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Climatic and Fruit Productivity Trends in Solan District, Himachal Pradesh, India

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Authors' contributions

This work was carried out in collaboration among all authors. Author HB designed the study, data analysis, performed the statistical analysis, and wrote the first draft of the manuscript. Authors AP and YT managed the analysis of the study. Authors SSR, SD, SKB and RSR provided the overall supervision, and final editing to the manuscript. All authors read and approved the final manuscript.

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ABSTRACT

The shortened duration of the winter season in the Himalayan region caused by snow melting has a negative impact on fruit crop growth and productivity. The present study focused on examining the impact of climate change on fruit crops in the Solan district of Himachal Pradesh, India, situated in the Himalayan region. The trend analysis of climatic variables (temperature and rainfall) along with

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the productivity of fruit crops was investigated. The climate data spanning 30 years (1990–2019), including average temperature (maximum, minimum, and diurnal) and annual rainfall used during crop development stages like pre-flowering, flowering, and fruit-setting stages. To evaluate climatic trends, the Standardized Anomaly Index (SAI) and Mann-Kendall Test for quantification were employed. The Multivariate Linear Regression Analysis was performed to establish a correlation between climatic variables and crop productivity. The findings indicated that during the pre-flowering stage, there was a gradual increase in average maximum temperature at a rate of 0.001°C per year, along with a corresponding rise in diurnal temperature at a rate of 0.036°C per year. However, annual rainfall and average minimum temperature exhibited non-significant decreasing trends, with rates of -0.044°C and -0.033 mm, respectively. During the flowering stage, there was a significant increase in minimum temperature at a rate of 0.151°C per year, while diurnal temperature exhibited a significant decrease of -0.158°C per year. Other variables did not exhibit substantial changes during this stage. In the fruit-setting stage, only the minimum temperature demonstrated a significant decrease over the study period. The response to climate change revealed an overall positive trend for all fruit crops, leading to higher productivity. The correlation study indicated that the phenological stages of each crop were more positively influenced by temperature than rainfall, owing to existing climatic variations. The current climatic conditions in the Solan district were found to be favorable and productive for crop development, as all crops showed increased productivity based on the trend analysis. The study highlights climatic trends and their impact on the productivity of fruit crops in the Himalayan region, which is useful for agricultural planning and adaptation strategies in response to changing climatic conditions.

Keywords: Trend analysis; productivity; temperature; rainfall; correlation; phenological stages.

1. INTRODUCTION

Horticulture holds a position of utmost significance within India, as fruits and vegetables contribute to 90% of the nation's total horticultural output. In India, a diverse array of horticultural crops including fruits like mangoes, bananas, papayas, cashew nuts and areca nuts, as well as vegetables such as potatoes and okra are successfully grown. Presently, India ranks as the second-largest global producer of fruits and vegetables. The condition of horticultural crops in India has witnessed remarkable improvement, with horticulture now contributing to 33% of the total agricultural production. In recent years, India has experienced substantial growth in horticultural production, characterized by notable expansions in cultivation areas, resulting in enhanced productivity. Fruit productivity has surged from 50.9 million tons in 2004–05 to 97.35 million tons in 2017–18 [1]. The effects of climate change impact four climate-sensitive regions in India, namely the Himalayan region, the Western Ghats, the Coastal Area, and the North-East Region. These regions are vulnerable in terms of agriculture, water availability, natural ecosystems and biodiversity, and public health [2]. Given their lower elevations, the crop processing systems in South Asia and sub-Saharan Africa are undeniably exposed to climate risks, and any increase in mean temperatures is expected to adversely affect horticultural crop production in these developing nations [3].

A study was conducted to demonstrate the impact of rising temperatures on the surrounding environment of citrus fruit and its consequential limitation on vegetative growth [4]. The temperature rise reflected in shifts of precipitation patterns leading to alterations in the frequency and intensity of both droughts and floods. South Asia is projected to witness an average precipitation change of 11% by the end of the twenty-first century, characterized by decreased dry seasons and increased precipitation throughout the year [5]. Himachal Pradesh is known as "India's Fruit Bowl" and has a significant source of employment opportunities, both on and off the farm. The horticulture industry contributes approximately 38% to the state's GDP from the primary sector, with agricultural and allied services accounting for 10% of the state GDP in 2015-16 [6]. As a result, reliance on agriculture/horticulture is imminent, as it employs around 62% of all employees in the state [7].

