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Climatic variability and its impact on maize and wheat yield in Himachal Pradesh

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सार– वर्तमान अध्ययन में वार्षिक और ऋतुनिष्ठ (खरीफ और रबी ऋतु) जलवायु परिवर्ती में परिवर्तिता, जैसे 1985 से 2021 तक वर्षा और तापमान का विश्लेषण किया गया और हिमाचल प्रदेश के विभिन्न सात स्थानों पर मक्का और गेहूं की फसलों की उत्पादकता पर इसका प्रभाव देखा गया। अध्ययन में पाया गया कि ख़रीफ़ ऋतु में अधिकतम तापमान को छोड़कर, व्यावहारिक रूप से सभी सात स्थानों पर अध्ययन की अवधि के दौरान वार्षिक और ऋतुनिष्ठ रूप से अधिकतम और न्यूनतम तापमान में उल्लेखनीय वृद्धि हुई। कांगड़ा जिले के न्यूनतम तापमान में सबसे अधिक सकारात्मक विचलन रबी ऋतु में यानी 2.12 डिग्री सेल्सियस पाया गया, जबकि सबसे कम सकारात्मक विचलन खरीफ ऋतु में यानी 0.50 डिग्री सेल्सियस पाया गया। पेटिट के एकरूपता परीक्षण से पता चला है कि 1998 के बाद वार्षिक न्यूनतम तापमान में उल्लेखनीय वृद्धि हुई है। जलवायु परिवर्तन वर्ष में वर्षा में सकारात्मक बदलाव दर्शा रहा है जो 1998 के बाद सभी स्थानों पर बढ़ती प्रवृत्ति दिखा रहा है। अधिकतम तापमान में वृद्धि से खरीफऋतुमें मक्के की फसल की पैदावार पर प्रतिकूल प्रभाव पड़ा और रबीऋतुमें गेहूं की पैदावार पर सकारात्मक प्रभाव पड़ा, जबकि वर्षा का मक्के और गेहूं की फसल की पैदावार पर सकारात्मक प्रभाव पड़ा।

ABSTRACT. The present study has analyzed variability in climate variables annually and seasonally (*kharif* and *rabi* season), *viz*. rainfall and temperature from1985 to 2021 and found its their impact on productivity of maize and wheat crops at different seven locations of Himachal Pradesh. The study found that, except for the maximum temperature in the *kharif* season, practically all of the seven sites had significant increases in maximum and minimum temperatures annually and seasonally over the study period. Highest positive deviation was found in minimum temperature of Kangra district *rabi* season *i.e*., 2.12 ºC while lowest was found in *kharif* season *i.e*., 0.50 ºC. Pettit's homogeneity test showed annual minimum temperature was significantly rise after 1998. Climate change year showing positive change in rainfall that is showing increasing trend after 1998 at all the locations. Increase in maximum temperature had adverse impact on maize crop yield in the *kharif* season and a positive impact on wheat yield in the *rabi* season, whereas rainfall had a positive impact on maize and wheat crop yield.

Key words– Mann-Kendall trends, Climatic variability, Pettit's homogeneity test and Crop yield model.

1. Introduction

Himachal Pradesh, which translates as "land of the Snowy Mountains", is a state in India's Himalayas. Hilly terrain, perennial rivers and substantial forest cover characterise the state. The Satluj, Ravi, Beas, Chenab and Yamuna are just a few of the rivers that originate or travel through Himachal. Aside from these, Himachal Pradesh's major river systems are supplemented by other smaller ones, such as Baspa, Parvati and Spiti. In the *Kharif* and *Rabi* seasons, these rivers are supplied by snow and rain, which provide irrigation. As a result of climate change, water resources are more likely to experience increased frequency and intensity of intense rainfall, as well as an increase in rainfall variability, an increase in the possibility of water shortages and droughts and a decrease in precipitation amounts as snow. Local rivers have increased their flow, lowering the average mean temperature in the lower and middle hills due to climate change. Agriculture's yields are impacted because of these changes. As a result, agricultural work requires a grasp of meteorological conditions because it is very susceptible to global climate change and hence must be reviewed. Increasing temperatures and decreasing rainfall are

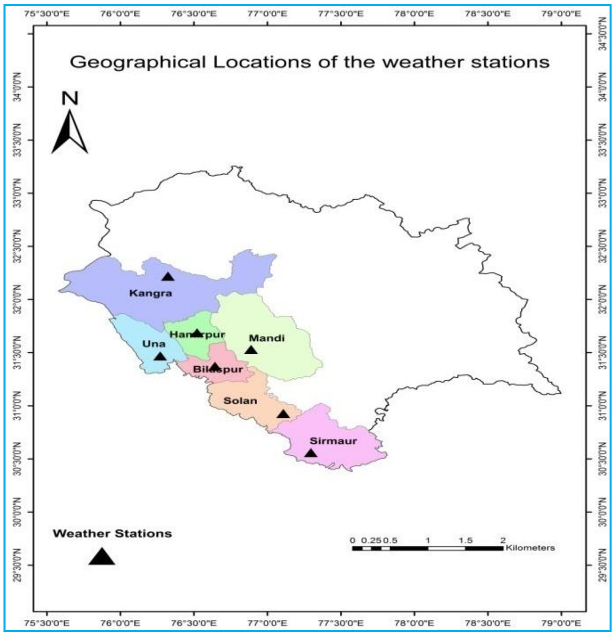


Fig. 1. Geographic Locations of the seven weather stations considered for the study

