Agriculture Association of Textile Chemical and Critical Reviews Journal (2025) 513-520

AATCC Review

28 June 2025: Received
17 August 2025: Revised
25 August 2025: Accepted
23 September 2025: Available Online

https://aatcc.peerjournals.net/

Original Research Article Open Access

Variability and trend analysis of temperature in relation to crops in the mid-hills of Nauni, Himachal Pradesh

Priyanka Jattan*[1], Mohan Singh[1], S. K. Bhardwaj[1], Neha Kumari[2], and Nikita[1]

[1]Department of Environmental Science, Dr. Yashwant Singh Parmar University of Horticulture and Forestry, Nauni, Solan, Himachal Pradesh, India

[2]Department of Seed Science and Technology, Dr. Yashwant Singh Parmar University of Horticulture and Forestry, Nauni, Solan, Himachal Pradesh, India

ABSTRACT

This study explores the shifting temperature trends and their influence on agricultural output in the Solan district of Himachal Pradesh over a 40-year period (1984–2023). The highest observed annual maximum and minimum temperatures were 34.9°C and 23.0°C, respectively, while the lowest recorded maximum and minimum values were 13.2°C and 0.2°C. Results from the Mann-Kendall trend test and Sen's slope estimator indicate a statistically significant upward trend in both maximum and minimum annual temperatures, increasing at rates of 0.04°C/year and 0.004°C/year, respectively. A seasonal breakdown revealed increased temperature trends during the monsoon, post-monsoon, and winter, whereas a decrease was noted during the summer months. Focusing on the growing season (March to August) from 1996 to 2021, the regression models were developed between maximum, minimum, mean, and diurnal temperature and yield of capsicum and tomato crops that explained a negative relationship between temperatures and yield. Optimal productivity for both crops was achieved under the following temperature ranges: maximum temperature of 25–30°C, minimum temperature of 15–20°C, and mean temperature of 20–25°C. The findings reveal a complex relation between climate variables and crop performance, highlighting the importance of adaptive farming practices and climate-resilient strategies to maintain and improve productivity under changing environmental conditions. This research offers valuable insights for policy formulation and agricultural planning, supporting the development of climate adaptation and mitigation frameworks aimed at safeguarding future crop yields in the face of ongoing climatic shifts. However, the study faced challenges related to uneven topography, and the complex interaction between temperature variability and crop response under hill agroclimatic conditions. Despite these limitations, this research provides valuable insights into the local impacts of climate variability on agricultural systems. The findings contribute to regional climate adaptation strategies and offer a basis for developing crop-specific management practices in the mid-hill ecosystem of Himachal Pradesh.

Keywords: *Maximum, Minimum, Mean, and Diurnal temperature, Mann–Kendall, Sen's slope estimator, Temperature Trends, Climate Variability, Seasonal Temperature Analysis, Climate Change, Environmental Impact.*

Introduction

Climate change is an undeniable and urgent issue that has garnered significant attention in recent decades. It is defined as long-term deviation from normal in temperature, precipitation, and other climatic factors (IPCC, 2021). Major contributing factors to climate change are the anthropogenic activities releasing GHG (Prasad, 2017). Deforestation further exacerbates the accumulation of greenhouse gases by reducing carbon sinks (Li et al., 2022). Urbanization (Liu et al., 2022) and changes in land use patterns further amplify the climate change (Vujovic et al., 2021).

From 1901 to 2021, India's annual mean temperature increased by 0.63°C per century (IMD, 2021) also it experienced significantly above-normal temperatures during 2021, making it the fifth warmest year since 1901. The pace of warming has accelerated, since the late 1970, with subsequent decades showing an even faster rate, with 11 of the 15 warmest years observed between 2007 and 2021. The consequences of rising temperatures has started showing its impact like increased frequency and intensity of extreme weather events (Muluneh, 2021), serious health risks (Mazdiyasni, 2017), negatively impacted cropping patterns and agricultural output, enhanced evaporation rates, reduced water availability, and complicating water management strategies (Lobell, 2008). Elevated temperatures can accelerate or hinder germination and promote vegetative growth until a threshold beyond which heat stress impairs photosynthesis, resulting in stunted growth and higher water requirements (Hatfield &Prueger, 2015). High temperatures during flowering can cause pollen sterility and poor fruit set reducing yields (Jagadish et al., 2007 Cleland et al., 2007).

The IPCC future projections indicated that the temperature potentially rise by 2-4°C by the end of the century, especially in northern and central India. Climate models predict that Himachal Pradesh may see average temperature increases of 1.5–2.5°C by the end of the 21st century under moderate emission scenarios and greater increases under high emission scenarios (IMD, 2021). These projections underscore the urgent need of regional temperature trend analysis for mitigation

*Corresponding Author: ***Priyanka Jattan***

DOI: https://doi.org/10.21276/AATCCReview.2025.13.04.513

and adaptation strategies to manage the adverse effects of rising temperatures.

Materials and Methods

Study site

The study was conducted in Solan district, which is located in the mid-hills of Himachal Pradesh, spans an area of approximately 1,936 km^2 between latitudes 33°12′40″ N and longitudes 79°04′20″ E. The district's altitude ranges from 1,200 to 1,275 meters above sea level. The annual average maximum and minimum temperatures was 25.4°C and 11.4°C, respectively. The highest maximum temperature of 32.6°C occurs during the summer, and the highest minimum temperature of 21.8°C occurs during the monsoon season whereas the lowest maximum and minimum temperature of 23.6°C and 7.4°C respectively, was recorded in winter season. The statistical trends were worked out using the standard procedure for maximum and minimum temperature and capsicum and tomato productivity.