Global climate change is occurring and exerting its influence across various sectors. However, this phenomenon manifests with slight variations at the regional level, and these variations can even differ within specific geographical regions based on statistical topography. The climatic trends also indicated decreasing trends of rainfall and on the contrary increase in maximum and minimum temperatures in the mountain state Himachal Pradesh [8] and farmers' perception of the region also corroborated similar climatic trends [9]. The studies to assess the impact of regional climate change on water resources also revealed decreasing trends in water resources and snowfall in higher altitudinal regions within the state [10]. When comparing the overall climate scenario of the state concerning its districts, it is difficult to forecast the influence on any sector. As a result, to investigate the effects of climate change on horticultural crops, this study concentrated on the state's Solan district. The study involved analyzing the district's climatic patterns and productivity trends, as well as assessing the magnitude of the observed changes. Subsequently, the overall impact of climate change, expressed as a percentage, was calculated for different phenological stages of fruit crops using multivariate linear regression analysis. Solan district in Himachal Pradesh holds significant importance as an alpine region within the state. The Himalayas, being highly responsive to climate change, experience rapid changes. The sensitive ecology of the Himalayas, shaped by its evolutionary history and geological composition, is gradually shifting towards an imbalanced state, resulting in noticeable alterations in its resources and temperature.

2. MATERIALS AND METHODOLOGY

2.1 Study Area

The research conducted in this study focuses on the Solan district of Himachal Pradesh, which is depicted in Fig. 1. The geographic coordinates of the district headquarters are approximately 30° 42" to 31° 15" N latitude and 76° 42" to 77° 20" E longitude. The district's terrain primarily consists of mountainous regions, spanning elevations ranging from 300 to 2250 m. The lower parts of the district experience a predominantly subtropical climate, while the upper parts exhibit a moist temperate climate. Although the majority of the Solan district falls within the subtropical range, there are a few regions that possess temperate zones.

2.2 Methodology

In this study, the trend analysis of climatic variables like temperature and rainfall was performed using the Mann-Kendall test [11,12] which was quantified by Sen's slope method [13,14,15]. Similarly, the trend analysis and Sen's slope were also performed for the productivity of crops. The average minimum and maximum temperature, diurnal temperature variations, and rainfall data for the Solan district were obtained from the India Meteorological Department (IMD), Shimla, spanning the period

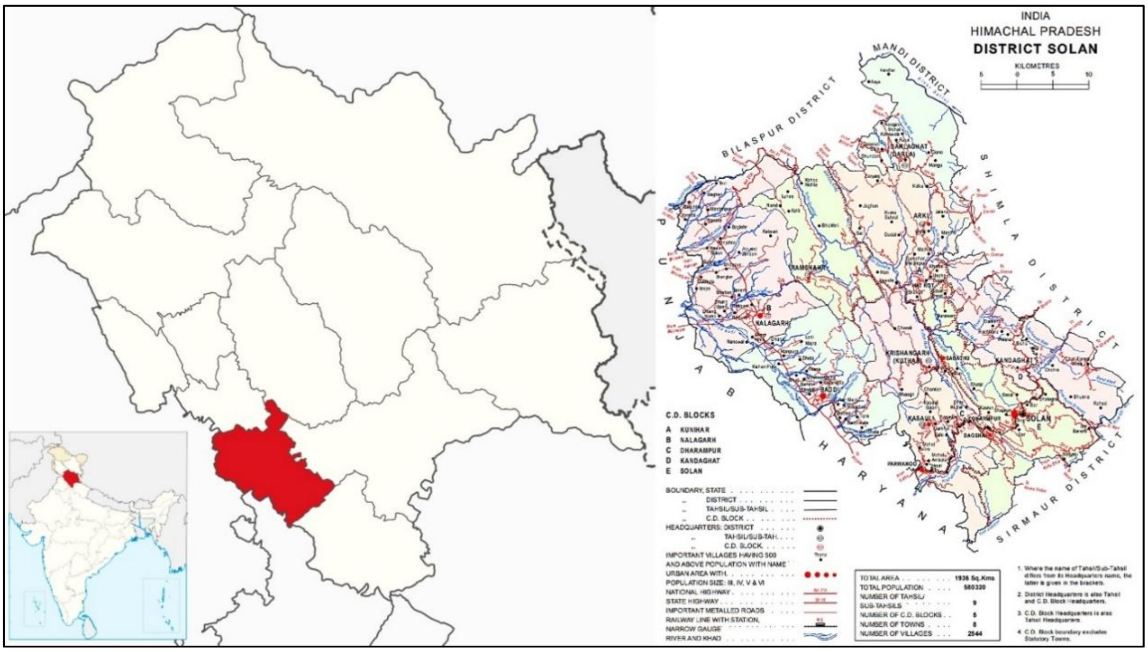

Fig. 1. Administrative map of Solan, Himachal Pradesh, India

from 1990 to 2019. Furthermore, the Department of Land Records, Government of Himachal Pradesh, provided data on the acreage and production of horticultural crops over the past three decades (1990-2019). Thirteen fruit crops within the horticulture sector were examined to investigate the effects, including apple (*Malus domestica*), plum (*Prunus domestica*), peach (*Prunus persica*), apricot (*Prunus armeniaca*), pear (*Prunus communis*), dry fruits, orange (*Citrus reticulata*), malta (*Citrus sinensis*), kagzi lime (*Citrus limon*), galgal (*Citrus medica*), mango (*Mangifera indica*), litchi (*Litchi chinensis*), and guava (*Psidium guajava*).