predicted in various research to lower agricultural production indirectly. Low and mid hills of Himachal have fertile land for agricultural crops in the north-western Himalayan region of India. Himachal Pradesh has various evidence of climate change. Lower yields can be caused by rising temperatures, more variable precipitation, less uniform distribution of rain and higher relative humidity. This combination has major consequences on crop production. There has been a decrease in the amount of wheat that can be harvested per hectare from 4.7 tonnes ha^{-1} in 1999-00 to 4.1 tonnes in 2005-06. (Sidhu *et al*. 2011; Kaur *et al.* 2022; Singh *et al*. 2023 & Kumar and Sidana, 2017). Maize and wheat productivity in Himachal Pradesh is heavily dependent on climate variability, hence this study examines the impact of climate change on maize and wheat productivity.

2. Data and methodology

Based on climate homogeneity, seven stations located at Dharamshala, Sundernagar, Nauni, Jhanduta, Hamirpur, Nahan and Una were selected as representatives for the seven districts in the low and mid hill zones of Himachal Pradesh, *viz*., Kangra, Mandi, Solan, Bilaspur, Hamirpur, Sirmaur and Una, respectively (Fig. 1).

Monthly minimum temperature, maximum temperature and rainfall data from 1985 to 2021 were obtained from the Regional Data Centre, IMD, Shimla.Climate change studies required more than 30 years data for analysis otherwise it concludes only the weather change of the selected region. Therefore, the study period was selected from 1985 to 2021. This study was submitted in the year 2021. The monthly weather data received have been consolidated for four climatic seasons, including winter (January-February), pre-monsoon (March-May), monsoon (June-September) and post-monsoon (October-December) and annual for study.

3. Magnitude and significance of temperature trend

The Mann-Kendall Rank Correlation Test was used to determine the magnitude of maximum, minimum and rainfall trends (Mann, 1945; Kendall, 1975; Burn and Hag Elnur, 2002; Arora *et al*., 2005; Singh *et al*., 2008; Obot *et al*., 2010; Subash *et al*., 2011; Tabari and Talaee, 2011; Pal and Al-Tabbaa, 2011; Jain *et al*., 2012; Safari, 2012; Singh, 2021 and Chakma and Biswas 2022). Standard deviation due to mean was used to calculate the deviation of climatic parameters. The Pettitt Homogeneity Test can detect rapid changes in climatological trend (Tomozeiu *et al*., 2000; Smadi and Zghoul, 2006; Zhang *et al*., 2009 and Kumaravaradan, 2014). After evaluating the temperature change, the rainfall was divided into two groups: before and after temperature change year. The smallest observation (sample minimum), lower quartile, median, upper quartile, and largest observation (sample maximum) presented by using Box plot technique. The space between the box's components indicates dispersion (spread) and skewness in the data. This tool compared seasonal and annually rainfall quantity and dispersion before and after climate change (Hartell and Skees, 2009).

Using panel data, empirical link between crop yields and meteorological variables established by Deschenes & Greenstone, 2007. This model captures the influence of time-invariant factors (such as soil quality and elevation) as well as farmers' autonomous changes (like planting dates or varieties, input utilisation, *etc*.). Panel data spatial fixed effects absorb location specific time variation crop yield drivers connected with meteorological factors. Our panel included districts data on maize and wheat yields, rainfall, maximum temperature and minimum temperature for seven districts in Himachal Pradesh's low and mid hills. Maize and wheat cereal crops were studied empirically. Data of area and production of each croprecorded from Shimla's economic and statistical department. Temperatures were translated into average crop-growing period temperatures, and daily rainfall was averaged to reflect cumulative crop-growing period rainfall.

Random effect panel model for climate impactsis specified as:

$$\log y_{it} = D_i + T_t + \beta X_{it} + \varepsilon_{it}$$

TABLE 1

Seasonal and annual of Temperature (minimum and maximum) and rainfall variability from 1985 to 2021 in low and mid hills of Himachal Pradesh