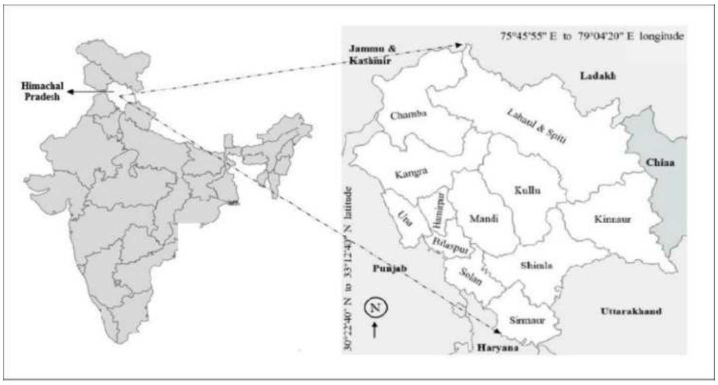

Fig 1. Study area

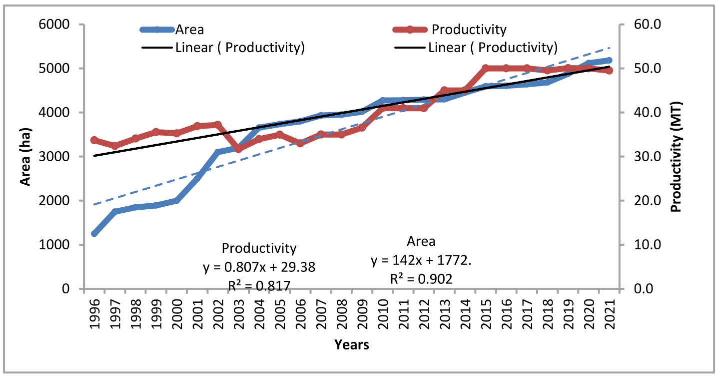

Fig 2. Area and productivity for Tomato

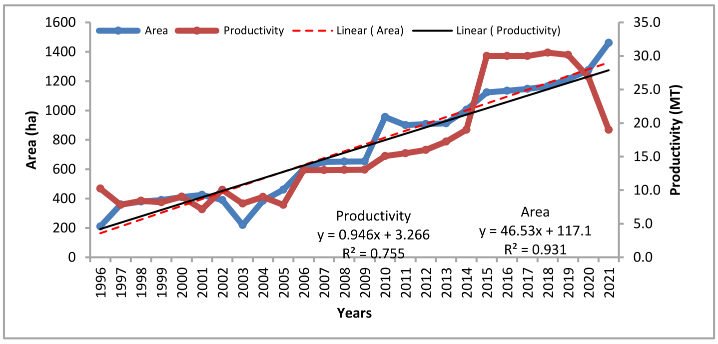

Fig 3. Area and productivity for capsicum

Data source

Daily temperature data for the Solan district, covering the period from 1984 to 2023, was collected from the Agro-meteorological Observatory at Dr. Yashwant Singh Parmar University of Horticulture and Forestry in Nauni, Solan. The normal temperature values were derived by averaging monthly data across these years. For seasonal trend analysis, the year was divided into four seasons: winter (January–February), summer (March–May), monsoon (June–September), and post-monsoon (October–December).

Data analysis techniques

Several techniques have been developed for analyzing temperature, typically categorized into two main types' viz., variability analysis and trend analysis.

Variability analysis

Variability analysis employs mean, standard deviation (SD), coefficient of variation (CV) and the percent contribution of annual temperature. Data was analyzed using SPSS software. Standard deviation measures the extent of variation in the data, while the coefficient of variation assesses the variability of temperature. A higher CV indicates greater variability, and it is calculated using the formula: $CV = \frac{\sigma}{\mu}$,

Where; CV represents the coefficient of variation, σ is the standard deviation, and μ is the mean temperature.

Trend analysis

a. Man-Kendall test

The Mann-Kendall (MK) trend test is a non-parametric method widely used to identify monotonic trends in meteorological data. This test evaluates whether there are statistically significant increasing or decreasing trends in the study area. The test's statistics are based on the signs (+ or -) of data values. MAKESENS software employs two types of statistics depending on the data set size: S-statistics for fewer than 10 data points and Z-statistics for 10 or more data points (Kendall, 1975).

The statistics S is calculated as shown in equation (I)

$$s = \sum_{i=1}^{n-1} \sum j = i^n + 1^{sgn(xj-xi)} \text{ (i)}$$

Where *xjandxi* and are annual values (in years) j and I, if j>i respectively, n is the number of data points and *sgn(xj-xi)* is calculated using equation (ii)

$$sgn(xj - xi) = \begin{cases} 1 \; if \; (xj - xi > 0) \\ 0 \; if \; (xj - xi = 0) \\ -1 \; if \; (xj - xi < 0) \end{cases} \text{ (ii)}$$

A positive or negative value of S indicates upward or downward trends respectively.

If numbers of data values are 10 or more, the S- statistics approximately behave as normally distributed and test is performed with normal distribution with the mean and variation as given below equation (iii) & (iv).

$$E(s) = 0 \text{ (iii)}$$

$$var(S) = \frac{n(n-1)(2n+5) - \sum_{i=1}^{n} ti(ti-1)(2ti+5)}{18} \text{ (iv)}$$

Where, n is number of tied (zero difference between compared values) group and is the number of data points in the ith tied group. The standard normal distribution (Z-statistics) is computed using equation (v).

$$z = \begin{cases} \frac{s-1}{\sqrt{var(s)}} ifs > 0 \\ 0\ ifs = 0 \\ \frac{s+1}{\sqrt{var(s)}} ifs < 0 \end{cases} \quad (v)$$

Statistically the significance of trend is assessed using the z-value. A positive value of Z shows upward (increasing) trend while the negative value indicates the downward (decreasing) trend.

b. Sen's estimator method: Sen's non parametric estimator method will be used for predicting the magnitude of weather data series which uses a linear model for trend analysis. The slope Ti is calculated as:

$$Ti = \frac{xj-xk}{j-k} \text{ For i=1, 2, 3…n}$$

Where, xj and xk are data values at time j and k (j>k) separately.

The median of these n values of Ti represented by Sen's slope estimation which is estimated by using the following equation

$$Qi = \begin{cases} T\frac{n+1}{2} fornisodd \\ \frac{1}{2}\left(T\frac{n}{2} + T\frac{n+2}{2}\right) forniseven \end{cases}$$

Sen's estimator (Qi) is calculated by using above equation, depending upon value of n is either odd or even then (Qi) is computed using 100(1-α) % confidence interval. A positive value of Qi indicate increasing trend and while negative value represent decreasing trend of time series data. Where a is a different significance level (0.05 and 0.01 etc.)

c. Linear regression analysis

Linear regression analysis is a parametric method frequently used to identify trends in data series (Kaur and Kaur, 2019). There were a number of studies exploring the relationship between climate and crop yields (Lobell and Field 2007; Auffhammer et al. 2006). Most of these studies have focused on the exposure to extreme temperatures on crop yield; using a fixed effects regression model this technique establishes a relationship between two variables (dependent and independent) by fitting a linear equation to the observed data. Initially, a scatter plot is used to determine whether a relationship exists between the variables of interest. The linear regression model is typically represented by the equation:

Y = aX + b,

Where Y is the dependent variable, X is the independent variable, a is the slope of the line and b is the intercept.

3. Results

3.1 Monthly and Seasonal temperature variability

The monthly highest and lowest of maximum and minimum temperatures recorded in different years in the study area over the last 40 years (1984-2023) is presented in Table 1. The highest ever maximum temperature was recorded on June 2, 1984 and May 6, 1994 (39.5°C) and the lowest on January 8, 2020 (4.0°C). The highest ever minimum temperature was recorded on June 16, 1986 (27.5°C) and the lowest on January 7, 2013 (-3.6°C). The highest ever annual mean monthly maximum and minimum temperature was recorded in June; 2005 (34.9°C) and 1986 (23.0°C) and the lowest in December, 1986 (13.2°C) and January, 1986 (0.2°C), respectively (Table 1).