2.2.1 Trend analysis

The Mann-Kendall Test, a generally accepted statistical test for trend analysis in climatological and hydrologic time series, were used to analyze seasonal patterns in climatic variables such as minimum, maximum, and diurnal temperatures, as well as rainfall (quantity and days) [16]. This statistical test has two advantages: first, since it is a non-parametric test, it does not require normally distributed master data. Second, the test has a low sensitivity to abrupt data breaks and time series that are not homogeneous. As a consequence, data gaps are filled by assigning a common value that is less than the master data set's smallest measure value. The Mann-Kendall Test works on the basic null hypothesis H_o of no trend i.e., data is independent with a random order that is tested against the alternative hypothesis H1.

The test follows a time series of n data points with Ti and Tj as two subsets of data where i = 1,2, 3, n-1 and j = i+1, i+2, i+3, …, n.

Each data point in an ordered time series is compared to the next data point, and if the next data point has a higher value, the statistic S is incremented by 1, while if the next data point has a lower value, S is decremented by 1. The final value of S, i.e., the Mann-Kendall S statistic, is calculated by the net results of all iterations.

$$S = \sum_{i=1}^{n-1} \sum_{j=i+1}^{n} \operatorname{sgn}(\mathrm{X}_j - \mathrm{X}_i)$$

$$\operatorname{sgn}(\theta) = \begin{cases} 1 & if\, \theta > 0 \\ 0 & if\, \theta = 0 \\ -1 & if\, \theta < 0 \end{cases}$$

Where Tj and Ti are the annual values in years j and i, j > i, respectively

A positive (negative) value of S indicates an upward (downward) trend.

Sen's Slope, which computes the linear rate of change and intercept, measures the magnitude of the pattern. After evaluating a range of linear slopes, Sen's Slope is determined as the median of all linear slopes, resulting in the magnitude of the observed seasonal pattern. The *P*-value is another statistic correlated with 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 software XL-STAT, 2020 for this analysis. For the period 1990-2019, the null hypothesis is checked at a 95% confidence level for minimum, maximum, and diurnal temperature, as well as rainfall (quantity and days). Annual productivity patterns for apple (*Malus domestica*), plum (*Prunus domestica*), peach (*Prunus persica*), apricot (*Prunus armeniaca*), pear (*Prunus communis*), dry fruits, orange (*Citrus reticulata*), malta (*Citrus sinensis*), kagzi lime (*Citrus limon*), galgal (*Citrus medica*), mango (*Mangifera indica*), litchi (*Litchi chinensis*), and guava (*Psidium guajava*) crops were also analyzed.

2.2.2 Standardized anomaly index

SAI is a widely used index for regional climate change studies that is determined by subtracting the long-term mean value of temperature and rainfall data sets from individual values and dividing them by their standard deviation [17].

2.2.3 Multivariate linear regression model

The linear multivariate regression statistical measure was chosen to assess the climate-crop relationship. A dependent variable is driven by multiple independent variables in a multivariate linear regression model and thus multiple coefficients are calculated. Pearson's correlation coefficient was used to determine the strength of the relationship between climatic variables and crop productivity in this analysis. A correlation coefficient of -1 indicates a perfectly negative linear relationship between the two variables; a correlation of 0 indicates no 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:

$$\Delta P = \text{constant} + (\alpha \times \Delta T_{min}) + (\beta \times \Delta T_{max}) + (\gamma \times \Delta T_{dt}) + (\delta \times \Delta R) + (\varepsilon \times \Delta Rd)$$

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. Coefficients α, β, γ and δ are the coefficients of minimum, maximum, diurnal temperature and rainfall, respectively. ΔT_{min}, ΔT_{max}, T_{dt}, ΔR and ΔRd are the observed changes in minimum, maximum, diurnal temperature, rainfall and rainy days respectively for the cropping seasons during the study period.

3. RESULTS

To assess the influence of climate change in the Solan district of Himachal Pradesh, temperature data (minimum, maximum, and diurnal) and rainfall variables were taken to detect the climatic variations. The Mann-Kendall trend test was used to study the seasonal trends in climatic parameters with a 95% confidence level using time series data from 1990 to 2019.

The results of the Mann-Kendall trend test indicated significant changes in the climatic variables during the fruit-setting and flowering seasons, reflecting a significant impact of climate change in the studied region.

3.1 Climatic Trends in Different Phenological Stages in Solan District, Himachal Pradesh

The investigation showed distinct trends in temperature and rainfall during various phenological stages. In the pre-flowering stage, there were non-significant increases observed in average maximum temperature at a rate of 0.001°C per year and non-significant decreases in average minimum temperature at a rate of -0.044°C per year. Similarly, diurnal temperature exhibited a non-significant increase of 0.036°C per year, and annual rainfall showed a non-significant decrease of -0.033 mm per year. The p-values for all these variables exceeded 0.05, indicating no statistical significance for the observed variations.

During the flowering stage, the average maximum temperature displayed a non-significant increase of 0.007°C per year (P=0.925). Conversely, the average minimum temperature showed a significant increase of 0.151°C per year (P=0.001). The diurnal temperature exhibited a highly significant decrease of -0.158°C per year (P=0.005), and annual rainfall during this stage significantly decreased by -0.082 mm per year (P=0.03).