Seasons	Districts	Minimum Temperature (°C)			Maximum Temperature (°C)			Rainfall (mm)		
		Average(°C)	D	τ	Average (°C)	D	τ	Average (mm)	D	τ
Kharif	Bilaspur	27.53	0.55	-0.036	32.75	0.99	0.087	767.87	369.40	0.333***
	Hamirpur	29.57	0.62	-0.027	34.11	1.12	-0.399***	727.42	265.90	0.129
	Kangra	26.78	0.50	0.228**	31.45	0.91	-0.429***	1445.89	1053.24	0.495***
	Mandi	31.11	0.59	-0.003	35.68	0.77	-0.308***	798.87	243.04	0.323***
	Sirmaur	19.72	0.68	-0.114	24.61	1.22	0.162	966.77	459.12	0.407***
	Solan	27.89	0.66	0.054	32.17	1.21	-0.348***	642.79	177.59	0.038
	Una	27.27	0.61	0.015	32.42	1.17	-0.015	702.39	248.67	0.317***
Rabi	Bilaspur	16.13	0.75	-0.033	24.37	1.21	0.453***	163.83	108.35	0.267**
	Hamirpur	18.42	0.66	0.276***	25.16	0.83	0.228**	182.19	109.11	0.222**
	Kangra	16.17	2.12	0.628***	21.58	0.98	0.003	267.14	189.96	0.372***
	Mandi	20.23	0.69	0.021	26.76	0.99	0.105	191.31	102.44	0.216*
	Sirmaur	9.46	0.63	0.348***	16.24	1.10	0.387***	155.98	112.55	0.039
	Solan	16.98	0.67	0.249**	23.52	1.04	0.051	163.16	114.81	0.186*
	Una	15.79	0.69	0.231**	22.99	1.09	0.462***	150.81	94.08	0.150
Annual	Bilaspur	21.64	0.49	0.183*	27.95	0.54	0.108	1301.34	467.21	0.059
	Hamirpur	23.78	0.78	0.477***	30.03	0.64	0.240**	1048.64	315.04	0.375***
	Kangra	20.59	0.50	0.441***	26.73	0.53	0.069	1492.98	808.35	0.637***
	Mandi	25.55	0.45	0.363***	31.60	0.50	0.252**	1126.66	332.11	0.477***
	Sirmaur	14.51	0.40	0.330***	20.29	0.54	0.030	1129.18	409.16	0.523***
	Solan	22.36	0.93	0.486**	28.29	0.54	0.054	919.19	273.74	0.390***
	Una	21.33	0.48	0.462***	27.58	0.52	0.263**	993.09	333.14	0.498***

Note : D = deviations and τ = Mann-Kendall Rank Correlation Test and ***, ** and * significant at 1, 5 and 10 percent levels respectively

where,

subscripts i and t in Equation denote districtand time, respectively.

y = yield of the crop

D = District random effects

T = Time fixed effects directing the change in yield of the crop

X = Climate variables vector

β = Parameter on Climate variables

ε = Stochastic error-term.

Climatic variables (maximum & minimum temperature and precipitation) affect agricultural yield in non-linear ways presented by Schlenker and Roberts, 2006; Guiteras, 2007; Jacoby *et al*., 2011. Equation includes average minimum and maximum temperatures, as well as rainfall, to allow for non-linear influences. This functional form's coefficients can be interpreted as proportional changes.

4. Results and discussion

4.1. *Climatic variability during kharif season*

The maximum temperature was recorded highest in Mandi district of Himachal Pradesh in 1988 (38.2 °C), while the maximum temperature was recorded lowest in Sirmaur district of Himachal Pradesh in 2008 (21.6 °C) during the study period. The minimum temperature throughout the *kharif* season ranged from 19.72 °C to 31.11 °C, with an average of 27.12 °C (Table 1). The maximum temperature in Himachal Pradesh's low and mid hills ranged from 0.77 °C to 1.22 °C above average during the *kharif* season. During the *kharif* season (June to September), Sirmaur district had the highest deviation from normal in maximum temperature (1.22 °C), while Kangra district had the lowest variance (0.50 °C) (Table 1). The highest average rainfall was reported in Kangra district (1445.89 mm), followed by Sirmaur (966.77 mm), Mandi (798.87 mm), Bilaspur (727.42 mm), Una (702.39 mm) and Solan (702.39 mm) (642.79 mm). In the last 37 years, the highest increase in rainfall during the *kharif* season was discovered in Kangra district (1053.24 mm) while the lowest increase was recorded in Solan district (177.59 mm).

4.2. *Climatic variability during Rabi season*

The average maximum temperature in *rabi* season (November to March) was recorded at different locations in ascending order, *i.e*., Sirmaur (16.24 °C), Kangra (21.58 °C), Una (22.99 °C), Solan (23.52 °C), Bilaspur (24.37 °C), Hamirpur (25.16 °C) and Mandi (26.76 °C). At all the selected areas in Himachal Pradesh's low and mid hills, the minimum temperature was found to be lowest in Sirmaur district (9.46 °C) and highest in Mandi district (20.23 °C), with an average value of 16.1 °C (Table 1). During the *rabi* season, the difference in lowest temperature from the normal ranged from 0.63 °C to 2.12 °C in different parts of Himachal Pradesh. Rainfall in Himachal Pradesh's low and mid hills ranged from 150.81 mm to 267.14 mm on average, with an average of 182.06 mm. In general, rainfall in Himachal Pradesh during the winter season varied from 94.08 to 189.96 mm at various areas.