The average annual maximum, minimum, mean and diurnal temperature was 25.4°C, 11.4°C, 18.4°C, and 14.0°C with corresponding standard deviations of 0.9°C, 0.7°C, 0.7°C and 0.9°C and had a coefficient of variation of 3.7%, 6.5%, 3.8% and 6.6%, respectively. The highest maximum, minimum, mean and diurnal temperature was in May (31.2°C), July (20.0°C), June (24.7°C) and November (17.4°C) with standard deviation of 1.7°C, 0.9°C, 1.3°C and 1.7°C and CV 5.4%, 4.8%, 1.3% and 9.5%, respectively, the lowest maximum temperature was in January (17.6°C) followed by February (19.5°C) with standard deviation of 2.0°C and 2.4°C and CV of 11.3% and 12.3%, respectively while the lowest minimum and mean temperature was recorded in January (2.2°C and 9.9°C) with standard deviation of 1.0°C and 1.2°C and CV of 46.1% and 12.5%, respectively (Table 2). The lowest diurnal temperature was in July and August (8.5°C) with a Standard deviation of 1.2°C and 1.1°C and CV 13.6% and 13.2%, respectively.

Table 1. Maximum and minimum temperature variations in Solan for the period of 1984-2023

Months	Maximum temperature (°C)				Minimum temperature (°C)			
	Annual Highest	Annual lowest	Daily highest	Daily lowest	Annual Highest	Annual lowest	Daily highest	Daily lowest
January	21.6 (2007)	13.5 (1984)	30.6(2009)	4.0(2020)	5.0 (1990)	0.2 (1986)	11.0(1990)	-3.6(2013)
February	26.1 (2006)	15.2 (1984)	29.5(2023)	4.4(2022)	8.2 (1987)	0.3 (2011)	14.0(1987)	-2.8(2008)
March	28.7 (2004)	18.6 (1990)	33.2(2022)	10.0(2020)	10.8 (1987)	4.1 (1988)	17.5(1987)	0.5(2017)
April	33.2 (2022)	24.5 (1997)	36.0(2022)	10.0(1987)	17.2 (1986)	10.2 (1995)	23.5(2009)	4.5(1997)
May	34.7 (1984)	24.8 (1987)	39.5(1994)	16.0(1987)	19.8 (1984)	13.2 (2023)	27.0(1984)	6.0(1987)
June	34.9 (2005)	26.2 (1985)	39.5(1984)	17.1(2010)	23.0 (1986)	16.6 (1985)	27.5(1986)	8.5(1985)
July	30.9 (1991)	25.2 (1985)	35.5(2021)	20.0(2023)	22.3 (1986)	16.0 (1985)	27.0(1989)	12.5(1985)
August	30.8 (1986)	25.9 (1985)	34.0(1987)	19.5(1987)	22.5 (1986)	13.5 (1985)	26.0(1986)	12.5(1985)
September	30.6 (2020)	25.7 (1985)	33.5(2020)	18.0(1986)	19.5 (1986)	11.2 (1985)	24.0(1986)	7.5(1985)
October	29.8 (2020)	22.7 (1997)	33.0(1987)	13.0(1987)	14.3(1987)	6.4 (1985)	25.0(1987)	2.5(1985)
November	25.2 (2016)	20.6 (1997)	30.2(2001)	10.0(1989)	9.8 (1986)	2.0 (1985)	12.5(1986)	-1.5(1984)
December	23.2 (2008)	13.2 (1986)	32.0(1999)	5.5(1991)	4.5 (1987)	0.9 (2011)	12.5(2004)	-2.7(2011)

Table 2. Descriptive statistics of maximum, minimum, mean and diurnal temperature for the period of 1984-2023

Months	Maximum temperature (◦C)			Minimum temperature (o C)			Mean temperature (º C)			Diurnal temperature (º C)		
	Avg	SD	CV (%)	Avg	SD	CV (%)	Avg	SD	CV (%)	Avg	SD	CV (%)
January	17.6	2.0	11.3	2.2	1.0	46.1	9.9	1.2	12.5	15.4	2.0	12.9
February	19.5	2.4	12.3	4.3	1.5	35.6	11.9	1.7	14.2	15.2	2.2	14.4
March	23.5	2.3	9.7	8.1	1.3	15.9	15.8	1.6	10.1	15.4	1.9	12.2
April	28.1	2.1	7.5	12.3	1.5	12.5	20.2	1.6	8.1	15.8	1.7	10.9
May	31.2	1.7	5.4	15.9	1.3	8.3	23.6	1.3	5.7	15.3	1.5	9.6
June	30.9	1.9	6.2	18.5	1.1	5.8	24.7	1.3	5.1	12.4	1.8	14.2
July	28.4	1.3	4.5	20.0	0.9	4.8	24.2	1.0	4.0	8.5	1.2	13.6
August	28.0	1.1	3.8	19.5	1.2	6.3	23.8	1.0	4.2	8.5	1.1	13.2
September	28.0	1.2	4.2	16.8	1.5	8.8	22.4	1.1	5.1	11.2	1.4	12.2
October	26.5	1.3	5.0	10.5	1.4	13.3	18.5	1.1	6.2	16.0	1.5	9.3
November	23.2	1.3	5.5	5.8	1.3	22.1	14.5	1.0	6.7	17.4	1.7	9.5
December	20.0	2.1	10.3	2.8	1.0	35.5	11.4	1.2	10.6	17.2	2.1	12.4
Annual	25.4	0.9	3.7	11.4	0.7	6.5	18.4	0.7	3.8	14.0	0.9	6.6
Summer	29.6	1.6	5.2	14.1	1.2	8.8	21.9	1.2	5.6	15.5	1.3	8.7
Monsoon	28.8	1.0	3.5	18.7	1.0	5.3	23.8	0.9	3.8	10.1	0.8	8.3
Post monsoon	23.3	1.4	5.8	6.4	1.0	14.9	14.8	0.9	6.1	16.9	1.5	8.8
Winter	20.2	1.7	8.5	4.9	0.8	17.2	12.5	1.1	8.5	15.3	1.7	10.8

The highest variability in maximum temperature was in February (CV=12.3%) the lowest variability in August (CV= 3.8%). The highest variability in minimum temperature was in January (CV= 46.1%) the lowest variability in July (CV=4.8%). The mean temperature was most variable in February (CV=14.2%) and lowest in July (CV=4.0%). The diurnal temperature was most variable in February (CV=14.4%) and lowest in August (CV=1.1%). The maximum, minimum, mean and diurnal temperature was showing a higher variability during the winter season with CV of 8.5%, 17.2%, 8.5 and 10.8%, respectively and lowest in monsoon season with CV of 3.5%, 5.3%, 3.8% and 8.3%, respectively. The annual was higher in diurnal temperature (CV=6.6%) followed by minimum temperature (CV=6.5%), compared to maximum (CV=3.7%) which was at par with the mean temperature (Table 2).