In the fruit-setting stage, both the average maximum and minimum temperatures portrayed significant decreases of -0.040°C (P=0.17) and -0.031°C (P=0.04), respectively. However, diurnal temperature and annual rainfall changes of 0.013°C (P=0.66) and -0.154 mm per year (P=0.05), respectively, were not statistically significant. Specifically, the minimum temperature only displayed a significant change during the fruit-setting stage (Table 1)

3.2 Standardized Anomaly Index (SAI)

The Standardized Anomaly Index (SAI) is a widely used metric in regional climate change studies. It is calculated by dividing individual values by their standard deviation, which is determined after subtracting the long-term mean value from the temperature and rainfall datasets [17]. The trend analysis of temperature parameters, including maximum, minimum, and diurnal temperature, as well as rainfall over 30 years computed the Standardized Anomaly Index (SAI) for each phenological stage (pre-flowering, flowering, and fruit-setting).

The findings revealed explicit patterns in temperature trends during different phenological stages. The average maximum temperature showed an increasing trend during both the pre-flowering and flowering stages, but a decreasing trend during the fruit-setting stage (Fig. 2a, 2b, and 2c). In contrast, the average minimum temperature displayed a decreasing trend during the pre-flowering and fruit-setting stages, while a notable increasing trend was observed during the flowering stage. The diurnal temperature exhibited an increasing trend during the pre-flowering and fruit-setting stages, but a decreasing trend during the flowering stage. Similar observations were seen for total rainfall in the district depicted in Fig. 2. There was a slight increase in rainfall during the pre-flowering and fruit-setting stages, while a decrease in rainfall was observed during the flowering stage. Recently, such studies for obtaining the trend analysis of main climate variables have been done in the state of Chhattisgarh [18].

Table 1. Illustrates the trend variation in climatic parameters during the three phenological stages i.e., pre-flowering, flowering, and fruit-setting stages of fruit crops of Solan district, H.P. India

Phenological Stages (Months)	Mean	Sen's slope	*P*- Value
Pre-Flowering (February to Mid-March)			
Average Maximum Temperature	20.945	0.001	.98
Average Minimum Temperature	6.089	-0.044	.08
Diurnal Temperature	14.856	0.036	.30
Annual Rainfall	8.741	-0.033	.66
Flowering (Mid-March to April)			
Average Maximum Temperature	25.153	0.007	.92
Average Minimum Temperature	9.653	0.151	.001**
Diurnal Temperature	15.499	-0.158	.005**
Annual Rainfall	2.792	-0.082	.034*
Fruit- Setting (May to June)			
Average Maximum Temperature	31.226	-0.040	.17
Average Minimum Temperature	17.436	-0.031	.04*
Diurnal Temperature	13.790	0.013	.66
Annual Rainfall	5.231	0.154	.06

