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Impact of Climate Change on Agriculture Production in District Kinnaur, Himachal Pradesh

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KEYWORDS Climate. Cropping Season. Productivity. Temperature. Trend Analysis

ABSTRACT Weather phenomena are influencing temperature and rainfall patterns in the region, which impacts crop production. Therefore, the present study was conducted with the objective of ascertaining the effect of climate change on agricultural crop productivity in the district of Kinnaur. During the kharif season, results revealed that the maximum temperature rose at the rate of 0.02°C per year. After 1999, the maximum temperature remained above the long-term average except for the years 2001, 2002, 2005, 2008, 2011, 2013 and 2014, indicating an overall warming trend. During the rabi crop season, diurnal temperature increased by 0.02°C per year, which was statistically significant. As per the outputs from Mann Kendal Tests, an overall increased productivity trend was recorded for maize, barley and common millets, wherein wheat showed a decreasing trend of -0.014 t ha^{-1} $year^{-1}$. This means that the observed significant maximum variations in climatic parameters for rice are 35.6 percent, 15.4 percent for maize, and 9.0 percent for common millets. Non-significant variations were recorded for wheat, barley and ragi.

INTRODUCTION

The agriculture sector is one of the most vulnerable ones to environmental change due to its susceptibility to variations in temperature and precipitation patterns, as well as naturally occurring climate limits, and the resulting barometric carbon dioxide (CO_2). Furthermore, it is one of the few fields that both mitigates and encourages the sequestration of fossil fuel by-products while still leaving a significant global carbon footprint (around 13% in 2010). The Himalayan environment is extremely prone to the dire effects of imminent climate change. While the focus of recent research and debate has been on glacial retreat and its effect on downstream water discharge, there is growing evidence of climate change's possible cascading impact on all related and satellite regions in the Himalayas. Because of its geological history and structural rock formation, the Himalayan ecosystem is rapidly approaching a state of disequilibrium, with visible changes in its resources and climate. The food systems are under increasing pressure from climate change, whose effects are becoming more noticeable. Among other effects, increasing temperatures, altered precipitation patterns, and extreme weather events are already lowering agricultural production and destabilising food supply chains. Millions of people are predicted to be at risk of hunger, malnutrition, and poverty by 2050 as a result of climate change (International Food Policy Research Institute 2022).

Over 72 million people live in the Indian Himalayan region, which is divided into ten states and 95 districts and covers a total area of 5 lakh square kilometres, accounting for roughly sixteen percent of the country's total land area. The Himalayan ecosystem is inherently vulnerable to natural disasters, which are susceptible to exacerbated occurrences of floods, droughts, and landslides triggered by drastic changes in climatic conditions, due to its high biological and socio-cultural diversity. HP is a mountainous state in northern India, located between latitudes 30° 22' 40" N and 33° 12' 40" N, and longitudes 75° 45' 55" E and 79° 04' 20" E in the western Himalayas. The state has a complex geological structure that dissects its topography into extreme altitudinal ranges from 350m to 6,975m above sea level. Because of the large elevation variations, it experiences a wide range of climates, from hot and humid tropical in the south to cold, alpine, and glacial in the north and east.

The population of the state is 6.86 million, with approximately ninety percent of the population living in rural areas. Agriculture employs roughly

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seventy-one percent of the population, with the most common farming systems being mixed farming, agro-pastoral, silvi-pastoral, and agro-horticulture. Despite this, only ten percent of the state's net area (55.67 lakh hectares) is occupied by cultivated land, with eighty-one percent of this cultivated area being rainfed. Only one lakh hectares of net sown area, however, has guaranteed irrigation. Rice, maize, barley, jowar, pulses, millet, potato, and several other off-season vegetables are among the state's main food crops. As can be seen from the map above, most of the agriculture exposure in the state is concentrated in Zones II and III. Nonetheless, each zone and district has a unique soil, climate, and precipitation pattern.

Guntukula and Goyari (2020) revealed that the effects of changing climatic conditions differ depending on the crop in question. Rice, cotton and groundnut yields are all adversely impacted by high temperatures. Rice, cotton and groundnut all benefit greatly from lower temperatures. In addition, rainfall has a negative impact on cotton and groundnut yields. For all study crops, maximum temperature appears to be a risk-reducing factor. For rice, cotton and jowar, the minimum temperature tends to be a risk-enhancing factor. As per the IPCC, because of warming, shifting precipitation patterns, and the increased occurrence of certain weather events, climate change has already influenced food security. According to reports, crop yields in many lower-latitude regions have been negatively affected by climate change, while yields in many higher-latitude regions (for example, corn, wheat and sugar beets) have been positively affected in recent decades. There is clear evidence that agricultural pests and diseases have already responded to climate change by expanding or contracting their infestations (IPCC 2019).

