.8% (Table 3). Therefore, in the present situation, the productivity of pulses has increased. Whereas, rice and maize showed very weak correlations, which was less than 5%. Furthermore, the pulses were significantly correlated with maximum temperature in the district whereas the rice and maize were least impacted. The increased productivity of crops and correlations indicate a positive impact of climatic variations in the district. In the Koshi basin, Bhatt, *et al.* (2014) also examined the relationship between crop yield (rice, maize, and wheat) and climate change, discovering a substantial impact from temperature and precipitation over the growing season.

3.2. Horticulture

To assess climatic variations in horticultural crops, temperature and rainfall were considered in pre-flowering, flowering, and fruit-setting stages for both temperate and subtropical crops based on their flowering periods. Rainfall and temperature anomalies for the climate data (1995–2021) were calculated using the Standardized Anomaly Index (SAI) for all phenological stages (Figs 5 & 6). The Mann-Kendall test was used to further observe these trends.

For the temperate region, no significant changes in temperature or rainfall were observed during the pre-flowering and flowering stages. However, maximum, minimum, and annual rainfall showed a declining trend, while diurnal temperature increased non-significantly. During the flowering stage, maximum temperature,

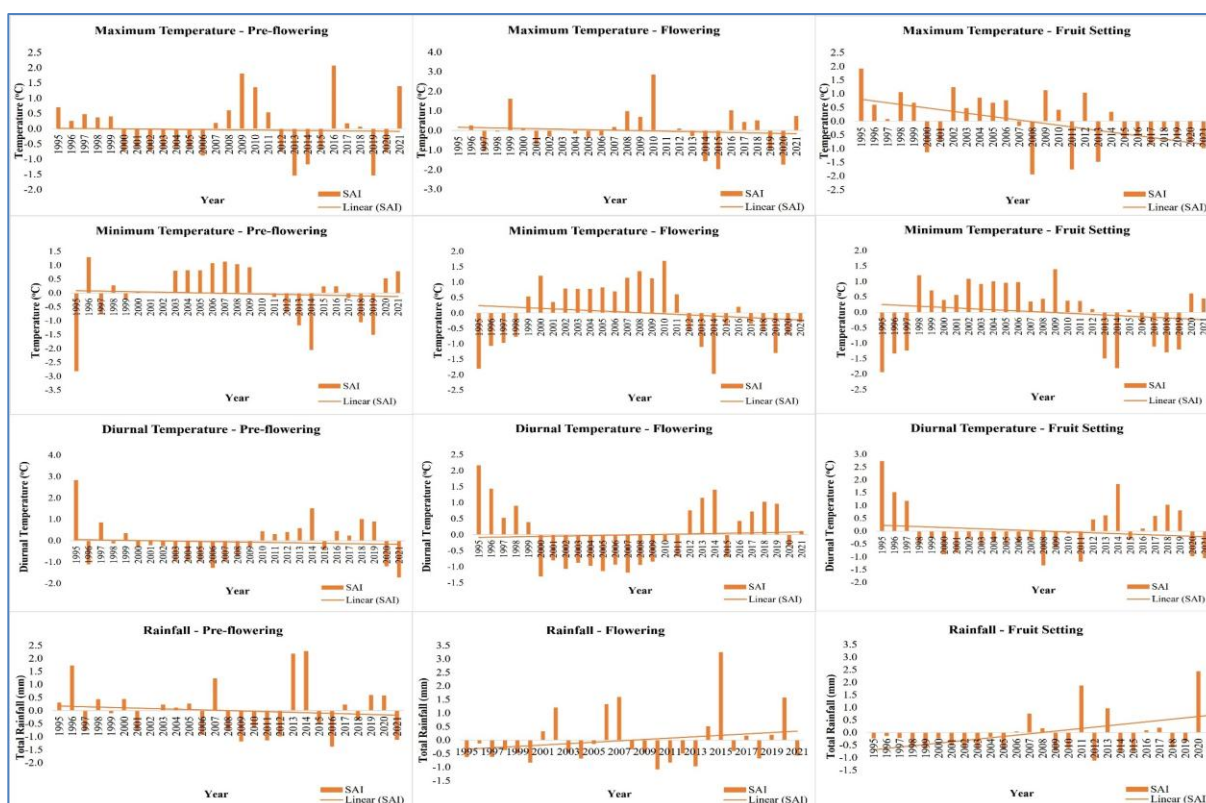


Fig. 5. Standardized Anomaly Index (SAI) of maximum, minimum, diurnal temperature, and rainfall for pre-flowering, flowering, and fruit set stages of the temperate region in Sirmour district, (1995–2021), Himachal Pradesh, India

TABLE 3

Multivariate Linear Regression Analysis: Crop Yields of Rabi and Kharif and Climate Parameters (1995–2021), Himachal Pradesh, India

Crop	Variable/ Statistics	Max Temp	Min Temp	Diurnal Temp	Rainfall	R ²	Change
Wheat	Coefficient	-.406	-.255	-.041	.349	.179	17.9%
	p-value	.018*	.100	.420	.037*		
Barley	Coefficient	-.437	-.552	.291	.232	.363	36.3%
	p-value	.011*	.001***	.071	.123		
Rice	Coefficient	-.103	.153	-.056	.129	.050	5%
	p-value	.305	.223	.390	.261		
Maize	Coefficient	-.064	.093	-.161	.166	.039	3.9%
	p-value	.376	.323	.212	.203		
Pulses	Coefficient	-.393	-.032	-.022	.149	.158	15.8%
	p-value	.021*	.436	.457	.230		

Significance Levels: *P < .05; ** P < 0.01; *** P < .001

diurnal temperature, and rainfall exhibited an increasing trend, whereas the minimum temperature decreased (Table 4). At the fruit-setting stage, the maximum and minimum temperatures significantly decreased by -0.057 °C/year and -0.042 °C/year, respectively, accompanied by declines in both diurnal temperature and rainfall. The climatic variations for different phenological stages of the sub-tropical region showed a significant reduction in the maximum temperature during the fruit setting stage, i.e., -0.050 °C/yr and an increase in the diurnal temperature during the pre-flowering stage i.e., .067 °C/yr. However,

the other climatic variables, like maximum, diurnal temperature, and rainfall during the pre-flowering and flowering stages, were increased, whereas the minimum temperature decreased non-significantly. Furthermore, during the fruit setting stage, the minimum temperature and rainfall decreased, and the diurnal temperature climbed non-significantly (Table 4).