**P< .05 (Significant) and ** P< .001 (Highly Significant)*

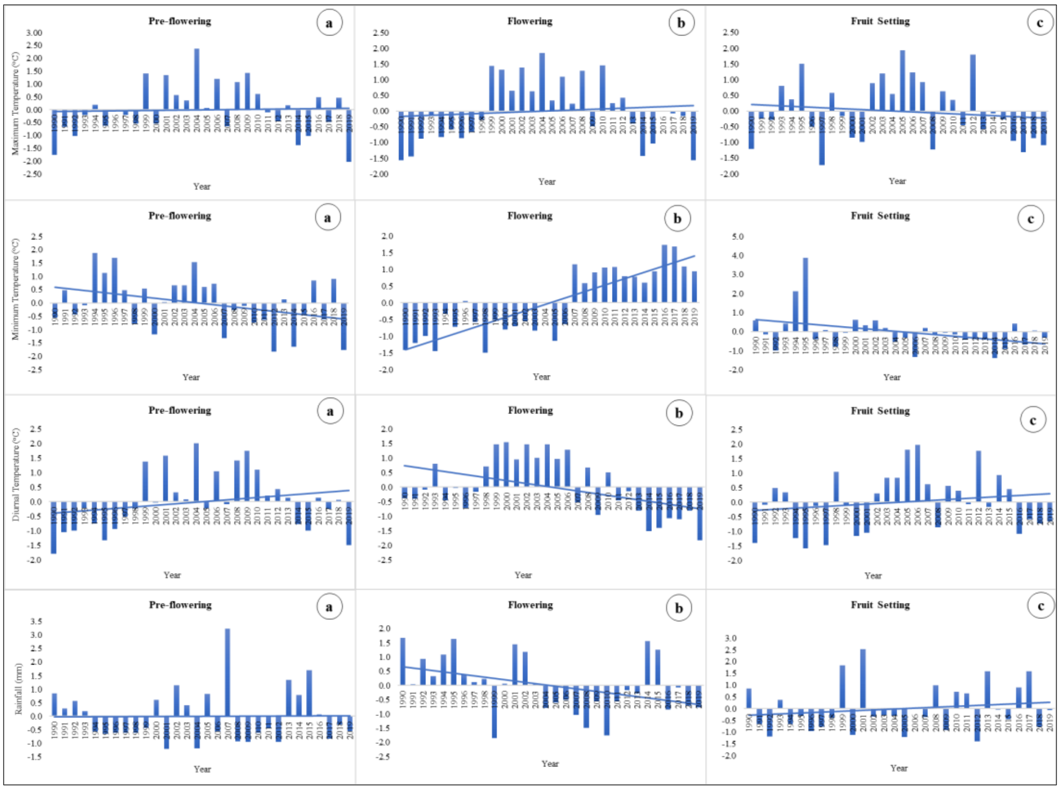

Fig. 2. Trend analysis using Standardized Anomaly Index (SAI) of temperature and rainfall during different phenological stages of fruit crops in the Solan district H.P. India

The productivity analysis of horticulture crops production data and trends, maximum, and minimum values are depicted in Fig. 3. The figure clearly illustrated that most crops in the Solan district exhibited an increasing trend in productivity, except for plums, pears, and dry fruits. However, in the Mann-Kendall test, the productivity showed a statistically significant increasing trend as depicted in Fig. 3. The results provided insights into the mean productivity, magnitude of crop productivity, and level of significance (Table 2).

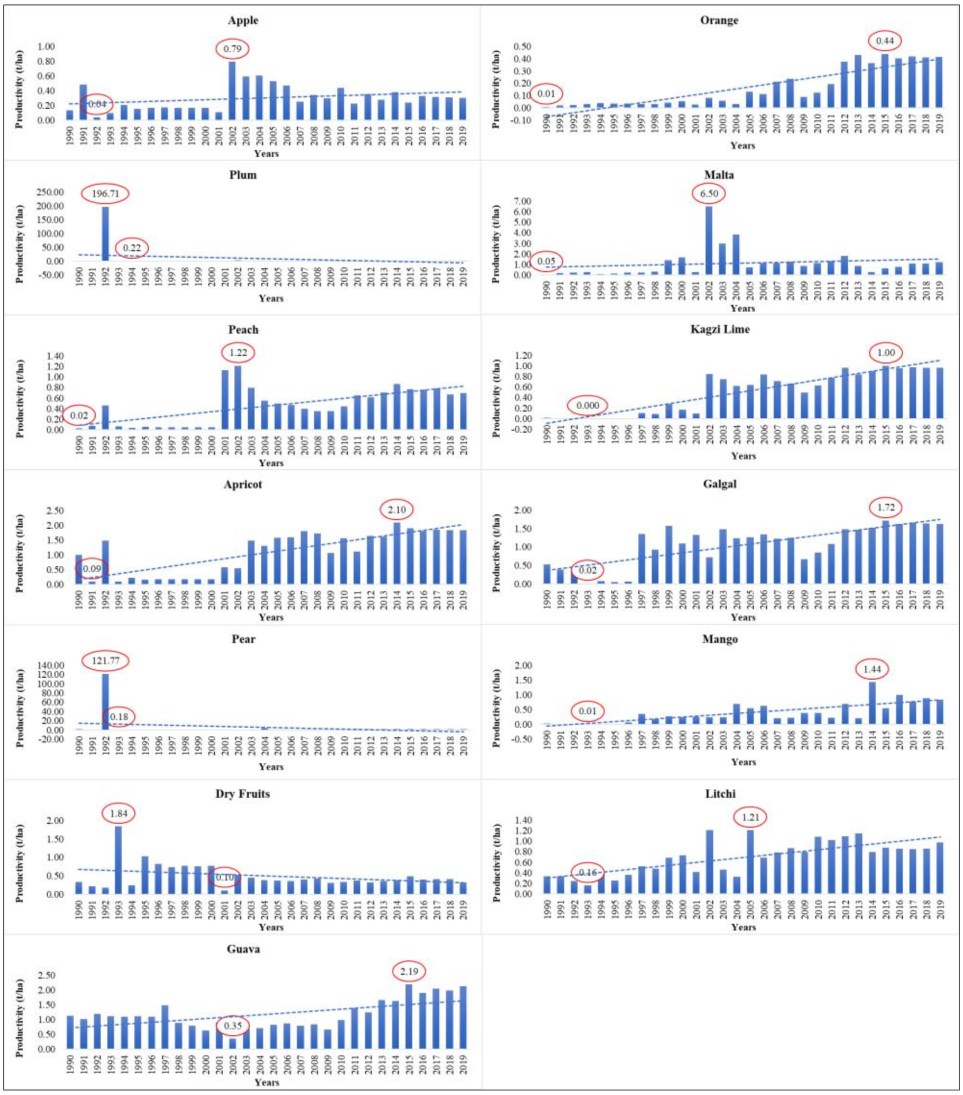

Fig. 3. Representation of productivity trends for different horticulture crops of Solan district H.P

Table 2. Mann Kendall Test results – showing magnitude and level of significance crop productivity for fruit crops (1990-2019)