Human managed ecosystems such as food production and livelihood sustenance are found to be highly vulnerable to changes in the weather phenomena in Asia. Saseendran et al. (2000) observed a reduction in crop duration due to increased temperature and predicted a possible increase in crop (rice) yields under rainfed conditions in Kerala. Kaur et al. (2011) identified direct and indirect effects of changes in climatic patterns of temperature, precipitation, and humidity on yields of rabi and kharif crops.

Objectives

In response, a status study was conducted with the following goals to determine how climate change has affected agricultural activities in the state, particularly in district Kinnaur:

- To investigate the seasonal patterns of climatic variables such as minimum, maximum, diurnal temperatures, and rainfall.
- To capture the temporal variation in the acreage, production, and productivity of agriculture crops in the district.
- To examine how the climate affects crop productivity in terms of a percentage.

MATERIAL AND METHODS

Within the context of the collocation of climate variability and agriculture productivity in district Kinnaur, Himachal Pradesh, the study was designed to determine the statistical impact of variations in climatic parameters (temperature and rainfall) on agricultural crop productivity. The study employs three different statistical measures, that is, trend analysis based on the Mann Kendall Test, Standardised Anomaly Index, and Multivariate Linear Regression Analysis to ascertain the impact of variation in climatic parameters on agriculture. The data for district Kinnaur was collected from the India Meteorological Department (IMD), Shimla, and covered the years 1990 to 2018. The rabi and kharif crop seasons, which run from November to April and May to October respectively, were used to compile this information. The Mann Kendall Test and the Standardised Anomaly Index were performed on this dataset. Wheat, barley, rice, maize and potato crops acreage and production data was collected from the Department of Land Records, Shimla covering the time period from 1970 to 2017.

Seasonal trends were analysed for climatic variables such as minimum, maximum, diurnal temperature, and rainfall from 1990 to 2018. Yearly trends were worked out for the productivity of selected crops and trend analysis was done by using the Mann-Kendall test using XLSTAT, 2017. Sen's slope method was used to quantify the trend (Sen 1968). The SAI is a widely used index for regional climate change studies, and it is measured by subtracting the long-term mean value of temperature and rainfall data sets from individual values and dividing them by their standard deviation (Koudahe et al. 2017). The correlation coefficient and multivariate regression analysis in SPSS-20 were used to investigate the relationship between the environment and the crop. The frequency of the relationship between climatic variables and crop productivity was measured using Pearson's correlation coefficient. To describe the contribution of anomalies in studied climatic parameters on crop productivity, the following linear model was used: P = constant + (T_{min}) + (T_{max}) + (T_{dt}) + (R), wherein P is the observed change in productivity due to minimum, maximum, diurnal temperature, and rainfall in the respective cropping season, and are the coefficients of minimum, maximum, diurnal temperature, and rainfall, respectively. T_{min}, T_{max}, T_{dt}, and R are the observed changes in the cropping seasons' minimum, maximum, diurnal temperature, and rainfall during the study period.

RESULTS

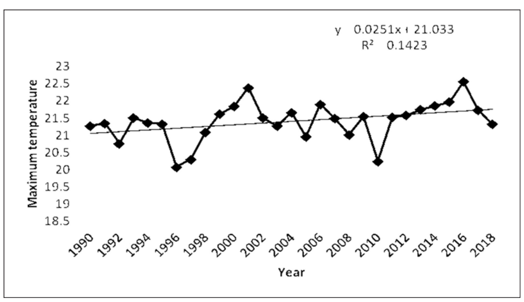
To capture the nerve of climatic changes in the district, temperature (min, max, diurnal), and rainfall parameters are considered as explanatory indicators. Based on the statistical analysis, the Mann Kendall trend test, the maximum and diurnal temperature showed significant changes during the kharif crop season for the study period

Table 1: Mann Kendall Test results – climatic trends for kharif and rabi season (1990-2018) Kinnaur, Himachal Pradesh

Climate variables	*Mean*	*Sen's slope*	*p-value*
	Kharif Season		
Maximum temperature	21.414	**0.02**	**0.01**
Minimum temperature	12.09	**0.04**	**1.000**
Diurnal temperature	0.066	0.46	0.307
Annual rainfall	108.56	0.78	0.312
	Rabi Season		
Maximum temperature	10.740	1.07	0.724
Minimum temperature	-0.423	-0.42	0.307
Diurnal temperature	11.163	**0.02**	**0.001**
Annual rainfall	73.883	-14.69	0.423

spanned across 28 years, while for the rabi crop season, only the diurnal temperature underwent statistically significant changes. Table 1 exhibits the results of the Mann-Kendall test at a ninety-five percent confidence level for the years 1990 to 2018, the mean, high, and diurnal temperatures, as well as rainfall, were measured.