4.3. *Annual Variability*

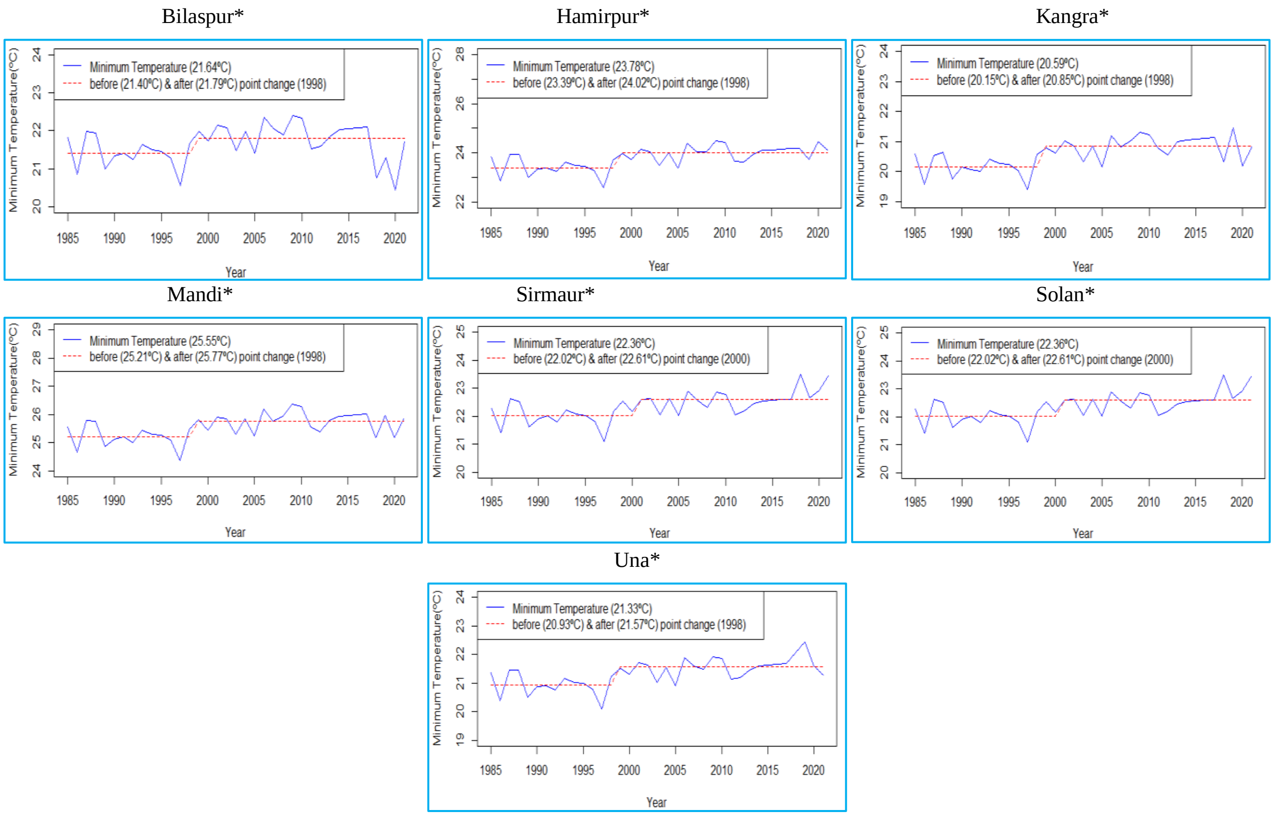
From 1985 to 2021, the annual maximum and minimum temperatures ranged between 20.29 °C to 31.6 °C and 14.51 °C to 25.55 °C with average values of 27.49 °C and 21.39 °C, respectively. Annual rainfall was more at Kangra (1492.98 mm) followed by Bilaspur (1301.34 mm), Sirmaur (1129.18 mm), Mandi (1126.66 mm), Hamirpur (1048.64 mm), Una (993.09 mm) and Solan (919.19 mm) in succession. Overall, rainfall annually had increased by 273.74, 315.04, 332.11, 333.14, 409.16, 467.21 and 808.35 mm from normal at Solan, Hamirpur, Mandi, Una, Sirmaur, Bilaspur and Kangra districts, respectively (Table 1).