Fruits crops	Mean	Sen's slope	*P*-value
Apple (*Malus domestica*)	0.309	0.007	.07
Plum (*Prunus domestica*)	8.095	0.080	.001**
Peach (*Prunus persica*)	0.471	0.027	.002**
Apricot (*Prunus armeniaca*)	1.097	1.071	.001**
Pear (*Prunus communis*)	5.229	0.048	.001**
Dry Fruits	0.498	-0.008	.17
Orange (*Citrus reticulata*)	0.169	0.016	.001**
Malta (*Citrus sinensis*)	1.158	0.034	.02*
Kagzi Lime (*Citrus limon*)	0.528	0.040	.001**
Galgal (*Citrus medica*)	1.720	0.044	.001**
Mango (*Mangifera indica*)	0.404	0.028	.001**
Litchi (*Litchi chinensis*)	0.706	0.027	.001**
Guava (*Psidium guajava*)	1.181	0.034	.02*

**P< .05 (Significant) and ** P< .001 (Highly Significant)*

3.3 Productivity Trends

Among the studied crops, a highly significant increase in productivity was observed for 11 fruit crops, while for the remaining two crops, the increase was non-significant. Specifically, plum, peach, apricot, pear, orange, malta, kagzi lime, galgal, mango, litchi, and guava exhibited significant increases in productivity, with rates of 0.080 t ha^{-1} yr^{-1}, 0.027 t ha^{-1} yr^{-1}, 1.071 t ha^{-1} yr^{-1}, 0.048 t ha^{-1} yr^{-1}, 0.016 t ha^{-1} yr^{-1}, and 0.034 t ha^{-1} yr^{-1}, respectively. Apple productivity increased at a rate of 0.007 t ha^{-1} yr^{-1} in the Solan district, but this increase was not statistically significant. Conversely, dry fruit productivity showed a decrease of -0.008 t ha^{-1} yr^{-1} (Table 2).

3.4 Crop Climate Relationships

The multivariate linear regression analysis was done to investigate the relationship between climate variables and crop productivity, as well as the influence of climate change on crop productivity. The Pearson coefficient and *P* value were computed for each climatic variable to assess their impact.

During the pre-flowering stage, the productivity of five crops (apple, malta, kagzi lime, mango, and guava) was significantly affected by climatic variables, with one or two climate variables directly influencing the pre-flowering stage and subsequently impacting crop productivity. For apple, there was a moderate positive correlation between average minimum temperature and diurnal temperature, with coefficients of 0.313 and 0.316, respectively. For malta, the average diurnal temperature exhibited a strong positive correlation of 0.651, indicating a significant impact on the pre-flowering stage, accounting for 52.6% of the variation. Similarly, kagzi lime and mango displayed moderately positive correlations of 0.360 and 0.412, respectively, with the average diurnal temperature (Table 3). However, guava showed a strong negative

Table 3. Multivariate Linear Regression Analysis between crop productivity and climatic parameters, (1990- 2019) for pre-flowering in Solan District, Himachal Pradesh, India

S No.	Crops	Variable	Pre-Flowering					
			Max T	Min T	DT	RF	R^2	% Change
1.	Apple	Coefficient	.270	.313	.316	-.019	.250	25
		P-value	.07	.04	.04	.46		
2.	Plum	Coefficient	-.080	-.174	.106	.173	.119	11.9
		P-value	.33	.17	.28	.18		
3.	Peach	Coefficient	.069	.047	.295	.164	.340	34
		P-value	.35	.40	.05	.19		
4.	Apricot	Coefficient	-.073	-.030	.197	.221	.399	39.9
		P-value	.35	.43	.14	.12		
5.	Pear	Coefficient	-.139	-.151	-.042	.097	.037	3.7
		P-value	.23	.21	.41	.30		
6.	Dry Fruits	Coefficient	-.092	.052	-.040	.096	.067	6.7
		P-value	.31	.39	.41	.30		
7.	Orange	Coefficient	-.218	-.041	.099	.267	.620	6.2
		P-value	.12	.41	.30	.07		
8.	Malta	Coefficient	.440	.132	.651	.003	.526	52.6
		P-value	.007	.24	.001	.49		
9.	Kagzi Lime	Coefficient	.074	-.173	.360	.116	.308	30.8
		P-value	.34	.18	.02	.27		
10.	Galgal	Coefficient	.057	-.089	.288	.080	.214	21.4
		P-value	.38	.31	.06	.33		
11.	Mango	Coefficient	.100	-.176	.412	.093	.370	37
		P-value	.29	.17	.01	.31		
12.	Litchi	Coefficient	-.066	-.134	.197	.245	.290	29
		P-value	.36	.23	.14	.09		
13.	Guava	Coefficient	-.526	-.054	-.449	-.047	.553	55.3
		P-value	.001	.38	.006	.40		

**P< .05 (Significant) and ** P< .001 (Highly Significant)*

Min T: Minimum Temperature, Max T: Maximum Temperature, DT: Diurnal Temperature, RF: Rainfall correlation (-0.526) with average maximum temperature, leading to a 55.3% impact on the pre-flowering stage. This suggests that the average maximum temperature harms guava productivity. The overall percentage impact varied among the crops, with guava exhibiting the highest impact (55.3%), followed by malta (52.6%), mango (37%), kagzi lime (30.8%), and apple (25%) (Table 3).