During the kharif season, the maximum temperature rose at the rate of 0.02°C per year (as exhibited by Sen's slope). After 1999, maximum temperature remained above the long-term average except



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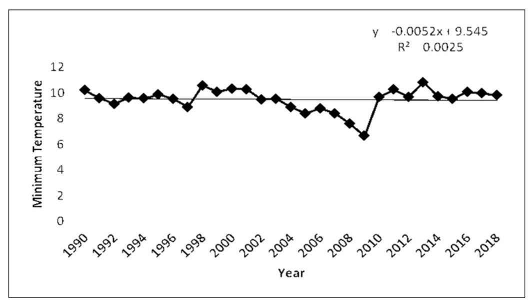

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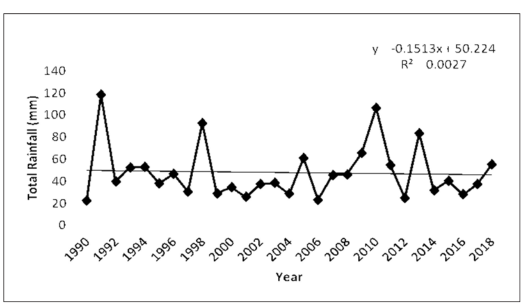

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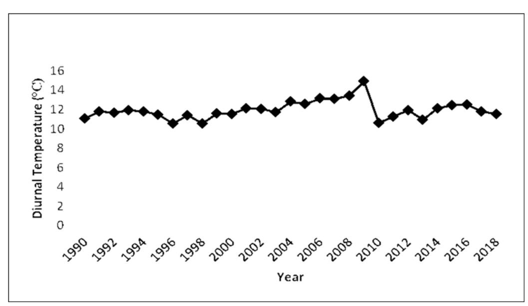

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Fig. 1(a-d). Variations in climatic parameters- minimum temperature, maximum temperature, diurnal temperature and total rainfall during kharif crop season (1990-2018), District Kinnaur, Himachal Pradesh