Overall this analyzed that there was considerable variability in temperature and hence, more vulnerable to extreme weather events. Similar results were obtained by the centre on climate change observed an average annual temperature increase by 0.5°C from 1980 to 2022, with the most pronounced warming during the winter and post-monsoon seasons. Arora et al (2005) reported a significant increase in both maximum and minimum temperatures from 1901 to 2003 which may increase the frequency and intensity of extreme temperature events (Ganeshi et al. 2023) over India.

3.2 Variability in temperature over the decades

The variability analysis of maximum and minimum temperatures on a decadal basis is showed in Tables 3 and 4. The mean annual maximum and minimum temperatures in the study area were 25.4°C and 11.4°C, with corresponding standard deviations of 0.9°C and 0.7°C, respectively. On a decadal basis, the average annual maximum temperature was recorded as 24.5°C (1984–1993), 25.5°C (1994–2003), 26.2°C (2004–2013), and 25.5°C (2014–2023). Similarly, the average annual minimum temperature was 11.3°C (1984–1993), 11.5°C (1994–2003), 11.3°C (2004–2013), and 11.5°C (2014–2023). These values indicate that the maximum temperature deviated between –0.9°C and +0.8°C, while the minimum temperature deviation ranged from –0.1°C to +0.1°C over the observed period. According to the results the highest maximum and minimum temperature was observed in the month of May (32.0°C) and July (20.3°C) during 2004-2013 and 1993-2003. Kaur and Kaur (2015) also analyzed long-term trends in temperature over the past four decades and reported that both minimum and maximum temperatures have increased over the past four decades at rates ranging from 0.02°C to 0.07°C per year.

On the other hand variability analysis of mean and diurnal temperatures on a decadal basis is depicted in Tables 5 and 6. The annual mean and diurnal temperatures in the study area were 18.4°C and 14.0°C, with corresponding standard deviations of 0.7°C and 0.9°C, respectively. On a decadal basis, the average annual mean temperature was recorded as 17.9°C (1984–1993), 18.5°C (1994–2003), 18.8°C (2004–2013), and 18.5°C (2014–2023). Similarly, the average annual diurnal temperature was 13.3°C (1984–1993), 14.0°C (1994–2003), 14.9°C (2004–2013), and 14.0°C (2014–2023). These values indicate that the mean temperature deviated between –0.5°C and +0.4°C, while the diurnal temperature deviation ranged from –0.8°C to +0.8°C over the observed period.

Table 3. Decadal statistical analysis of monthly, seasonal and annual variation of maximum temperaturefor the period of 1984-2023

	1984-1993				1994-2003				2004-2013				2014-2023			
	Mean	SD	CV (%)	Dev	Mean	SD	CV (%)	DEV	Mean	SD	CV (%)	DEV	Mean	SD	CV (%)	DEV
January	16.1	2.0	12.7	-1.5	17.9	1.4	7.6	0.3	18.8	2.0	10.8	1.2	17.6	1.7	9.7	0.0
February	18.1	2.1	11.5	-1.4	19.1	2.0	10.6	-0.3	20.5	2.6	12.8	1.1	20.1	2.4	11.8	0.7
March	21.9	2.0	9.1	-1.6	23.4	1.5	6.2	-0.1	25.2	1.7	6.8	1.7	23.5	2.7	11.6	0.0
April	27.2	1.6	5.8	-0.9	28.0	2.5	9.0	0.0	29.0	1.9	6.5	0.9	28.1	2.3	8.1	0.0
May	30.9	2.8	9.0	-0.3	31.7	1.0	3.1	0.5	32.0	0.7	2.0	0.8	30.3	1.1	3.7	-1.0
June	30.6	2.0	6.7	-0.3	30.9	1.8	5.9	0.0	31.4	2.3	7.3	0.5	30.7	1.6	5.2	-0.2
July	28.1	1.9	6.8	-0.3	28.6	1.0	3.5	0.1	28.9	1.0	3.4	0.5	28.2	1.0	3.7	-0.3
August	27.7	1.4	5.2	-0.3	27.8	0.9	3.2	-0.3	28.2	0.9	3.1	0.2	28.4	0.9	3.0	0.4
September	27.5	1.5	5.4	-0.5	27.7	0.9	3.2	-0.2	28.3	1.0	3.4	0.3	28.4	1.2	4.2	0.4
October	25.9	1.3	5.0	-0.6	26.6	1.6	6.1	0.0	26.8	1.0	3.5	0.3	26.8	1.3	4.9	0.3
November	22.0	1.0	4.7	-1.2	23.4	1.2	5.1	0.2	24.0	1.0	4.1	0.8	23.5	1.0	4.3	0.3
December	18.4	2.6	14.4	-1.6	20.4	1.8	8.7	0.4	21.1	1.3	6.1	1.0	20.3	1.5	7.3	0.2
Annual	24.5	0.7	2.9	-0.9	25.5	0.9	3.4	0.0	26.2	0.7	2.7	0.8	25.5	0.7	2.7	0.1
Summer	29.0	1.8	6.3	-0.6	29.9	1.5	5.0	0.2	30.5	1.1	3.6	0.9	29.2	1.5	5.0	-0.5
Monsoon	28.5	1.5	5.3	-0.3	28.7	0.5	1.6	-0.1	29.2	1.0	3.3	0.4	28.9	0.8	2.9	0.1
Post monsoon	22.1	1.4	6.1	-1.2	23.5	1.4	6.0	0.2	24.0	0.9	3.7	0.7	23.5	1.1	4.6	0.3
Winter	18.7	0.9	4.8	-1.5	20.2	1.3	6.5	0.0	21.5	1.5	7.0	1.3	20.4	1.8	9.0	0.2

Table 4. Decadal statistical analysis of monthly, seasonal and annual variation of minimum temperaturefor the period of 1984-2023