Similarly, during the flowering stage, malta exhibited significant and strong positive correlations with average maximum temperature (0.730) and diurnal temperature (0.623), resulting in the highest impact on this phenological stage (69.4%). For the apple crop, there was a moderately positive correlation with the average maximum temperature (0.320), contributing to a 20.7% impact on the flowering stage. In contrast, guava displayed strong negative correlations with average maximum temperature (-0.631) and diurnal temperature (-0.680), leading to a 56.5% impact on the flowering stage. In summary, malta had the highest total impact on the flowering stage (69.4%), followed by guava (56.5%) and apple (20.7%) (Table 4.). However, during the fruit-setting stage, mango was the most affected crop, with a 39.2% influence, followed by plum (18.6%), pear (16.5%), malta (16.2%), and apple (12.5%), as presented in Table 5. However, the remaining samples from various phenological stages exhibited correlations with high P-values that could not be adequately explained.

Table 4. Multivariate Linear Regression Analysis between crop productivity and climatic parameters, (1990- 2019) for flowering in Solan District, Himachal Pradesh, India

S No.	Crops	Variable	Flowering					% Change
			Max T	Min T	DT	RF	R^2	
1.	Apple	Coefficient	.320	-.137	.271	-.180	.207	20.7
		P-value	.04	.23	.07	.17		
2.	Plum	Coefficient	.061	.010	-.005	.013	.084	8.4
		P-value	.37	.47	.49	.47		
3.	Peach	Coefficient	.118	-.077	.033	.214	.336	33.6
		P-value	.26	.34	.43	.12		
4.	Apricot	Coefficient	.026	.027	-.101	.130	.369	36.9
		P-value	.44	.44	.29	.24		
5.	Pear	Coefficient	-.083	.096	-.139	.090	.044	4.4
		P-value	.33	.30	.23	.31		
6.	Dry Fruits	Coefficient	.130	-.041	.093	-.190	.083	8.3
		P-value	.24	.41	.31	.15		
7.	Orange	Coefficient	.044	.095	-.134	-.023	.535	53.5
		P-value	.40	.30	.24	.45		
8.	Malta	Coefficient	.730	-.178	.623	-.366	.694	69.4
		P-value	.001	.17	.001	.02		
9.	Kagzi Lime	Coefficient	.258	-.173	.199	-.128	.314	31.4
		P-value	.08	.18	.14	.25		
10.	Galgal	Coefficient	.207	-.120	.139	-.080	.254	25.4
		P-value	.13	.26	.23	.33		
11.	Mango	Coefficient	.289	-.196	.228	-.196	.390	39
		P-value	.06	.15	.11	.14		
12.	Litchi	Coefficient	.229	-.047	.127	-.152	.279	27.9
		P-value	.11	.40	.25	.21		
13.	Guava	Coefficient	-.631	.171	-.680	.265	.565	56.5
		P-value	.001	.18	.001	.07		

**P< .05 (Significant) and ** P< .001 (Highly Significant)*
Min T: Minimum Temperature, Max T: Maximum Temperature, DT: Diurnal Temperature, RF: Rainfall

Table 5. Multivariate Linear Regression Analysis-crop productivity and climatic parameters, (1990- 2019) for fruit-setting in Solan District, Himachal Pradesh, India

S No.	Crops	Variable	Fruit-Setting					
			Max T	Min T	DT	RF	R^2	% Change
1.	Apple	Coefficient	.317	.154	.162	-.090	.125	12.5
		P-value	.04	.20	.19	.31		
2.	Plum	Coefficient	.044	-.374	.293	-.194	.186	18.6
		P-value	.40	.02	.05	.15		
3.	Peach	Coefficient	.203	-.155	.281	.061	.140	14
		P-value	.14	.20	.06	.37		
4.	Apricot	Coefficient	.099	-.176	.209	-.023	.079	7.9
		P-value	.30	.17	.13	.45		
5.	Pear	Coefficient	-.137	-.334	.111	-.169	.165	16.5
		P-value	.23	.03	.28	.18		
6.	Dry Fruits	Coefficient	.175	.159	.040	-.200	.081	8.1
		P-value	.17	.20	.41	.14		
7.	Orange	Coefficient	.159	.080	.087	-.204	.108	10.8
		P-value	.20	.33	.32	.14		
8.	Malta	Coefficient	.314	-.123	.350	-.140	.162	16.2
		P-value	.04	.25	.02	.23		
9.	Kagzi Lime	Coefficient	-.173	-.357	.100	.014	.149	14.9
		P-value	.18	.02	.29	.47		
10.	Galgal	Coefficient	-.187	-.280	.033	-.009	.108	10.8
		P-value	.16	.06	.43	.48		
11.	Mango	Coefficient	-.220	-.607	.228	.007	.392	39.2
		P-value	.12	.001	.11	.48		
12.	Litchi	Coefficient	.033	-.046	.070	-.078	.073	7.3
		P-value	.43	.40	.35	.34		
13.	Guava	Coefficient	-.466	-.001	-.356	.091	.239	23.9
		P-value	.005	.49	.01	.31		