The productivity of fruits in the study district (Sirmour in HP) showed increased productivity for all crops except guava. The long-term trends of all crops

TABLE 4

Illustrates the trend variation in climatic parameters during the three phenological stages, i.e., pre-flowering, flowering, and fruit-setting stages, of temperate and sub-tropical regions of Sirmour district (1995–2021), Himachal Pradesh, India

Variables	Temperate Region			Sub-tropical Region		
	Mean	Sen's slope	p-value	Mean	Sen's slope	p-value
Pre-Flowering	<i>(November-February)</i>			<i>(February- Mid-March)</i>		
Average Maximum Temperature	-0.067	-0.006	.597	0.002	0.040	.179
Average Minimum Temperature	0.084	-0.022	.201	0.074	-0.007	.758
Diurnal Temperature	-0.175	.028	.378	-0.079	0.067	.008**
Total Rainfall	-0.012	-0.018	.659	0.006	0.007	.791
Flowering	<i>(March-April)</i>			<i>(Mid-March-April)</i>		
Average Maximum Temperature	0.002	0.001	1.00	0.002	0-.007	.692
Average Minimum Temperature	0.077	-0.037	.311	-0.009	-0.049	.113
Diurnal Temperature	-0.083	0.033	.134	-0.084	0.034	.146
Total Rainfall	0.024	0.008	.692	0.008	0.001	.895
Fruit- Setting	<i>(May-August)</i>			<i>(May-June)</i>		
Average Maximum Temperature	-0.096	-0.057	.031*	-0.051	-0.050	.034*
Average Minimum Temperature	0.082	-0.042	.047*	0.050	-0.044	.158
Diurnal Temperature	-0.105	0.018	.597	-0.091	0.000	.965
Total Rainfall	0.009	0.017	.290	0.000	-0.006	.860

Significance Levels: * $P \leq .05$; ** $P \leq 0.01$; *** $P \leq .001$

TABLE 5

Mann Kendall Test Results: Crop Yields of Fruit Crops of Sirmour district, (1995–2021), Himachal Pradesh, India

Fruits Productivity	Mean	Sen's slope	p-value
Temperate Fruits			
Apple	0.525	0.015	.049*
Plum	0.798	0.046	.0001***
Peach	1.355	0.064	.001***
Apricot	1.232	0.068	.0001***
Pear	1.233	0.059	.0001***
Dry Fruits	0.610	0.042	.0001***
Subtropical Fruits			
Orange	0.599	0.010	.035*
Malta	1.423	0.084	.0001***
Kagzi Lime	0.565	0.040	.0001***
Galgal	0.983	0.051	.001***
Mango	0.712	0.018	.012*
Litchi	1.540	0.024	.277
Guava	1.289	-0.007	.434

Significance Levels: * $P \leq .05$; ** $P \leq 0.01$; *** $P \leq .001$

were presented in Fig. 7 along with the lowest and highest productivity. All the temperate fruit crops showed a significant increase in the district, with the highest for apricot (0.068 t/ha/yr), followed by peach (0.064 t/ha/yr), pear (0.059 t/ha/yr), plum (0.046 t/ha/yr), dry fruits (0.042 t/ha/yr), and apple (0.015 t/ha/yr). Similar findings were observed in the Kullu district of the state, where pears, peaches, and apricots scaled significantly (Vaidya, *et al.*, 2019). Among the sub-tropical crops, the highest significant increase was observed for malta, i.e., 0.084 t/ha/yr, followed by galgal (0.051 t/ha/yr), Kazi lime

(0.040 t/ha/yr), litchi (0.024 t/ha/yr) (non-significantly), mango (0.018 t/ha/yr), and orange (0.010 t/ha/yr), whereas the productivity of guava showed decline (Table 5). Concisely, the productivity of all crops in the temperate and subtropical regions of Sirmour district increased, except guava. Similar observations were also reported by Bharti, *et al.*, (2023) for the Solan district, which has almost similar climatic conditions.

Alongside variations in the climatic variables and productivity trends, the relationship between climate and