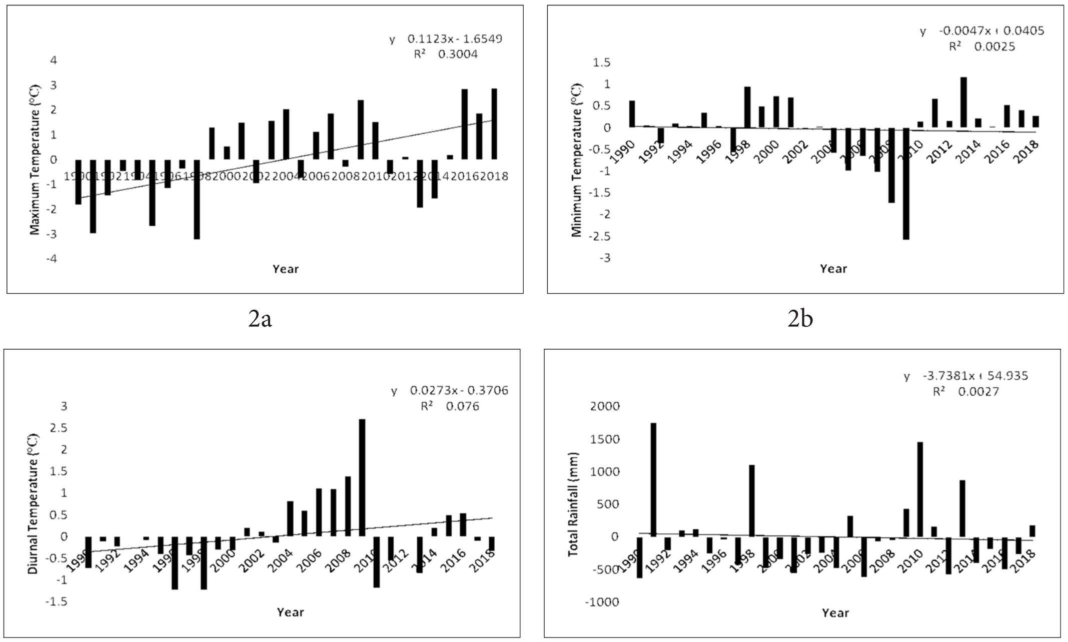

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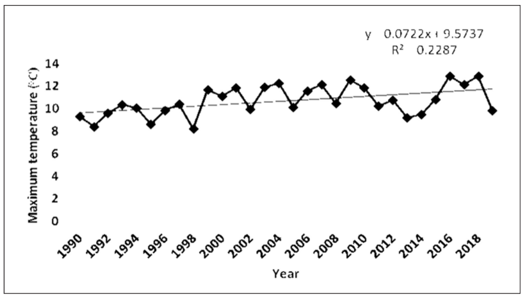
Fig. 2(a-d). SAI for climatic parameters- minimum temperature, maximum temperature, diurnal temperature and total rainfall during kharif crop season (1990-2018), District Kinnaur, Himachal Pradesh

for the years 2001, 2002, 2005, 2008, 2011, 2013 and 2014 indicating an overall warming trend. Rainfall, on the other hand, did not show any significant variation from 1990 to 2018.

The minimum temperature did not show any significant trend during the kharif season. Rainfall and diurnal temperature, on the other hand, did not show any significant variation from 1990-2018. As per the output from SAI (Figs. 1 a-d) during the kharif crop season, after 1999, maximum temperature remained above the long-term average except for the years 2002, 2005, 2008, 2011, 2013 and 2014, indicating an overall warming trend during the maximum temperature. With a few dips like 1992, 1998, 2004, 2006, 2008 and 2010, 17 years of showing a warming trend, which is above the long-term average during the minimum temperature. Rainfall, on the other hand, showed variation in 10 years, which is above the long-term average. These years are 1991, 1994, 1993, 1998, 2003, 2009, 2010, 2011, 2013, and 2018 during the kharif crop season.

During rabi crop season, diurnal temperature registered statistically significant increase of 0.02°C per year in district Kinnaur. Meanwhile, the maximum and minimum temperature and rainfall did not show significant changes from 1990-2018. According to SAI data, there was a continuous drop from 1990 to 1999, after which maximum temperatures remained above the long-term average in the years 2000, 2001, 2003, 2004, 2006, 2008, and 2010. In case of minimum temperature 13 years out of 28 years were registered above the long-term average. During rainy seasons, there were a few dips in 1994, 1996, 1998, 1999, 2000, 2001, 2004, 2006, 2008, 2010, 2011, and 2012, with some years exceeding the long-term average (1990, 1991, 1992, 1995, 2002, 2003, 2005, 2007 and 2014).

The discussed temperature and rainfall patterns are not limited to district Kinnaur but are corroborated by various observations from other studies in the Himalayan region. When comparing minimum annual temperatures with maximum annual temperatures, Poudel and Shaw (2016) found a 0.07°C difference. From 1980 to 2010, the minimum temperature in the Nepal-bound Himalayan region increased by 0.02°C while the maximum temperature increased by 0.02°C. Monthly and annual mean temperatures, mean



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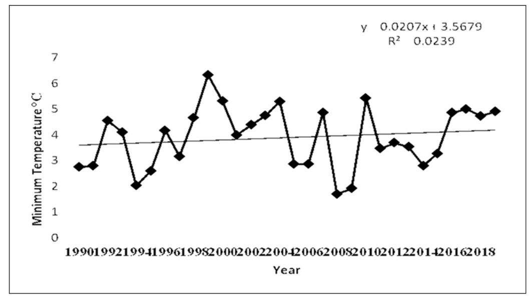

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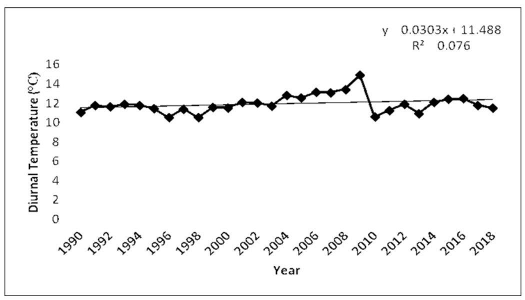

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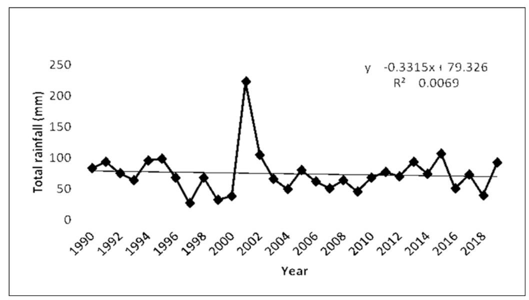

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Fig. 3 (a-d). Variations in climatic parameters- minimum temperature, maximum temperature, diurnal temperature and total rainfall during rabi crop season (1990-2018), District Kinnaur, Himachal Pradesh

maximum temperature, and mean minimum temperature have all risen over time.