4.4. *Mann Kendall trend analysis*

In the *kharif* season, Mann-Kendall test revealed that significantly increase in the minimum temperature of Kangra district while in the other districts were showed non-significantly decreasing trend. However, minimum temperature of *rabi* season was showed significantly increasing trend in all the districts except district Bilaspur. Annually minimum temperature was showed highly significant increasing trend. Maximum temperature was significantly increasing trend in the *rabi* season of Bilaspur, Hamirpur, Sirmaur and Una districts. The results of were in correspondence with the study conducted by Pathania and Guleria (2011) wherein it was observed that the increasing trends of minimum temperatures in various regions of the Himachal Pradesh state and the study further suggested that there is a dire need to change the cropping pattern as well as to improve technological interventions for a changing climate pattern. From the months of June to September, average maximum temperature was significantly decreasing trend in the Hamirpur, Kangra, Mandi and Solan districts. But annually average maximum temperature was showed significant increasing trend in the districts of Hamirpur, Mandi and Una. Rana and Randhawa (2013) also suggested similar findings and revealed that a maximum temperature significantly rise in the pre-monsoon season has been observed in all districts except the Bilaspur district of Himachal Pradesh. Kapoor and Shaban (2014) also observed similar results in Kullu district and reported that overall increase in the annual average maximum temperature. Rainfall was showed significantly increasing trend annually and seasonally (*Kharif* and *Rabi* seasons) in all the districts of low and mid Hills of Himachal Pradesh except Hamirpur and Solan district in *Kharif* season, Sirmaur and Una in *rabi* season and annually Bilaspur district showed also increasing trend but non-significantly. The results of were in correspondence with the study conducted by Rana and Randhawa (2013) and Pathaniaand Guleria (2011) observed that rainfall trends found to be increased in districts of Hamirpur, Kangra, Una and Solan. Annually significantly increasing trend in maximum temperature, minimum temperature and rainfall as designated by Mann-Kendall statistics, therefore a need to find out the point change year in the minimum and maximum temperature in Himachal Pradesh for different location. It helps us to know the climate change year form which year temperature was starting rising significantly and impact of temperature change on rainfall.

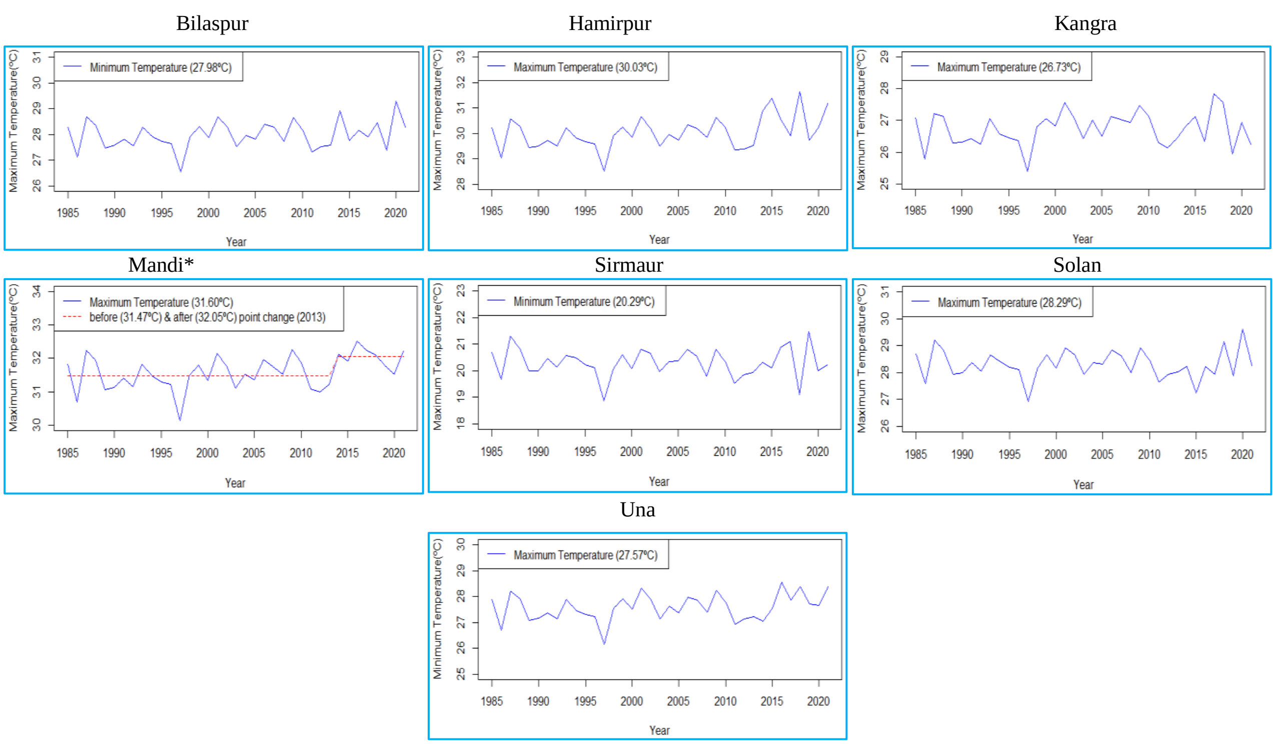
4.5. *Temperature point change year (Pettit's Homogeneity Test)*

From the previous section, study revealed that annually minimum temperature was increasing significantly and similarly results were recorded by the Pettit's homogeneity test. In the mean minimum temperature, significant climate change year was found 1998 in all the districts except solan district in which significantly climate change year was 2000 (Fig. 2). From 1985 to 2021, the minimum temperature was increased by 0.39 °C, 0.63 °C, 0.70 °C, 0.56 °C, 0.48 °C, 0.59 °C and



Note: *denote significantchange year in temperature at 5percent level of significance

Fig. 2. Point change year in the mean minimum temperature of all the districts of Himachal Pradesh since 1985-2021



Note : *denote significantchange year in temperature at 5percent level of significance