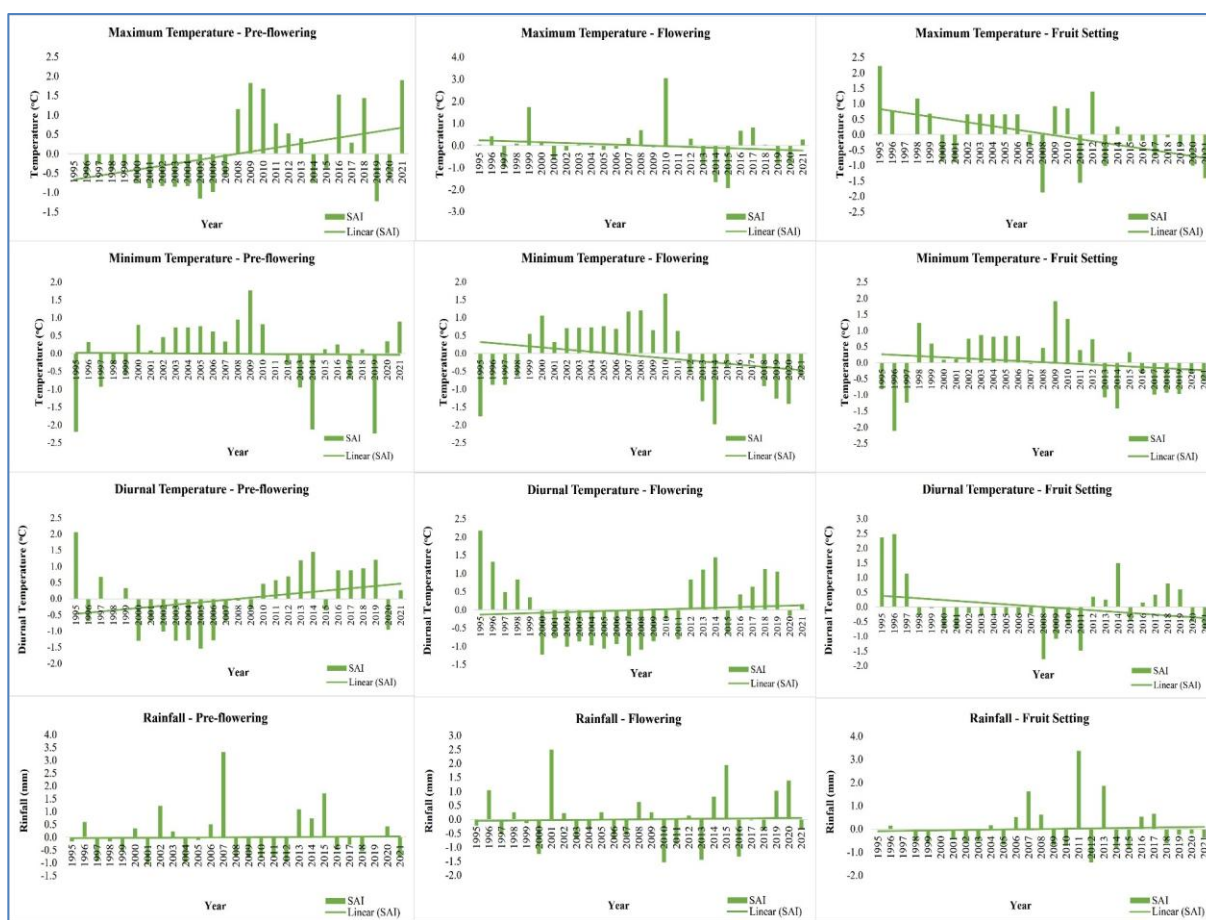


Fig. 6. Standardized Anomaly Index (SAI) of maximum, minimum, diurnal temperature, and rainfall for pre-flowering, flowering, and fruit set stages of the sub-tropical region in Sirmour district, (1995–2021), Himachal Pradesh, India

crop was also studied, which is presented in Table 5 below. The pre-flowering and flowering stages of apples were significantly influenced by the minimum temperature, which showed a moderately negative correlation *i.e.*, -0.409 and -0.369 respectively. Whereas, the fruit setting stage showed a moderately negative correlation (-0.333) with maximum temperature. The declined maximum and minimum temperatures during pre-flowering stage during the winter season fulfilled the chilling requirement of the apple crop which boosted productivity. Sometimes, due to insufficient snowfall and rainfall during the winter, particularly in the mid-hill regions of Himachal Pradesh, adequate chilling hours are not being reached (Jindal, *et al.*, 2001). This will lead to inconsistent and poor flowering, which is the cause of low yields and poor fruit set (González Nogue, *et al.*, 2023). Apple plantations in Rajgarh, Sirmour, and the lower parts of Kullu have vanished, making this one of the most obvious signs of climate change (Pramanick, *et al.*, 2015).

For the plum crop, all the variables showed very weak correlations, indicating the least impact on the crop. The pre-flowering stage of the peach showed a significant,

moderate negative correlation (0.422) with minimum temperature and diurnal temperature *i.e.*, $.532$, which means if the temperature rises, the productivity will rise, and if decreases the productivity may be affected. The apricot crop showed a significant positive correlation with maximum temperature ($.439$) during the pre-flowering stage, and the rainfall also showed a moderate positive correlation during the flowering (0.422) and fruit set stages ($.541$). However, minimum and diurnal temperatures showed a significant and moderate negative correlation *i.e.*, -0.344 and -0.453 respectively. In general, the fruit-setting stage of apricot was highly impacted (Table 6).

Another important temperate fruit crop was pear, which showed a moderately positive correlation ($.370$) with the maximum temperature for the pre-flowering stage and the minimum temperature ($.365$) and rainfall ($.479$) for the flowering stage. As mentioned above in Table 4, both the temperature and rainfall variables decreased during the pre-flowering and flowering stages resulting in increased productivity. However, in future, if these variables increase due to climate change, the productivity