Meanwhile, Bhutiyani et al. (2007) found a 1.6°C rise in temperature in the northwest Himalayas, indicating a faster rate of winter warming. Specifically, in Himachal Pradesh, the rate of increase in maximum temperature was observed to vary with altitudinal zones (higher altitudes registered a higher rate of increase). Rainfall trends in the Himalayan region have been found to remain consistent according to Joshi et al. (2011), as observed in this research.

Acreage and Production Assessment of Major Agricultural Crops

In Figures 5 (a-f), the important food crops of the district are paddy, maize, wheat, barley, millets, ragi and common millets. Acreage under these crops has also witnessed a change over time. Temporal trends of change in area, production, and productivity of different food crops in the Kinnaur are illustrated in Figures 5 (a-f). Rice crop acreage witnessed a drastic decrease from 66 ha to 3 ha from the year 1990 to 2018, while production decreased from 57 MT in 2016 to 2 MT in 2014. During the years 1970 to 2017, the acreage of wheat decreased from 1911 ha to 201 ha and production decreased from 2457 MT to 185 MT. The area and production of the maize crop decreased from the year 1970 to 2017. From 1970 to 2017, the area decreased from 550 ha to 83 ha and production decreased from 1057 MT to 209 MT. In the case of the barley crop, the area decreased from 2828 ha to 627 ha and production also showed a decreasing trend from 5140 MT to 83 MT. Ragi also showed a decreasing trend from the year 1970 to 2017.

As per the outputs from Mann Kendal Tests, an overall increased productivity trend is recorded for maize, barley and common millets (see Table 2), wherein,wheat showed a decreasing trend of -0.014 t ha^{-1} $year^{-1}$. Maize showed an increased crop yield of 0.019 t ha^{-1} $year^{-1}$ while common millet and barley showed an increasing trend of 0.006, 0.0015 t ha^{-1} $year^{-1}$, respectively.

According Table 1, only maize, and common millets showed significant variations in productivity

Table 2: Mann Kendall Test results – crop yields for kharif and rabi season (1971-2009) Kinnaur, Himachal Pradesh

Crops	*Sen's slope*	*p-value*	*Kendall's tau*
Wheat	**-0.014**	**0.000**	0.332
Barley	**0.015**	**0.001**	0.330
Rice	0.011	0.224	0.353
Maize	**0.019**	**<0.0001**	0.568
Potato	0.175	0.212	0.521
Common Millet	**0.006**	**0.014**	0.006
Ragi	0.006	0.432	0.506

(as determined by *p*-values at 95 percent confidence intervals). Weather phenomena are too difficult to have an immediate effect on any industry. Climate change is projected to have a major economic effect on agriculture, particularly as time passes in the 'as is' scenario. Various studies aimed at forecasting the future course of climatic effects on agriculture have projected a decline in grain yields as temperatures rise in many developing countries, despite recent census data suggesting development (Mendelsohn and Dinar 1999; Kumar and Parikh 2001). Furthermore, although an overall rise in mean temperature is certain, the effect on agricultural productivity is highly dependent on the extent and timing of extreme temperatures, according to estimates by Gornall et al. (2010).

Climate-crop Juxtaposition

A correlation study was performed to assess the relationship between climatic variability and crop productivity using the statistical approach of Pearson's coefficient. In district Kinnaur, the findings revealed a clear relationship between climate variability and rabi crop productivity, such as wheat, whereas there was no such relationship for kharif crops (rice and maize). Rice crop productivity showed a strong and optimistic trend (0.587) when the effects of maximum temperature, diurnal temperature, and rainfall were tested (with a *p*-value of 0.001). The effects of variability in maximum temperature, diurnal temperature, and rainfall showed a significant and positive trend (coefficient value 0.587 with *p*-value 0.001 for rice), with coefficient value 0.357 and *p*-value