Fig. 3. Point changeyear in themean maximum temperature ofall the districts of Himachal Pradesh since 1985-2021

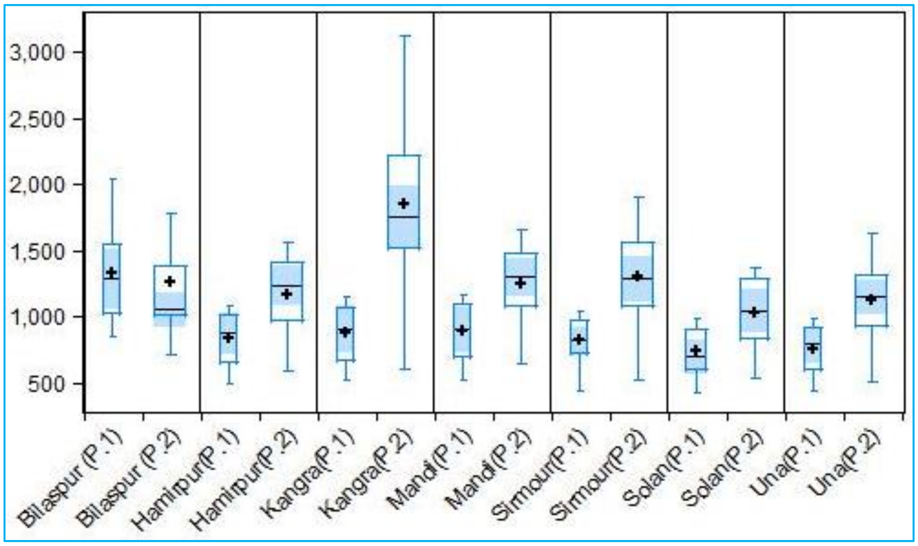


Fig. 4. Variability in the extent and dispersal of rainfall in different district fromperiod-1 to period-II

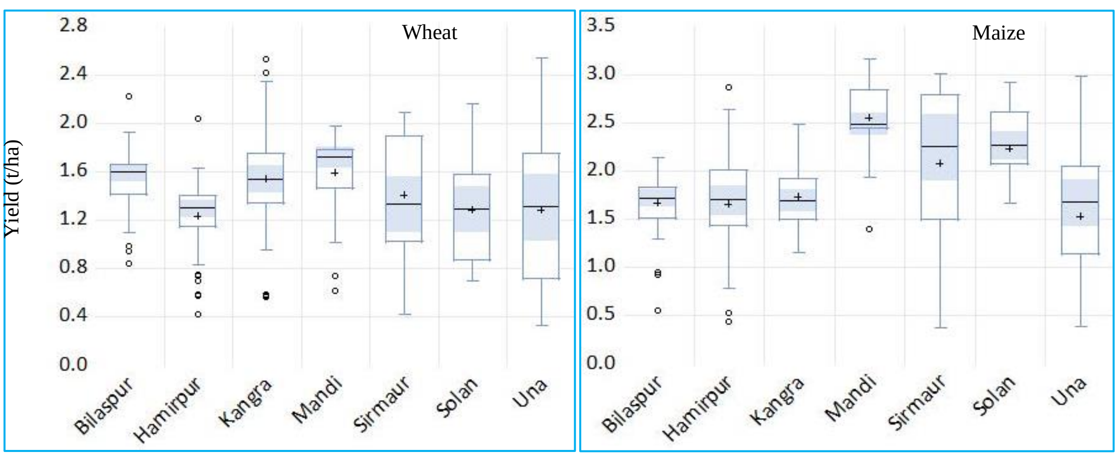


Fig. 5. Variability in the extent and dispersal of Wheat and Maize yield (t/ha) in different district, 1985-2020

0.64 °C in Bilaspur, Hamirpur, Kangra, Mandi, Sirmaur, Solan and Una district, respectively. Jaya (2014) also studied point change year in Tamil Nadu and revealed that the climate change has occurred in 1987 in the Western Zone, in 1988 in Cauvery Delta Zone, in 1994 in North-Eastern Zone and in 1995 in Southern Zone. However, maximum temperature was change significantly by 0.58 °C in the year of 2013 and all the districts does not show significant change in temperature in particular year (Fig. 3). Because of the significant trend and consistent shift as shown by the minimum temperature, 1998 was designated as the year of climate change, and its impact on rainfall patterns was investigated by dividing it into two periods: 1985-1998 and 1999-2021, which were divided into period-1 (P.1) and period-2 (P.2) climate change periods for almost districts except for Mandi district.