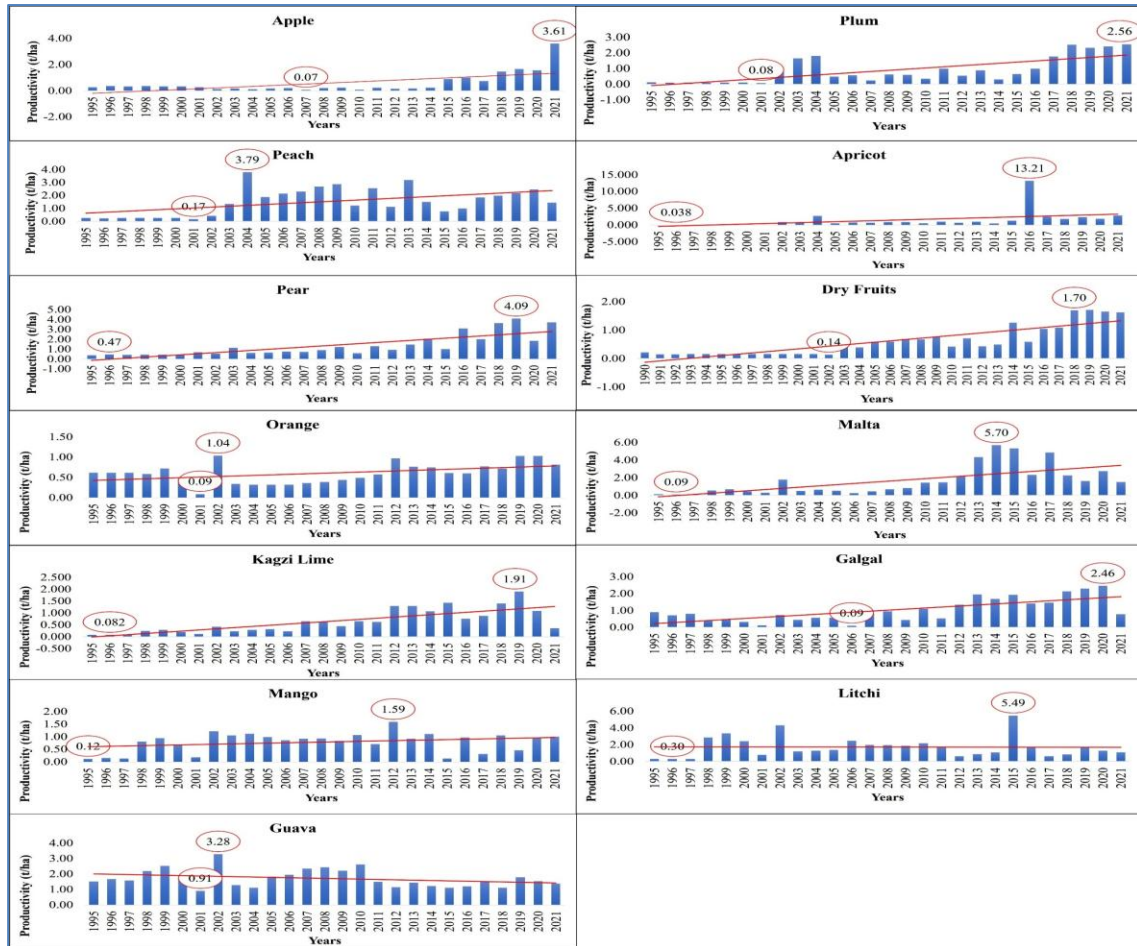


Fig. 7. Trend analysis of fruit productivity of different horticulture crops in Sirmour district, (1995–2021), Himachal Pradesh, India

of crops will be affected. These findings also corroborated a study conducted for sub temperate in mid hills to temperate climate in high hills of the state which indicated that increasing temperature positively benefited temperate fruits viz., pear, peach, plum and apricot tan apple in Himachal Pradesh which is a promising adaptation for apple shifting region in the face of climate change (Rana, *et al.*, 2017).

Minimum temperature had a negative correlation (-.554) during the fruit setting stage, suggesting that raising the minimum temperature boosted productivity because higher temperatures promoted fruit set and good coloration. Rainfall, on the other hand, had a strong positive connection (0.382). Also, the pre-flowering stage of dry fruits was positively correlated with diurnal temperature only (0.444) The correlation with the minimum temperature for flowering and fruit setting stage showed a significant moderate negative correlation (-0.373) and strong negative correlation (-0.508) which indicate that if the temperature increases, production may decline. However, these minor temperature fluctuations

have less effect and hence support the fruit yield. Additionally, the rainfall during these phenological stages also showed a significant, moderately positive correlation. Hence the current variations in the rainfall patterns show if rainfall increases, productivity will also enhance, and if the rainfall decreases, productivity will decline.

The subtropical fruit crop, for example, orange showed a significant, moderate positive correlation with rainfall only during the flowering (0.442) and fruit set stages (0.355). The malta crop showed a significant, moderate negative correlation with the minimum temperature during all phenological stages (-0.471, -0.416 and -0.338 respectively), whereas for the flowering stage, the rainfall was positively correlated (0.443). This indicates that if the temperature during all phenological stages increases, productivity will decline. The current temperature condition is supporting the increased productivity. Additionally, the kagzi lime, where the pre-flowering stage was negatively correlated by minimum temperature (-0.505) and positively correlated by rainfall (0.345) in the flowering stage. Similarly, for the galgal,

TABLE 6

Representation of Multivariate Linear Regression Analysis between fruit productivity and climatic parameters for different phenological stages in Sirmour district, (1995–2021), Himachal Pradesh, India