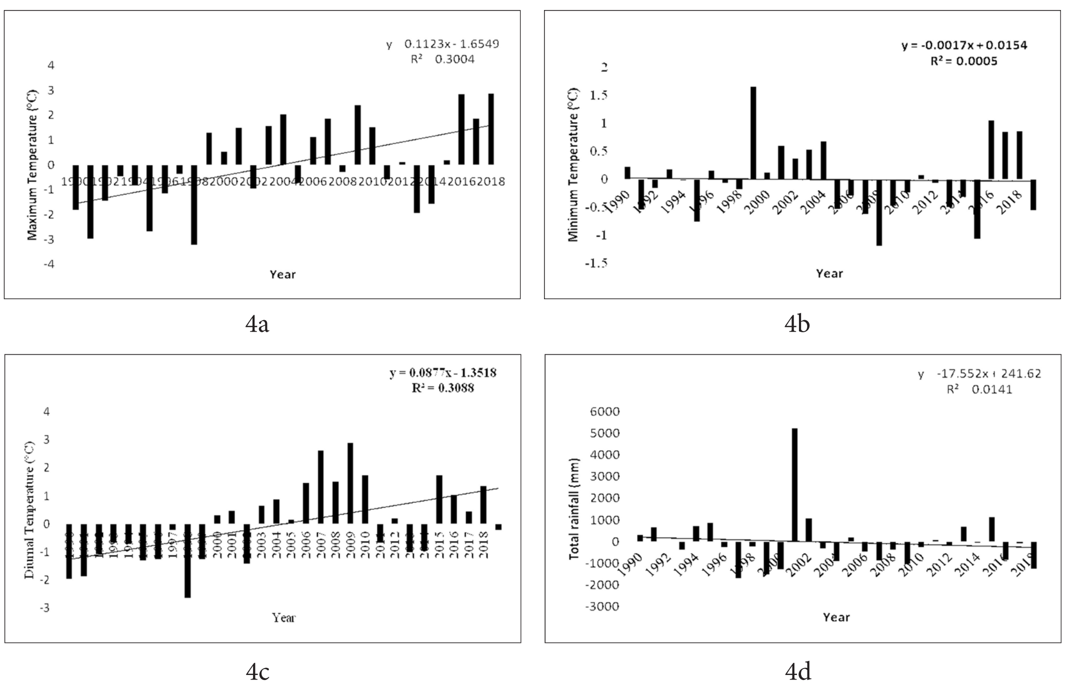
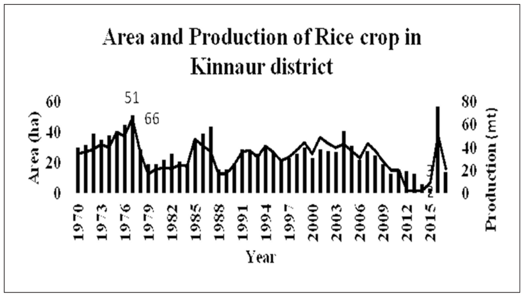


Fig. 4(a-d). SAI for climatic parameters- minimum temperature, maximum temperature, diurnal temperature and total rainfall during rabi crop season (1990-2018), District Kinnaur, Himachal Pradesh



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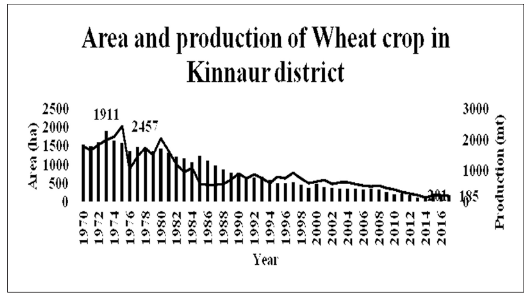

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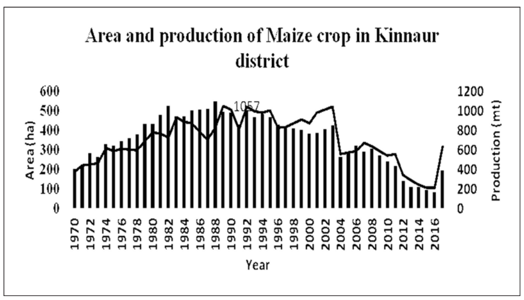

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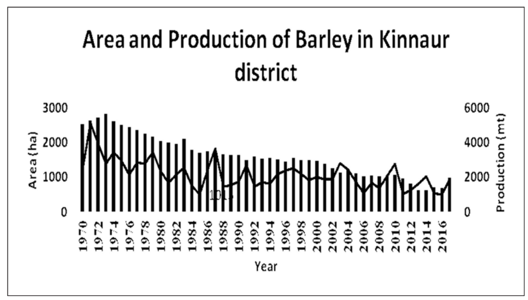