4.6. *Variability in rainfall after Temperature change*

Fig. 4 depicts the variability in the extent and dispersal of rainfall in several districts from period-1 to period-II. The results depicted that the average rainfall, dispersion in rainfall and variation in rainfall was showed increase in quantity from period-1 to period-2 in all the districts except Bilaspur. Jaya (2014) also reported similar results in the south-west monsoon in the Stateas the August rainfall has increased with more dispersion in

TABLE 2

Unit root test of panel data by using Levin-Lin-Chu test

Model	Yield	Minimum Temperature	Maximum Temperature	Rainfall
Maize Yield Model	At Level*	At Level*	At Level*	At Level*
Wheat Yield Model	At Level*	First Difference*	At Level*	First Difference*

Note: * denote significance level at 5 percent level

TABLE 3

Results of Hausman Test for selection of Fixed and Random Effect Panel Data Model

Model	Hypothesis	Hausman	Test Statistics	*P*-value	Hypothesis
Maize Yield Model	H_0= Fixed Effect Model H_1= Random Effect Model	χ^2	1.23	0.743	H_0 was selected
Wheat Yield Model	H_0= Fixed Effect Model H_1= Random Effect Model	χ^2	0.60	0.897	$H_0$was selected

Western, North-Western, Cauvery Deltaand Southern Zones. The average rainfall was almost similar in both the periods of district Bilaspur but dispersion and variation were decreased from period-1 to period-2. Highest change in rainfall were recorded in Kangra district followed by Sirmaur, Mandi, Solan, Una and Hamirpur.

Mann-Kendall figures show an increased trend in maximum temperature, minimum temperature, rainfall and significant point change in mean minimum & maximum temperature presented by Pettit’s homogeneity test, change in magnitude and dispersion of rainfall between both the period was shown with the help of Box-whisker plot undergone significant changes from 1985 to 2021 posing threats to yield of major cereal crops grown in the Himachal Pradesh state.

4.7. *Yield Variability*

The variability was demonstrated using various statistical methods and explained in the preceding section. Over the last four decades, scientific advances in food crops, together with investments in irrigation, infrastructure, and institutions, have driven India out of the food insecurity syndrome. However, the growing population keeps the challenge of producing more food as significant as in the past. The food production systems are now under the confluence of a number of biotic and abiotic stresses including the climate change. Then, there is a necessity to investigate the variability in wheat and maize crop yields. Variability is also used to assess yield risk. Fig. 5 depicted the district-level variations in wheat and maize crop productivity. The study observed highest variability across both crops in the districts of Bilaspur, Hamirpur, Kangra, and Mandi, whereas the remaining districts demonstrate less variability. Temperature and rainfall variations were also observed in the respective districts. Crop output in the tropical area of the Himalayas is vulnerable to variations in the climatic condition. Changes in the climate will increase yield risks in the selected districts. For quantification of impact, there is a need to study the impact of climatic conditions on wheat and maize crop yields.

4.8. *Impact of climate change on maize and wheat yield*

The climatic variables *viz*., minimum and maximum temperature, precipitation, and district (cross-sectional unit) in the regression analysis to account for non-linear effects. The log-linear model was considered in the present study, because it decreases the volatility in endogenous variable, wheat and maize yield (kg ha^{-1}) in Himachal Pradesh's low and mid hills. This functional form's coefficients are easily explainable as proportional changes. However, before dealing with panel data the underlying time series must be checked to see if it is unit root or stationarity.

The Levin-Lin-Chu test was used to determine the unit root in the data. In the Levin-Lin-Chu test, the null hypothesis (H_0) is that the data is unit root and the alternate hypothesis (H_1) is that the data is stationary. Table 2 shows the results of the unit root test on panel data. The unit root test analysis revealed that the data used for the maize yield model were significantly stationary at level, whereas the wheat yield model revealed that yield and maximum temperature were significantly stationary at level, while minimum temperature and rainfall were stationary at first difference from 1985 to 2020.

TABLE 4

Diagnostic checks for wheat and maize yield model of panel data in the low and mid hills zone of Himachal Pradesh

Model	Null hypothesis	Test	Test statistic	p-value	Decision
Maize Yield Model	No group wise heteroscedasticity in fixed effect regression model	Modified Wald test	χ^2= 780.51*	0.000	Heteroscedasticity is present
Wheat Yield Model	No group wise heteroscedasticity in fixed effect regression model	Modified Wald test	χ^2= 14.00*	0.050	Heteroscedasticity is present
Maize Yield Model	No cross-sectional independence in the panel	Pesaran CD test	Pesaran = 4.533*, Average absolute value of the off-diagonal elements=0.191*	0.000	Cross-sectional dependence in the panel
Wheat Yield Model	No cross-sectional independence in the panel	Pesaran CD test	Pesaran = 5.172*, Average absolute value of the off-diagonal elements=0.233*	0.000	Cross-sectional dependence in the panel

Note: * denote significance level at 5 percent level

Table 3 presented the results of Hausman test which revealed that the panel data impact of maize and wheat yield model will prefer fixed effect model or whether random effect model for the present study. Hausman chi-square test statistics was not found statistically significant that means H_0 selected and fixed effect panel data analysis was used for studying the impact of the exogenous variables in maize and wheat yield model.

To increase the efficiency of the maize and wheat yield model use the Modified Wald test and Pesaran CD test for diagnostic checking of the models and model wise results are presented in Table 4. Diagnostic results revealed that heteroscedasticity and cross-sectional dependence is present in both the models. Due to these limitations, choose the fixed effect model and robust standard error term to increase the efficiency and unbiased estimates of the maize and wheat yield model.