**P< .05 (Significant) and ** P< .001 (Highly Significant)*
Min T: Minimum Temperature, Max T: Maximum Temperature, DT: Diurnal Temperature, RF: Rainfall

4. DISCUSSION

Based on the findings, the impact of climate change on horticultural crops in the Solan district is deciphered. Both significant and non-significant variations in average temperature and annual rainfall directly or indirectly correlated with the phenological stages of crops, consequently affecting productivity. During the pre-flowering stage, there were non-significant variations in temperature and rainfall. The multivariate linear regression analysis revealed that five crops (Apple, Malta, Kagzi lime, Mango, and Guava) were significantly affected during this stage. Because temperature and its interactions with other factors will be the most significant feature of human-induced climate change for crop development given the apparent lack of a direct influence of [CO_2] on the rate of development. In plants lacking a vernalization requirement, or if that requirement has been met, the length from sowing to flowering and maturity is mostly regulated by temperature and photoperiod responses [19,20].

The significant increase in average maximum and diurnal temperature positively influenced these crops, as temperature and its interactions influenced crop development. In the flowering stage, there was a significant increase in the minimum temperature (0.151°C per year), while the diurnal temperature experienced an annual decrease of -0.158°C. This trend aligns with similar observations in the Kullu district, where the average minimum temperature in Zone 2 increased by 0.89°C every decade, while the minimum temperatures in February and March rose by approximately 1.12°C and 0.97°C, respectively, every ten years [21]. The annual rainfall also significantly decreased during this stage (-0.082 mm per year). Similar patterns were observed in the Sirmour district, where the total spring and summer rainfall decreased by 25.87 mm over time, while winter and autumn rainfall increased by 21.90 mm and 23.86 mm, respectively, compared to the baseline period [22]. The climatic variations have a clear impact on crop productivity and increase vulnerability in climate-dependent agricultural systems. In the fruit-setting stage, climatic parameters showed a positive impact on crop productivity in the Solan district. The overall increase in crop productivity in the district, particularly in temperate fruits such as pear, peach, plum, and apricot, might be attributed to the favorable impact of climate change [23]. The average maximum and diurnal temperatures showed significant associations with the flowering stage of malta crops, resulting in increased crop output. Warmer temperatures during springtime can enhance pollen viability and fruit set, leading to improved crop productivity [24]. The average maximum and diurnal temperatures showed significant associations with the flowering stage of malta crops, resulting in increased crop output. Higher temperatures during springtime promote fruit ripening and pollination, thereby benefiting overall productivity [25]. A similar study conducted for Kullu district revealed that climatic parameters have an 18-35% change in the productivity of stone fruits viz. pear, apple, cherry, almond and plum compared to technological interventions using historical data [26].

The correlation analysis of climate parameters with fruit crops indicated that temperature played a crucial role. It significantly affected each phenological stage of crop development, while rainfall does not exhibit significant correlations at any phenological stage, except for a significant increase during the flowering stage. A similar study conducted in other regions like the Kullu district also revealed the impact of climatic parameters on crop productivity, demonstrating changes in productivity compared to historical data and technological interventions. The agricultural ecosystems in the Himalayan foothills also benefitted during the COVID-19 pandemic due to improved direct radiant energy, resulting in increased gross primary productivity [27]. In conclusion, the study highlights the importance of understanding the impact of climate change on crop productivity and the role of temperature as a critical factor influencing phenological stages in horticultural crops in the Solan district. These findings are valuable for implementing appropriate horticulture strategies to cope with changing climatic conditions and maximize crop productivity.

5. CONCLUSION

The crop productivity in the Solan district was found to be directly influenced by regional climatic variations. The analysis of climate variables revealed significant trends, with a significant increase in average minimum temperature during the flowering stage and a declining trend in diurnal temperature and annual rainfall. The fruit-setting stage experienced a significant decrease in minimum temperature. The fluctuations in temperature and rainfall were observed to be correlated with specific phenological stages, emphasizing the direct association between temperature and crop productivity. Among the thirteen fruit crops studied, apple, malta, kagzi lime, mango, guava, plum, and pear exhibited considerable sensitivity to these climatic variations. All crops, except for dry fruits, demonstrated increased productivity, indicating an overall positive contribution to the district's horticulture output. These observed changes proved beneficial for the Solan district, as positively impacted crop performance. However, any sudden changes in climate parameters may have future implications for crop productivity. As the climate continues to evolve, understanding and adapting to these variations will be crucial in ensuring sustainable horticulture practices and securing the region's food production.

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COMPETING INTERESTS

Authors have declared that no competing interests exist.

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