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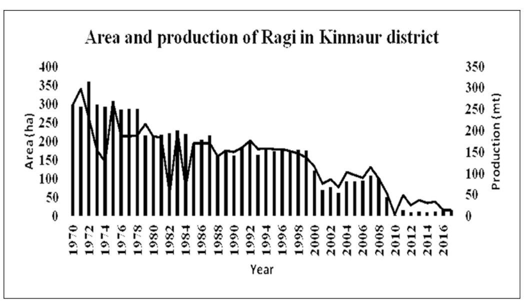

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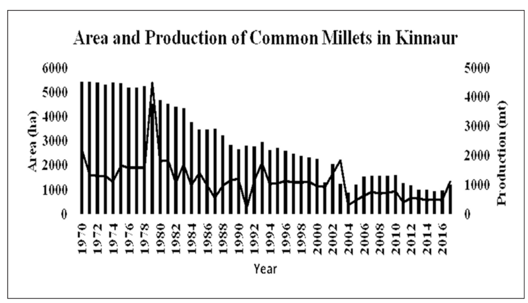

5f

Fig. 5(a-d). Area and production of rice, wheat, maize, barley, ragi and common millets crop in Kinnaur district from 1970-2017, District Kinnaur, Himachal Pradesh

0.031 for maize and 0.56, -0.53 with *p*-value 0.001, 0.002 for common millets.

Table 3 illustrates the regression outcome of de-trended climate variables such as minimum, maximum, and diurnal temperatures, as well as rainfall, which are related to crop productivity. For all assessed crop varieties, that is, wheat, barley, rice, maize, ragi and common millets, only 12.6 percent, 12.8 percent, 35.6 percent, 15.4 percent, 8.2 percent, and 9.0 percent respectively, of productivity variability could be explained by temperature and rainfall variations in the district. This means that the observed significant maximum variations in climatic parameters for rice are 35.6 percent, 15.4 percent for maize, and 9.0 percent for common millets. Non-significant variations were recorded for wheat, barley and ragi. Wheat, barley, and rice productivity declines have been interpreted similarly. The remaining variances in crop output are allegedly caused by factors such as access to better seed varieties, increased fertiliser use, and better farming practices (Sharma 2011).

Table 3: Multivariate Linear Regression Analysis – crop yields and climatic parameters, (1990-2017) Kinnaur, Himachal Pradesh

Crop	*Variable / Statistics*	*Maximum temperature*	*Minimum temperature*	*Diurnal temperature*	*Rainfall*	*R^2*	*Change (%)*
Wheat	Coefficient	0.171	-0.178	0.208	0.008	0.126	12.6%
	p-value	0.192	0.182	0.145	0.484		
Barley	Coefficient	0.137	-0.224	0.217	-0.076	0.128	12.8%
	p-value	0.243	0.126	0.134	0.351		
Rice	Coefficient	0.141	0.587	-.042	-.086	0.356	35.6%
	p-value	0.237	**0.001**	0.416	0.332		
Maize	Coefficient	0.193	0.357	-0.130	-0.26	0.154	15.4%
	p-value	0.162	0.031	0.255	0.448		
Ragi	Coefficient	0.024	0.257	0.026	-.121	0.082	8.2%
	p-value	0.452	0.097	0.447	0.269		
Common Millets	Coefficient	**0.568**	0.242	-0.538	0.130	0.090	9.0%
	p-value	**0.001**	0.107	0.002	0.235		

Climate and productivity data was detrended by computing the difference in values from one year to the next.

DISCUSSION

As per the findings revealed and discussed above, the climatic trends for average maximum, minimum, diurnal temperature, and annual rainfall are highly variable. The average maximum and minimum temperature for the kharif season have increased significantly in the Kinnaur district of Himachal Pradesh. According to a statement released by the India Meteorological Department (IMD), according to data from the period of 1981 to 2010, the average maximum, minimum, and mean temperatures for the entire nation in March 2022 were 33.10°C, 20.24°C, and 26.67°C respectively, as opposed to the normal values of 31.24°C, 18.87°C and 25.06°C. As a result, for the entire nation, the average maximum, average minimum, and mean temperatures are all above normal by 1.86°C, 1.37°C, and 1.61°C, respectively. The average maximum temperature recorded in March 2022 was 33.10°C, breaking the previous record of 33.09°C set in 2010 for the same month, which is the highest ever recorded in the last 122 years for the period 1901-2022 (IMD 2022). Similarly, for the rabi season only, the diurnal temperature increased significantly at a rate of 0.02°C. However, the other climatic variables during this season did not show any significant variations.