Crops	Statistics	Pre-Flowering					Flowering					Fruit Setting				
		Max T	Min T	DT	RF	R ²	Max T	Min T	DT	RF	R ²	Max T	Min T	DT	RF	R ²
Apple	Coefficient	.069	-.409	-.047	-.056	.237	-.239	-.369	-.150	.287	.164	-.333	-.203	-.108	.154	.135
	P-value	.366	.017*	.408	.390		.115	.029*	.228	.073		.042*	.155	.295	.222	
Plum	Coefficient	.121	.203	-.168	-.067	.073	-.027	-.170	-.263	.212	.090	-.261	-.186	.107	.150	.148
	P-value	.274	.154	.201	.370		.446	.199	.092	.144		.094	.176	.298	.227	
Peach	Coefficient	-.065	.422	.171	-.168	.251	.072	.154	.027	-.195	.047	.071	.039	.532	-.189	.300
	P-value	.374	.014*	.197	.202		.361	.221	.447	.165		.363	.424	.002**	.173	
Apricot	Coefficient	.439	.208	-.083	.198	.233	-.187	-.212	-.214	.422	.298	-.176	-.344	-.453	.541	.382
	P-value	.011*	.149	.340	.161		.175	.145	.141	.014*		.190	.040*	.009**	.002**	
Pear	Coefficient	.370	-.204	.090	.179	.279	-.007	.365	-.185	.479	.249	-.262	-.554	.046	.382	.349
	P-value	.029*	.157	.328	.186		.486	.031*	.178	.006**		.093	.001***	.410	.025*	
Dry Fruits	Coefficient	.259	.047	.444	.084	.293	-.191	-.373	-.233	.404	.186	-.236	-.508	.149	.335	.347
	P-value	.096	.409	.010**	.338		.169	.028*	.121	.018*		.118	.003**	.229	.044*	
Orange	Coefficient	-.101	-.279	-.109	.021	.078	-.030	-.173	-.295	.442	.283	.087	-.011	.131	.355	.156
	P-value	.308	.079	.295	.459		.442	.194	.067	.010**		.333	.479	.257	.035*	
Malta	Coefficient	-.116	-.471	.093	.124	.359	-.131	-.416	.101	.483	.318	-.099	-.338	-.031	.252	.156
	P-value	.282	.007**	.322	.288		.258	.015*	.307	.005**		.312	.042*	.440	.102	
Kagzi Lime	Coefficient	-.144	-.505	-.251	.022	.264	.046	-.226	.086	.345	.153	-.132	-.139	-.026	.249	.111
	P-value	.236	.004**	.103	.457		.409	.128	.335	.039*		.256	.245	.450	.106	
Galgal	Coefficient	-.102	-.361	-.132	.091	.140	.036	-.279	.016	.398	.187	.046	-.197	.113	.249	.085
	P-value	.307	.032*	.255	.326		.430	.079	.469	.020*		.409	.163	.288	.106	
Mango	Coefficient	.406	.320	.039	-.143	.199	.399	.113	-.429	-.275	.336	-.343	.363	-.503	-.043	.371
	P-value	.018*	.052	.423	.238		.020*	.287	.013*	.083		.040*	.031*	.004**	.416	
Litchi	Coefficient	.427	.380	.039	-.235	.264	.121	.143	.026	-.556	.318	-.434	.510	-.574	-.228	.491
	P-value	.013*	.025*	.423	.119		.274	.238	.449	.001***		.012	.003**	.001***	.126	
Guava	Coefficient	.100	.185	-.002	-.177	.069	.134	.359	-.240	-.234	.221	-.030	.406	-.094	.025	.201
	P-value	.310	.178	.497	.189		.252	.033*	.114	.120		.442	.018*	.320	.451	

Abbreviations used: Min T: Minimum temperature, Max T: Maximum temperature, DT: Diurnal temperature, RF: Rainfall and R²: R-Squared or the coefficient of determination; Significance Levels: *P ≤ .05; ** P ≤ 0.01; *** P ≤ .001

minimum temperature showed a significant, moderate negative correlation (-0.361) during the pre-flowering stage, and rainfall showed a moderate positive correlation (0.398) at the flowering stage. Here, both crops showed equal impact on the same phenological stages. The observations for the mango showed a moderate positive correlation with maximum temperature during the pre-flowering and flowering stages (0.406 and 0.399 respectively), whereas a negative moderate correlation was found with diurnal temperature in the flowering stage (-0.429).

The fruit setting stage of the mango was greatly impacted by all temperature variables, i.e., with maximum temperature, a significant moderate negative correlation (-.343) was observed and a strong negative correlation

(-0.503) with diurnal temperature, while minimum temperature exhibited a moderate positive correlation (0.363). For the litchi crop, the maximum and minimum temperatures showed a moderate positive correlation (0.427 and 0.380) at the pre-flowering stage, whereas there was a strong negative correlation (-0.556) with rainfall during the flowering stage. Furthermore, during the fruit setting stage, the maximum and diurnal temperatures showed a strong negative correlation (-0.434 and -0.574 respectively), while with the minimum temperature, a strong positive correlation was observed i.e., 0.510 (Table 6). Findings for the guava revealed that only the minimum temperature showed a significant, positive correlation during the flowering (0.359) and fruit set stages (0.406).

The impact during the pre-flowering stage was observed for the malta crop (35.9%), whereas the plum, orange, and guava were the least impacted. Whereas, the flowering stages of mango (33.6%), litchi (31.8%), and malta (31.8%) were highly impacted, while the remaining were least impacted. Additionally, the fruit setting stage of litchi was highly impacted, i.e., 49.1% among all crops, followed by apricot (38.2%), mango (37.1%), pear (34.9%), dry fruits (34.7%), and peach (30%). The observed impact in terms of percentage was responsible for the temperature and rainfall variables; the remaining percentage out of 100% was contributed by other factors like humidity, seed quality, variety, cultivation practice, etc. The overall influence on the productivity of all crops was positive and synergistic, resulting in increased productivity of all crops except for guava.