	1984-1993				1993-2003				2004-2013				2014-2023			
	Mean	SD	CV(%)	DEV	Mean	SD	CV(%)	DEV	Mean	SD	CV(%)	DEV	Mean	SD	CV(%)	DEV
January	2.2	1.5	35.3	-0.1	2.3	0.9	40.1	0.1	1.9	1.0	54.2	-0.3	2.6	0.4	15.6	0.3
February	4.1	2.0	24.3	-0.2	4.1	1.0	23.6	-0.2	4.1	1.9	45.3	-0.1	4.8	1.0	21.4	0.5
March	7.8	2.1	140.1	-0.3	8.1	1.0	12.0	0.0	8.5	0.9	10.5	0.4	8.1	0.9	11.6	0.0
April	12.5	1.9	112.4	0.2	11.9	1.2	10.2	-0.4	12.8	1.8	13.7	0.5	12.0	1.2	10.4	-0.3
May	16.3	2.0	121.6	0.4	16.2	1.1	7.0	0.3	16.0	0.6	3.8	0.1	15.1	1.1	7.1	-0.8
June	18.7	1.8	97.0	0.2	18.7	0.8	4.2	0.3	18.5	0.6	3.2	0.1	17.9	0.6	3.4	-0.5
July	19.5	1.7	87.4	-0.5	20.3	0.3	1.4	0.3	20.0	0.5	2.7	0.0	20.1	0.4	2.0	0.2
August	19.0	2.3	90.3	-0.5	19.8	0.4	2.1	0.2	19.5	0.5	2.6	-0.1	19.9	0.5	2.6	0.3
September	16.5	2.5	79.5	-0.3	16.7	1.1	6.4	-0.1	16.6	0.8	4.9	-0.2	17.4	1.0	5.6	0.6
October	10.4	2.3	95.6	-0.1	10.5	1.0	9.1	-0.1	10.3	1.2	11.2	-0.2	10.9	0.8	7.2	0.4
November	5.5	2.1	49.1	-0.3	6.0	0.7	11.8	0.2	5.4	0.7	13.7	-0.4	6.4	1.0	15.3	0.6
December	3.0	1.1	43.0	0.2	3.0	0.8	26.6	0.2	2.4	1.1	48.0	-0.4	2.8	1.0	34.1	0.0
Annual	11.3	1.3	91.1	-0.1	11.5	0.3	2.4	0.1	11.3	0.5	4.7	-0.1	11.5	0.4	3.4	0.1
Summer	14.4	1.7	117.8	0.3	14.0	1.0	7.4	0.0	14.4	0.9	6.6	0.3	13.6	1.1	8.3	-0.5
Monsoon	18.4	1.9	88.8	-0.3	18.9	0.4	1.9	0.2	18.6	0.4	2.3	-0.1	18.9	0.4	2.2	0.2
Post monsoon	6.3	1.6	71.5	-0.1	6.5	0.6	8.6	0.1	6.0	0.8	12.5	-0.4	6.7	0.6	8.3	0.3
Winter	4.7	1.2	76.5	-0.2	4.8	0.5	10.5	0.0	4.8	1.0	20.7	0.0	5.1	0.5	9.1	0.3

Table 5. Decadal statistical analysis of monthly, seasonal and annual variation of mean temperaturefor the period of 1984-2023

	1984-1993				1993-2003				2004-2013				2014-2023			
	Mean	SD	CV(%)	DEV	Mean	SD	CV(%)	DEV	Mean	SD	CV(%)	DEV	Mean	SD	CV(%)	DEV
January	9.1	1.6	17.5	-0.8	10.1	0.9	8.8	0.2	10.3	1.3	12.5	0.4	10.1	0.8	8.1	0.2
February	11.1	1.7	15.6	-0.8	11.6	1.4	11.9	-0.2	12.3	1.9	15.7	0.5	12.4	1.5	12.2	0.6
March	14.8	1.7	11.4	-1.0	15.8	1.1	7.0	-0.1	16.8	1.3	7.4	1.0	15.8	1.8	11.4	-0.0
April	19.8	1.6	8.0	-0.4	20.0	1.8	9.0	-0.2	20.9	1.6	7.8	0.7	20.0	1.6	7.9	-0.1
May	23.6	2.1	8.7	0.0	23.9	1.0	4.0	0.4	24.0	0.5	2.1	0.5	22.7	1.0	4.6	-0.9
June	24.6	1.7	6.9	-0.0	24.8	1.2	5.0	0.1	25.0	1.3	5.2	0.3	24.3	0.8	3.2	-0.4
July	23.8	1.7	7.1	-0.4	24.4	0.6	2.3	0.2	24.4	0.6	2.3	0.2	24.1	0.5	2.2	-0.1
August	23.4	1.8	7.5	-0.4	23.8	0.6	2.4	-0.0	23.9	0.6	2.3	0.1	24.2	0.5	2.0	0.4
September	22.0	1.9	8.5	-0.4	22.2	0.6	2.7	-0.1	22.4	0.8	3.4	0.0	22.9	0.9	3.8	0.5
October	18.1	1.7	9.4	-0.4	18.5	1.0	5.6	-0.0	18.6	0.8	4.1	0.0	18.9	0.9	4.8	0.4
November	13.8	1.3	9.5	-0.8	14.7	0.6	4.4	0.2	14.7	0.8	5.2	0.2	15.0	0.7	4.5	0.4
December	10.7	1.6	14.9	-0.7	11.7	0.8	6.9	0.3	11.7	1.1	9.6	0.3	11.5	1.1	9.2	0.1
Average	17.9	0.9	5.1	-0.5	18.5	0.6	3.0	0.1	18.8	0.6	3.2	0.4	18.5	0.4	2.4	0.1
Summer	21.7	1.5	6.7	-0.2	22.0	1.2	5.6	0.1	22.4	0.9	3.9	0.6	21.4	1.2	5.6	-0.5
Monsoon	23.5	1.6	7.0	-0.3	23.8	0.4	1.6	0.0	23.9	0.6	2.5	0.2	23.9	0.4	1.9	0.1
Post monsoon	14.2	1.2	8.1	-0.6	15.0	0.8	5.3	0.1	15.0	0.7	4.7	0.2	15.1	0.7	4.6	0.3
Winter	11.7	0.6	5.5	-0.9	12.5	0.8	6.4	-0.0	13.2	1.1	8.6	0.6	12.8	1.1	8.6	0.2

Table 6. Decadal statistical analysis of monthly, seasonal and annual variation of diurnal temperaturefor the period of 1984-2023