Except for wheat, agricultural production of the crops has increased over the last 38 years. The productivity of wheat has decreased by -0.014 t ha^{-1} $year^{-1}$ in Kinnaur. According to an investigation by Mall et al. (2006), a 1°C rise in temperature resulted in an 8.1 percent decrease in wheat productivity. According to data on agricultural production in India from 1967 to 2016 for several crops, average land productivity declines as average temperatures rise, and this effect quickens with greater degrees of warming (International Food Policy Research Institute 2022). Under a moderate climate change scenario, yields of India's crops are predicted to decline by 1.8 to 6.6 percent by the middle of the century (2041-2060) and by 7.2 to 23.6 percent by the end of the century (2061-2080).

In contrast, the rabi season barley crop increased significantly, reaching 0.015 t ha^{-1} $year^{-1}$. Productivity of kharif crops such as maize and common millet increased significantly at 0.019 and 0.006 t ha^{-1} $year^{-1}$ respectively, except for rice, potato and ragi, which increased but not significantly. The contribution of climatic variables in terms of impacting the productivity of agricultural crops for both seasons was also discussed in percentage. According to climate and crop linkage analysis, rice has been impacted the most (35.6%), followed by maize, barley, wheat, common millets, and ragi. This means that the impact of climatic variables (average maximum, minimum, diurnal temperature, and annual rainfall) on the agricultural crop yield of Kinnaur district is very low. There are many other factors like seed quality, pathogen and insect incidence, crop shifting, microclimatic conditions, etc., which are directly linked to the crop yield. Food security is anticipated to be impacted by climate change on a global, regional, and local scale. In the future, if climate change persists, it may impact food quality, access to food, and availability. For instance, decreasing agricultural output may be a result of expected temperature rises, modifications to precipitation patterns, variations in extreme weather events, and decreases in water availability (USEPA 2022).

CONCLUSION

The study's main objective was to ascertain the statistical impact of climate change on agricultural crop productivity in Himachal Pradesh, with a particular emphasis on the Kinnaur area. After 1999, the maximum temperature remained above the long-term average except for the years 2001, 2002, 2005, 2008, 2011, 2013 and 2014, indicating an overall warming trend. During the kharif season, the maximum temperature increased at a rate of 0.02°C each year (as demonstrated by Sen's slope). On the other side, rainfall did not significantly vary between 1990 and 2018. For the rabi crop season, a district's diurnal temperature showed a statistically significant increase at a rate of 0.02°C per year.

According to the results of the Mann-Kendal tests, the productivity trends for barley, rice, maize, potatoes, common millets, and ragi are all on the up, but wheat exhibited a declining trend of -0.014 t $ha^{-1}year^{-1}$. Barley, rice, maize, potatoes, common millets and ragi all had higher productivity of 0.015 t $ha^{-1}year^{-1}$, 0.011 t $ha^{-1}year^{-1}$, 0.019 t $ha^{-1}year^{-1}$, 0.006 t $ha^{-1}year^{-1}$, and 0.006 t $ha^{-1}year^{-1}$, respectively. Wheat, barley, rice, maize, ragi, and common millets were all analysed crop varieties, and the impact of climatic variables only contributed 12.6 percent, 12.8 percent, 35.6 percent, 15.4 percent, 8.2 percent, and 9.0 percent respectively, to the change in production, whereas, wheat, barley and ragi all showed non-significant variations. Only the climatic factors mentioned above are used to explain this proportion. However, additional factors also account for the remaining portion of the impact.

RECOMMENDATIONS

Although necessary, adaptation is essential for food systems. To better sustain rural livelihoods and provide a nutritious diet for everyone, food production, distribution, and consumption methods must all adapt to climate change. This is true even while population and income development raise the demand for food. Crops and varieties that are more tolerant of climate change would adapt more readily to temperature fluctuations and humidity, drought, pests, and diseases. Improving micro-reservoirs or spring-shed management is important rather than using water shed management to conserve rainwater (rainwater harvesting) to strengthen water security. Also, there is a need to use conventional crop varieties, such as millets and pseudo-cereals, which need relatively little water and can tolerate harsh weather.

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