The findings indicated that decline in temperatures during the pre-flowering and flowering stages, which fulfilled the chilling requirements of temperate regions. For apples and other temperate crops, temperatures of 7 °C and lower are suitable for chilling needs (IPCC, 2007). Chilling plays a crucial role in flowering and subsequent fruit setting, both qualitatively and quantitatively (Sharma, *et al.*, 2015). Adequate chilling has led to enhanced flowering and fruit setting, ultimately improving crop productivity (Singh, *et al.*, 2016). Consequently, the current climatic variations in the temperate regions of the district have proven beneficial, resulting in increased productivity.

Since this research focused on the specific region of Himachal Pradesh, similar regional studies have been conducted across the State to account for its unique and diverse topography. Himachal Pradesh exhibits significant regional variations in temperature, rainfall, and drought frequency (Kumar and Attri, 2025; Rana *et al.*, 2012). The effects of temperature and precipitation fluctuations on horticulture, agriculture, and the mountain environment in various regions of the state have been examined in earlier research (Prasad and Rana, 2006; Vijayshri *et al.*, 2015; Vaidya *et al.*, 2019; Sharma *et al.*, 2022; Bharti *et al.*, 2023, 2024).

The study showed that understanding the complexity of climate change demands local studies. Those are important for the establishment of both, specific and global adaptation strategies which will aid in tackling climate change as a whole (Adger, *et al.*, 2005). The global climate models are improved by enriching them with local knowledge about particular regional vulnerabilities and resilience (Easterling and Apps, 2005). Therefore, it is necessary to encourage local studies on climate to achieve effective ways of dealing with global

warming and adaptation (Hulme, 2016). The study indicated that agricultural ecosystems in the Himalayan foothills also benefitted due to the improvement in direct radiant energy and normalized difference vegetation index which positively increased the gross primary productivity as studied COVID-19 pandemic. (Pokhariyal, *et al.*, 2021). Research on local climate change is therefore essential to comprehending and reducing global climate change.

4. Conclusions

The impact assessment study conducted in Sirmour district yielded significant findings for both agricultural and horticultural crops. In the past three decades (till 2021), summer season temperature trends revealed a notable decrease in both maximum and minimum temperatures, at rates of -0.080 °C/year and -0.090 °C/year, respectively. Agricultural productivity trends indicated a significant increase in rice and pulses yields, at 0.046 t/ha/year and 0.020 t/ha/year, respectively, while maize productivity showed a non-significant upward trend. These findings suggest an overall positive influence of climatic variations on agricultural crops. In horticulture, phenological analysis for temperate regions revealed a significant decline in maximum and minimum temperatures during the fruit-setting stage. Similarly, in subtropical regions, a significant reduction in maximum temperature was observed during the same stage. Productivity trends for subtropical fruit crops demonstrated a general increase over the study period, except for guava, which showed a decline. The trends indicated that temperature and rainfall variations have positively influenced horticultural productivity in Sirmour district over the past 27 years. The findings suggested that climatic variations have positively influenced both agricultural and horticultural productivity over the past three decades. However, the decline in guava productivity highlights the need for targeted adaptation strategies. Alongside, this type of study can be enriched by adding other parameters to understand the crop productivity and climate-crop relationship. This study emphasizes the value of localized research, which helps to design customized mitigation and adaptation policies and offers insightful perspectives on the particular impacts of climate change.

Acknowledgement

The authors are thankful State Centre on Climate Change (SCCC) O/o HIMCOSTE, Shimla, specifically to Dr. S.S. Randhawa, Principal Scientific Officer (Retired), for his guidance and coordination during the research work. The authors acknowledge the India Meteorological Department (IMD), Shimla, Himachal Pradesh and the Department of Economics and Statistics, Government of

Himachal Pradesh, for offering the complete datasets that were necessary for this research. Further, I am deeply grateful to Ms. Aditi Panatu, Scientific Professional, SCCC for her constant support and valuable help during this research work.

Authors' contributions

Harish Bharti: Conceptualization, methodology, data collection and analysis, manuscript writing. (email: harishbharti733@gmail.com).

Ranbir Singh Rana: Conceptualization, methodology, validation, Interpretation of results correction and editing. (email: ranars66@gmail.com).