	1984-1993				1993-2003				2004-2013				2014-2023			
	Mean	SD	CV(%)	DEV	Mean	SD	CV(%)	DEV	Mean	SD	CV(%)	DEV	Mean	SD	CV(%)	DEV
January	13.9	1.6	11.7	-1.4	15.6	1.5	9.5	0.3	16.9	1.9	11.4	1.5	15.1	1.9	12.4	-0.3
February	14.0	2.2	15.9	-1.2	15.0	1.6	10.4	-0.1	16.4	2.4	14.8	1.2	15.3	2.0	13.2	0.2
March	14.1	2.3	16.3	-1.3	15.3	1.1	7.3	-0.1	16.8	1.1	6.3	1.4	15.4	1.9	12.4	0.0
April	14.7	1.5	10.1	-1.1	16.1	1.6	9.9	0.3	16.2	1.7	10.3	0.4	16.1	1.9	11.6	0.3
May	14.7	2.5	17.3	-0.7	15.5	0.9	5.8	0.2	16.0	0.7	4.6	0.7	15.1	0.6	4.2	-0.2
June	12.0	1.8	14.9	-0.5	12.2	1.3	10.7	-0.3	12.9	2.1	16.7	0.4	12.8	1.9	14.5	0.3
July	8.7	1.3	14.6	0.2	8.3	1.0	11.6	-0.2	9.0	1.1	12.5	0.5	8.0	1.2	14.7	-0.5
August	8.7	1.6	18.3	0.2	8.0	0.8	10.1	-0.5	8.7	0.9	10.0	0.3	8.5	1.0	12.1	0.1
September	11.0	1.6	14.9	-0.1	11.0	1.5	14.1	-0.2	11.7	0.9	7.9	0.5	10.9	1.3	12.0	-0.2
October	15.5	1.6	10.5	-0.5	16.1	1.6	10.1	0.1	16.5	1.5	9.0	0.5	15.9	1.2	7.7	-0.1
November	16.5	2.1	12.5	-0.9	17.4	1.5	8.4	-0.0	18.6	0.9	4.6	1.2	17.1	1.5	8.6	-0.3
December	15.4	2.5	15.9	-1.8	17.4	2.3	12.9	0.2	18.7	0.9	5.0	1.4	17.4	1.3	7.4	0.2
Average	13.3	1.1	8.4	-0.8	14.0	0.6	4.5	-0.0	14.9	0.4	2.9	0.8	14.0	0.7	5.0	-0.0
Summer	14.7	1.9	13.3	-0.9	15.8	0.8	5.3	0.3	16.1	1.0	6.4	0.6	15.6	1.0	6.6	0.1
Monsoon	10.1	1.0	9.5	-0.0	9.8	0.3	3.2	-0.3	10.6	0.9	8.3	0.4	10.1	1.0	9.9	-0.1
Post monsoon	15.8	1.8	11.3	-1.1	17.0	1.4	8.3	0.1	17.9	0.9	4.8	1.1	16.8	1.0	5.8	-0.1
Winter	14.0	1.7	12.2	-1.3	15.3	1.2	7.7	-0.0	16.7	1.2	7.0	1.4	15.3	1.5	9.9	-0.0

Mann–Kendall (MK) test and Sen's slope estimator trends of Maximum and minimum temperatures:

The Mann–Kendall test and Sen's slope estimator were applied to the time series data from 1984 to 2023 for the study area. The results of the MK test and Sen's slope estimator are presented in Table 7. The trend analysis has been done for all the months of the year, climatic seasons (winter, summer, monsoon, and post-monsoon), and the whole year. The results of trend analysis showed a statistically significant increase in maximum and mean temperature in most months, particularly inFebruary (Z=2.7** and 2.3*) **a**ndNovember (Z=3.1** and 2.5*) While the minimum temperature trends were increasing non-significantly. According to the results May month showed a significantly decreasing trend in all temperature parameters (T_{max}, T_{min}, T_{mean}). Overall, the annual trends showed a significant increase in maximum (Z=2.5*) and diurnal (Z=2.2*) temperature. On a seasonal basis, winter and post-monsoon season are increasing significantly at 5% and 1% level of significance, and the monsoon season remains relatively stable. Themean temperaturealso showed significant increasing trends during the post-monsoonand winter (Z=2.8**) seasons, indicating a long-term warming in the mid hills of Himachal Pradesh. The Diurnal Temperature Range showed a significant increasing trend in winter (Z=2.5*) at 5% level of significance, indicating that day temperatures are rising faster than night temperatures, which may have important implications for agriculture and crop stress.

Table 7: Monthly, seasonal and annual trend analysis of maximum, minimum, mean and diurnal temperature from 1983-2023

	T_{max}			T_{min}			T_{meam}			$T_{Diurnal}$		
Time series	Z- statistics	Q-statistics	Trends	Z- tatistics	Q- tatistics	Trends	Z- tatistics	Q- tatistics	Trends	Z- tatistics	Q-tatistics	Trends
January	2.1*	0.07	↑	0.97	0.02	↑	2.0*	0.040	↑	1.7+	0.056	↑
February	2.7**	0.09	↑	1.41	0.03	↑	2.3*	0.055	↑	2.3*	0.067	↑
March	1.6	0.06	↑	0.52	0.01	↑	1.13	0.026	↑	2.2*	0.065	↑
April	1.4	0.03	↑	-0.06	-0.001	↓	0.83	0.018	↑	1.9+	0.047	↑
May	-1.7+	-0.04	↓	-1.40	-0.03	↓	-2.2*	-0.033	↓	0.01	0.000	↑
June	-0.2	-0.01	↓	-1.33	-0.018	↓	-0.66	-0.010	↓	1.3	0.034	↑
July	0.1	0.00	↑	0.87	0.006	↑	0.00	0.000	↑	-0.90	-0.013	↓
August	2.2*	0.03	↑	1.57	0.017	↑	2.6**	0.024	↑	0.71	0.012	↑
September	2.2*	0.03	↑	1.06	0.025	↑	2.1*	0.037	↑	0.27	0.008	↑
October	1.5	0.02	↑	1.43	0.029	↑	2.1*	0.027	↑	0.59	0.015	↑
November	3.1**	0.06	↑	1.04	0.018	↑	2.5*	0.035	↑	1.06	0.021	↑
December	1.6	0.05	↑	-1.03	-0.015	↓	1.4	0.028	↑	1.83+	0.059	↑
Annual	2.5*	0.04	↑	0.55	0.004	↑	1.95+	0.020	↑	2.2*	0.031	↑
Summer	-0.1	0.00	↓	-0.80	-0.012	↓	-0.22	-0.008	↓	1.20	0.020	↑
Monsoon	0.9	0.01	↑	0.87	0.007	↑	0.99	0.009	↑	0.69	0.007	↑
Post monsoon	2.5*	0.05	↑	0.24	0.003	↑	2.1*	0.026	↑	1.48	0.030	↑
Winter	3.1**	0.07	↑	1.39	0.015	↑	2.8**	0.041	↑	2.5*	0.062	↑

*(*Significant at 5% level of significance, ** at 1% level of significance, ↑=Increasing trend and↓=Decreasing trend)*

The tomato plant's life cycle can be divided into four stages: vegetative, first flowering cluster and first fruit-set, fruit filling and last ripening and harvest. The vegetative and flowering stages require relatively warm temperatures to promote vigorous growth, proper leaf development and successful flower initiation. The fruit filling stage begins when soil temperatures reach 18–21°C, which is also the optimal range for transplanting seedlings. During this stage, moderate and stable temperatures are essential for proper fruit enlargement and quality. The final ripening and harvest stage benefits from mild temperature conditions, which enhance the synthesis of pigments and sugars, especially in capsicum, which transitions through green, yellow, orange, and red stages. Each color stage corresponds to specific flavor profiles and culinary uses, and temperature directly influences the rate of ripening and pigment development. The regression models were developed between maximum, minimum, mean and diurnal temperature and yield (MT/ha) of selected crops. The graph depicts that all temperatures parameters had a negative impact on capsicum and tomato yield (Figure 4 & 5). The coefficients of deterministic explained the negative relationship between all the temperature parameters and selected crop yield. The variability of capsicum crop was explained by 17%, 9%, 18% & 6% whereas 20%, 8%, 20% and 10% in tomato crop. The results of regression model indicated that the heatstressduring critical growth periodsmay reduce productivity, and temperature management strategies may be needed under warming climate scenarios.