Results of the fixed effect panel data regression of climatic variability and district wise impact on maize and wheat yield is presented Table 5. Maize yield model shows an increase in long run *kharif* season maximum temperature that's cause reduction in maize yield significantly, however long run increase in monsoon rainfall that's rise the maize yield in the low and mid hills of Himachal Pradesh. The result of maximum temperature to some extent is in line with the study (Ahmed *et al.*, 1992; Devasirvatham, 2012; Birthal *et al*. 2014; Singh *et al*. 2022). Increase in climatic variables (minimum, maximum and rainfall) were found significantly positive impact in Mandi and Solan districts which increase the maize productivity in the respective districts, while significantly negative impact in Kangra and Una districts shows decrease in productivity in the respective districts, significantly.

TABLE 5

Fixed effect panel data regression of climatic variability and Districts wise impact on maize and wheat yield in low and mid hills of Himachal Pradesh

Particulars	Maize Yield Model	Wheat Yield Model
	Coefficients	Coefficients
Minimum Temperature (°C)	0.000036 (0.048)	-0.040 (0.029)
Maximum Temperature (°C)	-0.022** (0.012)	0.026** (0.012)
Rainfall (mm)	0.00012** (0.000057)	0.00028** (0.00013)
Hamirpur	-0.026 (0.143)	-0.222** (0.099)
Kangra	-0.058* (0.031)	0.069* (0.038)
Mandi	0.499*** (0.204)	-0.0037 (0.122)
Sirmaur	-0.062 (0.416)	0.112** (0.057)
Solan	0.235** (0.104)	-0.156* (0.091)
Una	-0.216** (0.102)	-0.207** (0.092)
Intercept	1.124 (1.472)	-0.245 (0.501)
σ_u	0.229	0.128
σ_v	0.426	0.380
ρ	0.224	0.103
R^2	0.199**	0.295**

Notes: ***, ** and * denote significance at 1, 5 and 10 percent levels, respectively, Figures in parentheses are the robust standard error of the respective coefficients

Wheat yield model reveals that the long run increase in winter season maximum temperature and rainfall cause significant increase in wheat yield, while minimum temperature shows negative impact but found non-significant. Kangra and Sirmaur districts shows the significantly positive impact on wheat yield that means increase in temperature and rainfall have increase the wheat yield in the respective districts. However, enhancement in climatic condition shows the significant decrease in the Hamirpur, Solan and Una districts wheat yield. When all the districts have equal to zero that maize and wheat yield models shows the impact of climate change in the Bilaspur district of Himachal Pradesh. Maize yield model shows 22.40 per cent of the variance is due to differences across panels but 10.30 per cent of the variance is due to differences across panels in the wheat yield model. Results of maximum temperature and rainfall were contradictory in comparison to studies conducted in Punjab and India (Mall *et al.* 2006, Kalra *et al.* 2007; Birthal *et al.*, 2014; Pattanayak and Kumar 2013; Singh *et al.*, 2022 and Kumar and Sidana, 2017). Maximum temperature was less than the optimum temperature in Himachal Pradesh which results show that increase in maximum temperature that will increase the yield in the Himachal Pradesh. Irrigation intensive land was less in Himachal Pradesh in comparison to other states which results increase in rainfall increases the wheat yield in Himachal Pradesh.

5. Conclusions

In *rabi* season, the minimum temperature showed significant significantly increasing trend at different locations of low and mid hills of Himachal Pradesh while during *kharif* season its increasing trend only in Kangra district. During *rabi* season and annually, maximum temperature was showed significant increasing trend however, maximum temperature significantly showing decreasing trend in all the locations except Bilaspur and Sirmaur districts non-significantly. The significant trend and consistent shift as shown by the minimum temperature, 1998 was taken as the year of climate change. The minimum temperature was increased significantly by 0.39 °C, 0.63 °C, 0.70 °C, 0.56 °C, 0.48 °C, 0.59 °C and 0.64 °C in Bilaspur, Hamirpur, Kangra, Mandi, Sirmaur, Solan and Una district, respectively since 1998. After climate change year 1998, highest change in rainfall were recorded in Kangra district followed by Sirmaur, Mandi, Solan, Una and Hamirpur. Climate change will impact food security by affecting food availability, access, supply stability, and price volatility. Our findings imply a significant decline in maize and wheat production by maximum and minimum temperature with significant climate change. Adaptation measures include autonomous, planned, short-term, and long-term. These include mixed/intercropping, afforestation, cultivating drought-tolerant crops, changing planting dates and crop kinds. According to Aggarwal (2009), planting earlier reduces climate-induced damage to wheat by 60-75 percent. Water harvesting, conservation, and efficient usage are other key adaptations. Micro-irrigation, watershed management, and insurance can prevent 70 percent of drought-related losses (ECA, 2009). Drought-resistant cultivars can lower output risks by 30-50 percent. Besides these, it is critical to expand access to credit and crop insurance for farmers to adopt adaptation and mitigation strategies.

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