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

References

- Adger, W.N., Arnell, N.W. and Tompkins, E.L., 2005, "Successful adaptation to climate change across scales", *Global Environmental Change*, **15**, 2, 77-86. doi : <https://doi.org/10.1016/j.gloenvcha.2004.12.005>.
- Bharti, H., Panatu, A., Sharma, P., Randhawa, S.S., Dhiman, S. and Rana, R.S., 2024, "Impact of climatic variations in horticulture sector, Kinnaur, Himachal Pradesh, India", *MAUSAM*, **75**, 2, 313-326. doi : <https://doi.org/10.54302/mausam.v75i2.827>.
- Bharti, H., Panatu, A., Thakur, Y., Randhawa, S.S., Dhiman, S., Bhardwaj, S.K. and Rana, R.S., 2023, "Climatic and Fruit Productivity Trends in Solan District, Himachal Pradesh, India", *International Journal of Environment and Climate Change*, **13**, 10, 1036-1048. doi : <https://doi.org/10.9734/ijec/2023/v13i102749>.
- Bhatt, D., Maskey, S., Babel, M.S., Uhlenbrook, S. and Prasad, K.P., 2014, "Climate trends and impacts on crop productions in the Koshi River basin of Nepal", *Regional Environment Change*, **14**, pp. 1291-1301. doi : <https://doi.org/10.1007/s10113-013-0576-6>.
- Easterling, W.E. and Apps, M., 2005, "Assessing the consequences of climate change for food and forest resources: A view from the IPCC", *Climatic Change*, **70**, 1-2, pp. 165-189. doi : <https://doi.org/10.1007/s10584-005-5956-9>.
- Gammans, M. and Merel Ortiz-Bobea, A., 2017, "Negative impacts of climate change on cereal yields: Statistical evidence from France", *Environmental Research Letters*, **12**, p. 054007. doi : <https://doi.org/10.1088/1748-9326/aa6b0c>.
- Getahun, M., Fininsa, C., Bekeko, Z. and Mohammed, A., 2022, "Analysis of the Spatial Distribution and Association of Wheat Fusarium Head Blight with Biophysical Factors in Ethiopia", *European Journal of Plant Pathology*, **164**, pp. 391-410. doi : <https://doi.org/10.1007/s10658-022-02569-9>.
- González Noguera, C., Delgado, A., Else, M. and Hadley, P., 2023, "Apple (*Malus × domestica* Borkh.) dormancy – a review of regulatory mechanisms and agroclimatic requirements", *Frontiers in Horticulture*, **2**, 1217689. doi : <https://doi.org/10.3389/fhort.2023.1217689>.
- Gopirajan, A.T.S., Kumar, P., and Joshi, P.K., 2022, "Unravelling the complex and dynamic Himalayan socio-ecological systems: a systematic review", *Environment, Development and Sustainability*, **24**, 2, pp. 1532-1559. doi : <https://doi.org/10.1007/s10668-021-01527-5>.
- Gora, J.S., Verma, A.K., Singh, J. and Choudhary, D.R., 2019, "Climate Change and Production of Horticultural Crops from: Agricultural Impacts of Climate Change" CRC Press. <https://www.routledgehandbooks.com/doi/10.1201/9780429326349-3> [Accessed on 02 Aug 2023].
- Hulme, M., 2016, "Weathered: Cultures of Climate". London: SAGE Publications. pp 178. <https://doi.org/10.4135/9781473957749>.
- IBM Corp., 2019, "IBM SPSS Statistics for Windows" (Version 26.0). Armonk, NY: IBM Corp.
- IPCC, 2007, *Climate Change 2007: The Physical Science Basis Contribution of Working Group I to the Fourth Assessment Report of the Intergovernmental Panel on Climate Change*. Solomon, S., Qin, D., Manning, M., Chen, Z., Marquis, M., Averyt, K.B., Tignor, M. and Miller, H.L. (Eds.). Cambridge University Press, Cambridge, United Kingdom and New York, NY, USA, 996 pp..
- Jindal, K.K., Chauhan P.S. and Mankotia M.S., 2001, "Apple productivity in relations to environmental components", In: Productivity of temperate fruits. Edited By K.K. Jindal and D.R. Gautam, pp. 12-20.
- KC, K.B., Tzadok, E. and Pant, L., 2022, "Himalayan ecosystem services and climate change driven agricultural frontiers: a scoping review". *Discover sustainability*, **3**, 1, p. 35. doi : <https://doi.org/10.1007/s43621-022-00103-9>.
- Kendall, M.G., 1975, "Rank Correlation Methods", New York, NY: Oxford University Press.
- Koudahe, K., Kayode, A., Samson, A., Adebola, A. and Djaman, K., 2017, "Trend Analysis in Standardized Precipitation Index and Standardized Anomaly Index in the Context of Climate Change in Southern Togo", *Atmospheric and Climate Sciences*, **7**, pp. 401-423. doi : <https://doi.org/10.4236/acs.2017.74030>.
- Kumar, A. and Attri, P.K., 2025, "Analysis of seasonal rainfall trends in Himachal Pradesh by Mann-Kendall and Sen's Slope estimator test", *Journal of Agrometeorology*, **27**, 1, pp. 104-106. doi : <https://doi.org/10.54386/jam.v27i1.2804>.
- Lumivero, 2024, "XLSTAT Statistical and Data Analysis Solution". Available at: [XLSTAT Statistical and Data Analysis Solution](https://www.xlstat.com/en)
- Mann, H.B., 1945, "Nonparametric tests against trend", *Econometrica*, **13**, pp. 245-259. doi : <https://doi.org/10.2307/1907187>.
- Matthews, R.B., Horie, T., Kropff, M.J., Bachelet, D., Centeno, H.G. Shin, J.C., Mohandass, S., Singh, S. Defeng, Z. and Lee, M.H., 1995, "A regional evaluation of the effect of future climate change on rice production in Asia", *Modeling the Impact of Climate Change on Rice Production in Asia*, CAB International, UK, pp. 95-139.
- Mbow, C., Rosenzweig, C., Barioni, L.G., Benton, T.G., Herrero, M., Krishnapillai, M., Liwenga, E., Pradhan, P., Rivera-Ferre, M.G., Sapkota, T., Tubiello, F.N. and Xu, Y., 2019, "Food Security. In: *Climate Change and Land: an IPCC special report on climate change, desertification, land degradation, sustainable land management, food security, and greenhouse gas fluxes in terrestrial ecosystems*" [Shukla, P.R. Skea, J. Calvo, Buendia, E. Masson-Delmotte, V. Pörtner, H.O. Roberts, D.C. Zhai, P. Slade, R. Connors, S. Van Diemen, R. Ferrat, M. Haughey, E.