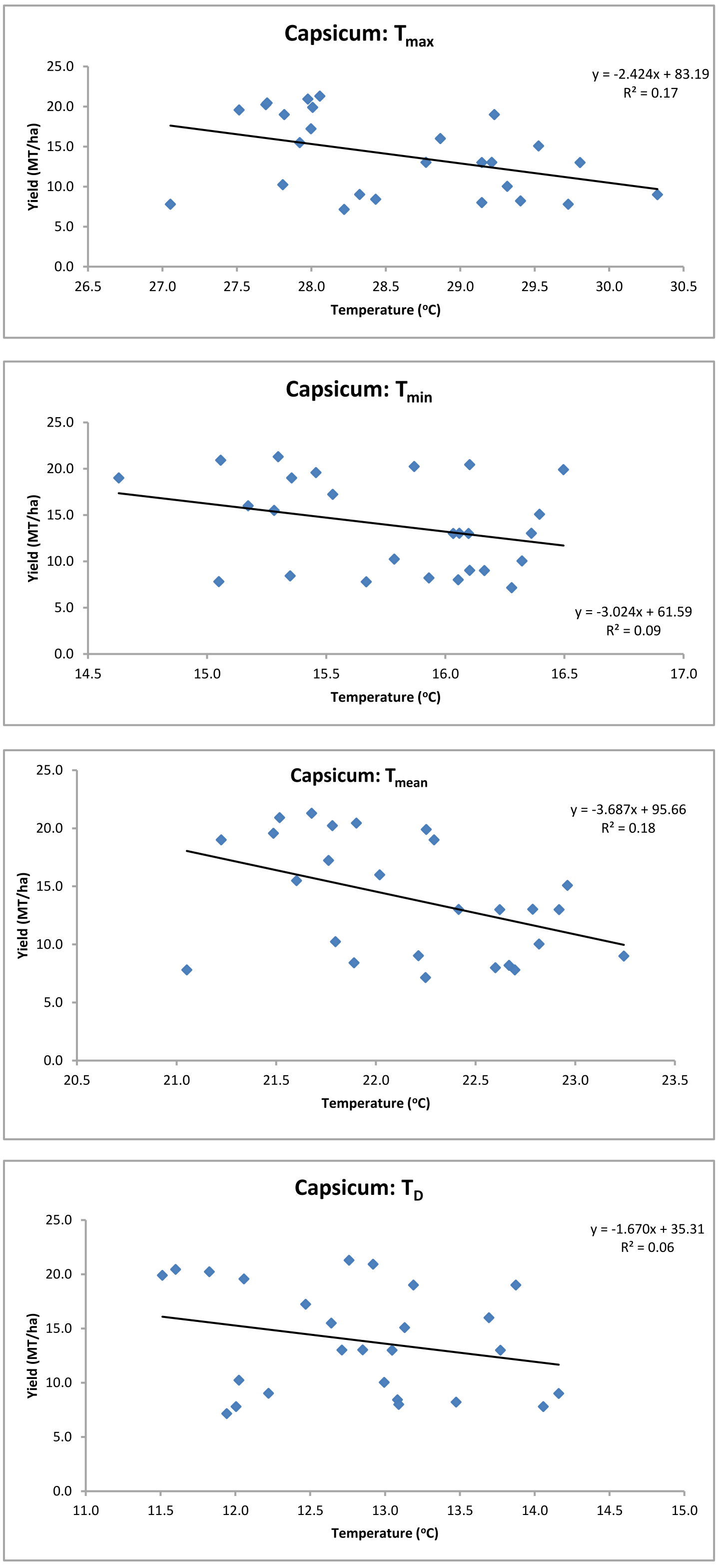

Fig 4. Relationship between temperature parameters and yield of capsicum crop

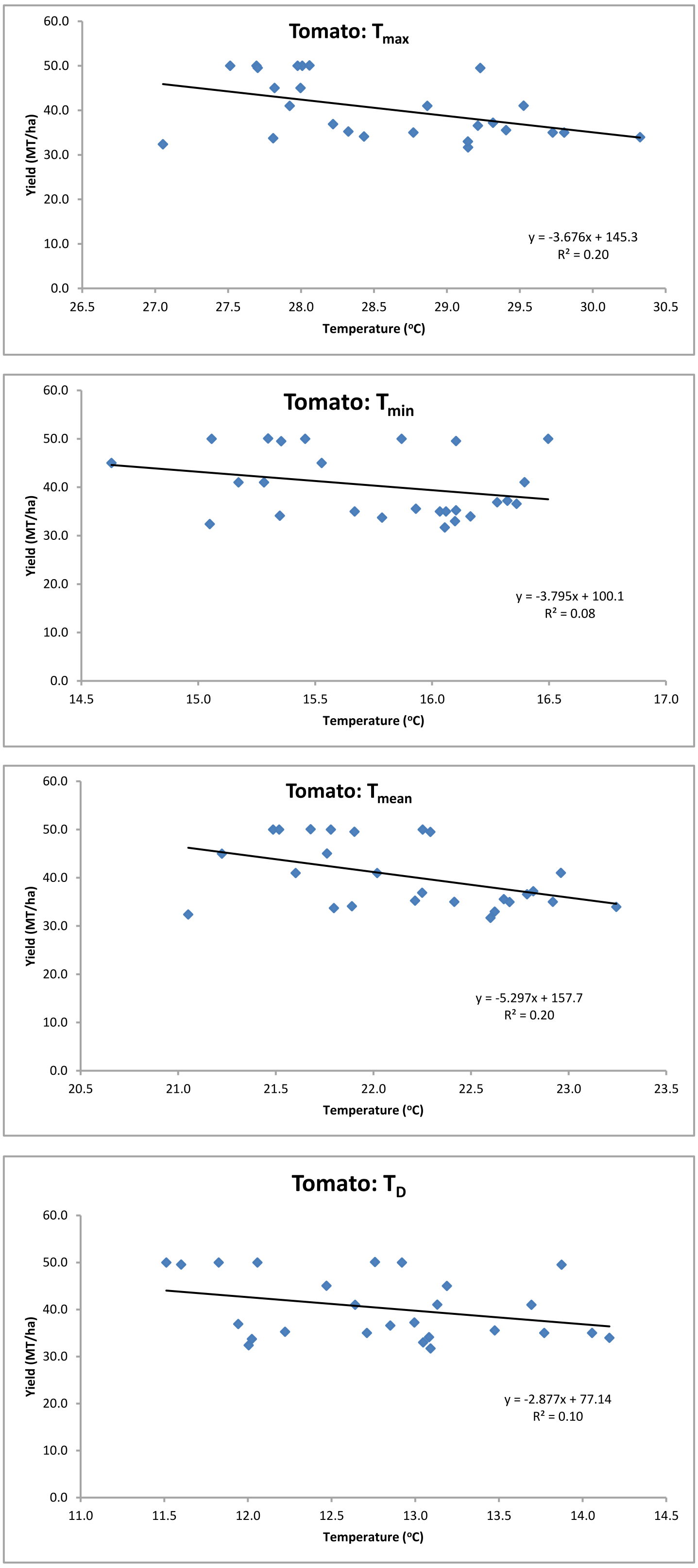

Fig 5. Relationship between temperature parameters and yield of tomato crop

Conclusion

This comprehensive study on temperature patterns in the mid hills of Himachal Pradesh over the past four decades (1984-2023) reveals significant climatic changes with reflective implications for agricultural productivity. The trend analysis indicates a significant increase in maximum, mean, and diurnal temperatures, especially during winter and post-monsoonseasons, while May and early summer months show declining temperature trends indicating seasonal variability in warming patterns. This shows that the yield and temperature are inversely correlated. For maximum yield of capsicum and tomato maximum temperature ranged from 25-30°C, the minimum ranged from 15-20°C and the mean temperature ranged from 20-25°C. These findings underscore the complex relationship between climatic factors and agricultural productivity, emphasizing the need for adaptive agricultural practices and climate-resilient strategies to sustain and enhance crop yields amidst ongoing climatic changes. The study provides critical insights for policymakers and agricultural stakeholders in planning and implementing effective climate adaptation and mitigation strategies to address the challenges posed by rising temperatures and their impact on crop-production.

Acknowledgements: The authors are also grateful to the Department of Environmental Science, UHF, Nauni and The Agromet Observer who have made contributions over the years to record and collect the temperature data presented in this research paper.

Author contribution: Idea generation, data analysis, data processing and writing

Future Scope of the Study

Future studies can focus on longer-term temperature datasets and include other climatic parameters such as precipitation and humidity to provide a more integrated understanding of climate change. Additionally, incorporating advanced climate models can help predict future temperature trends at local and regional scales, aiding policymakers and environmental planners.

Conflict of Interest Statement

Conflict of Interest

"The authors declare no conflict of interest."

References

1. Arora, M., Goel, N. K., and Singh, P. (2005). Evaluation of temperature trends over India. *Hydrological Sciences*, 50, 81–93. https://doi.org/10.1623/hysj.50.1.81.56330.

2. Auffhammer, M., Ramanathan, V., and Vincent, J. R. (2006). Integrated model shows that atmospheric brown clouds and greenhouse gases have reduced rice harvests in India. *Proceedings of the National Academy of Sciences*, 103(52), 19668–1972. https://doi.org/10.1073/pnas.0609584104.

3. Cleland, E. E., Chuine, I., Menzel, A., Mooney, H. A., and Schwartz, M. D. (2007). Shifting plant phenology in response to global change. *Trends in Ecology and Evolution*, 22(7), 357–365. https://doi.org/10.1016/j.tree.2007.04.003.

4. Ganeshi, N. G., Mujumdar, M., Takaya, Y., Goswami, M. M., Singh, B. B., Krishnan, R., and Terao, T. (2023). Soil moisture revamps the temperature extremes in a warming climate over India. *npj Climate and Atmospheric Science*, 6, 12. https://doi.org/10.1038/s41612-023-00334-1.