- Luz, S. Neogi, S. Pathak, M. Petzold, J. Portugal Pereira, J. Vyas, P. Huntley, E. Kissick, K. Belkacemi, M. Malley, J. (eds.]. doi : <https://doi.org/10.1017/9781009157988.007>.
- Mishra, S.K., Shekh, A.M., Pandey, V., Yadav, S.B. and Patel, H.R., 2015, "Sensitivity analysis of four wheat cultivars to varying photoperiod and temperature at different phenological stages using WOFOST model", *Journal of Agrometeorology*, **17**, 1, pp. 74-79. doi : <https://doi.org/10.54386/jam.v17i1.978>.
- OECD, 2017, "Economic Survey of India". OECD Publishing, Paris. doi : http://dx.doi.org/10.1787/eco_surveys-ind-2017-en.
- Pohlert, T., 2018, "Non-Parametric Trend Tests and Change-Point Detection", Technical Report. <https://doi.org/10.13140/RG.2.1.2633.4243>.
- Pokhariyal, S., Patel, N.R., Rana, R.S., and Chauhan, P., 2021, "Environmental Impact of Lockdown Amid COVID-19 Over Agricultural Sites in Himalayan Foothills", *Journal of the Indian Society of Remote Sensing*, **49**, pp. 1651-1659. doi : <https://doi.org/10.1007/s12524-021-01343-4>.
- Pramanick, K.K., Kishore, D.K., Kashyap, P., Shukla, A.K., Watpade, S., Kumar, J., Jindal, K.K. and Sharma, G., 2015, "Role of Changing Climate on Chilling Unit Accumulation and Yield for Apple (*Malus X domestica* Borkh) cultivation at Shimla, Himachal Pradesh, India", *International Journal of Tropical Agriculture*, **33**, 2, pp. 1039-1044.
- Prasad, R. and Rana, R.S., 2006, "A study of maximum temperature during March 2004 and its impact on Rabi crops in Himachal Pradesh", *Journal of Agrometeorology*, **8**, 1, 91-99. doi : <https://doi.org/10.54386/jam.v8i1.882>.
- Press Information Bureau, 2020, "Third advance estimates of production of food grains, oilseeds and other commercial crops for 2019-20" by GoI, Available online <https://pib.gov.in/PressReleaseDetailm.aspx?PRID=1624044> [Accessed on dated 5th March, 2024].
- Rana, R., Singh, S., Chander, N., Sood, R., Sharma, R. and Aditya, A., 2014, "Impacts of changes in climate on mountain water resources of Himachal Pradesh", *MAUSAM*, **65**, 2, pp. 153-160. doi : <https://doi.org/10.54302/mausam.v65i2.956>.
- Rana, R.S., Bhagat, R.M., Singh M.M., Kalia, V., Singh, S. and Prasad, R., 2012, "Trends in Climate variability over Himachal Pradesh", *Journal of Agrometeorology*, **14**, 1, pp. 35-40. doi : <https://doi.org/10.54386/jam.v14i1.1378>.
- Rana, R.S., Kalia, V., Singh, S., Randhawa, S.S., Chauhan, R., Katoch, A. Sandal, A., Thakur, R.K. and Upadhyay, S.K., 2021, "Climate vulnerability assessment of farming systems in Himachal Pradesh, Indian Himalayas", *Mountain Research and Development*, **41**, 4, pp. R50-R60. doi : <https://doi.org/10.1659/MRD-JOURNAL-D-20-00056.1.S1>.
- Rana, R.S., Bhagat, R.M., Kalia, V., Lal, H., and Sen V., 2013, "Indigenous perceptions of climate change vis-a-vis mountain agricultural activities in Himachal Pradesh, India", *Indian Journal of Traditional Knowledge*, **12**, 4, pp. 596-604.
- Rana, R.S., Singh, M., Pathania, R., Upadhyay, S.K. and Kalia, V., 2017, "Impact of changes in climatic conditions on temperate fruit production of Himachal Pradesh", *MAUSAM*, **68**, 4, 655-662. doi : <https://doi.org/10.54302/mausam.v68i4.760>.
- Rao, C.S., Prasad, R.S. and Mohapatra, T., 2019b, "Climate Change and Indian Agriculture: Impacts, Coping Strategies, Programmes and Policy". *Technical Bulletin/Policy Document* 2019. Indian Council of Agricultural Research, Ministry of Agriculture and Farmers' Welfare and Ministry of Environment, Forestry and Climate Change, Government of India, New Delhi. p 25.
- Ruchel, Q., Zandoná, R.R., Fraga, D.S., Agostinetto, D. and Langaro, A.C., 2020, "Effect of High Temperature and Recovery from Stress on Crop-Weed Interaction", *Bragantia*, **79**, 4, 582-591.
- Sharma, H.K., Gupta, J.K., Suman, V. and Belavadi, V.V., 2015, "Studies on flowering phenology, pollinator diversity, supplemented pollination and their impact on fruit set in apple under changing climatic scenario in Kullu valley of Himachal Pradesh", *International Journal of Farm Sciences*, **5**, 4,156-164.
- Sharma, P., Bharti, H., Panatu, A., Randhawa, S.S. and Rana, R.S., 2022, "Impact of Climate Change on Agriculture Production in District Kinnaur, Himachal Pradesh", *Journal of Biodiversity*, **13**, 1-2, 14-23. doi : <https://doi.org/10.31901/24566543.2022/13.1-2.104>.
- Singh, N., Sharma, D.P. and Chand, H., 2016, "Impact of climate change on apple production in India: A review", *Current World Environment*, **11**, 1, p.251.
- Vaidya, P., Randhawa, S., Sharma, P., Sharma, Y.P., Satyarthi, K. and Randhawa, S.S., 2019, "Climatic variability during different phenophases and its impact on temperate fruit crops", *Journal of Agrometeorology*, **21**, 3, pp. 366-371. doi : <https://doi.org/10.54386/jam.v21i3.262>.
- Vijayshri, S., Rana, R.S., Chauhan, R.C. and Aditya, 2015, "Impact of climatic variability on apple production and diversity in Kullu valley, Himachal Pradesh", *Indian Journal of Horticulture*, **72**, 1,14-20. doi : <http://dx.doi.org/10.5958/0974-0112.2015.00003.1>.