5. Hatfield, J. L., and Prueger, J. H. (2015). Temperature extremes: Effect on plant growth and development. *Weather and Climate Extremes*, 10, 4–10. https://doi.org/10.1016/j.wace.2015.08.001.

6. IPCC. (2021). Summary for policymakers. In: *Climate Change 2021: The Physical Science Basis.* Contribution of Working Group I to the Sixth Assessment Report of the Intergovernmental Panel on Climate Change. Cambridge University Press, United Kingdom and New York, 3–32. https://doi.org/10.1017/9781009157896.001.

7. Jagadish, S. V. K., Craufurd, P. Q., and Wheeler, T. R. (2007). High temperature stress and spikelet fertility in rice (*Oryza sativa* L.). *Journal of Experimental Botany*, 58(7), 1627–1635. https://doi.org/10.1093/jxb/erm003.

8. Kaur, H., and Kaur, P. (2015). Temperature features in different agroclimatic zones of Punjab. *Agricultural Research Journal*, 52(4), 32–35. https://doi.org/10.5958/2395-146X.2015.00057.5.

9. Kaur, N., and Kaur, P. (2019). Maize yield projections under different climate change scenarios in different districts of Punjab. *Journal of Agrometeorology*, 21(2), 154–158. https://doi.org/10.54386/jam.v21i2.225.

10. Kendall, M. G. (1975). *Rank Correlation Methods* (4th ed.). Charles Griffin, London. Sen, P. K. (1968). Estimates of the regression coefficient based on Kendall's Tau. *Journal of the American Statistical Association*, 63, 1397–1412.

11. Li, X., Stringer, L. C., and Dallimer, M. (2022). The impacts of urbanisation and climate change on the urban thermal environment in Africa. *Climate*, 10, 164. https://doi.org/10.3390/cli10110164.

12. Li, Y., Brando, P. M., Morton, D. C., Lawrence, D. M., Yang, H., and Randerson, J. T. (2022). Deforestation-induced climate change reduces carbon storage in remaining tropical forests. *Nature Communications*, 13, 1964. https://doi.org/10.1038/s41467-022-29601-0.

13. Lobell, D. B., and Field, C. B. (2007). Global scale climate–crop yield relationships and the impacts of recent warming. *Environmental Research Letters*, 2, 014002. https://doi.org/10.1088/1748-9326/2/1/014002.

14. Mazdiyasni, O., AghaKouchak, O., Davis, S. J., Madadgar, S., Mehran, A., Ragno, E., Sadegh, M., Sengupta, A., Ghosh, S., Dhanya, C. T., and Niknejad, M. (2017). Increasing probability of mortality during Indian heat waves. *Science Advances*, 3, e1700066. https://doi.org/10.1126/sciadv.1700066.

15. Muluneh, M. G. (2021). Impact of climate change on biodiversity and food security: A global perspective—A review article. *Agriculture & Food Security*, 10, 36. https://doi.org/10.1186/s40066-021-00318-5.

16. Prasad, R., Patial, J., and Sharma, A. (2017). Trends in temperature and rainfall extremes during recent years at different stations of Himachal Pradesh. *Journal of Agrometeorology*, 19(1), 51–55. https://doi.org/10.54386/jam.v19i1.755

17. SCCAP. (2012). *State Strategy and Action Plan on Climate Change.* Department of Environment Science and Technology, Government of Himachal Pradesh, Shimla.

18. Vujovic, S., Haddad, B., Karaky, H., Sebaibi, N., and Boutouil, M. (2021). Urban heat island: Causes, consequences, and mitigation measures with emphasis on reflective and permeable pavements. *CivilEng*, 2(2), 459–484. https://doi.org/10.3390/civileng2020026.