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Impact assessment of climate change on agriculture sector in Himachal Pradesh case study: District Mandi

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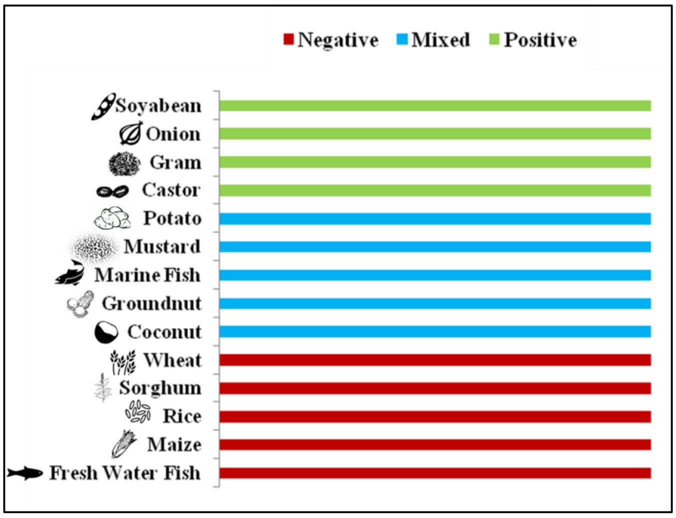
Abstract
Agriculture sector plays a vital role in global economic, nutritional and food security along with conservation of natural resource use. At the same time, it is one of the most vulnerable sectors to the impacts of climate change, owing to its sensitivity to extreme and sudden variations in temperature and precipitation. To this effect, a status study was conducted with a view to ascertain the impact of climate change on agricultural activities in District Mandi. The mean maximum temperature increased by 0.035 °C per year during Kharif crop season. Meanwhile, the diurnal temperature exhibited a increasing trend of 0.057 °C per year. Rainfall did not register any statistically significant result during the study period. Moreover, the Standardized Anomaly Index of maximum temperature depicted a warming trend from 2002 onwards except for dips in 2004 and 2008. During the Rabi crop season, the diurnal temperature increased by 0.030 °C per year. Maximum and minimum temperature and Rainfall did not register any statistically significant result. Meanwhile, the Standardized Anomaly Index (SAI) of maximum temperature showed a warming trend from 2006 onwards whereas minimum temperature showed warming trend from 2005 onwards. As per the output from the multivariate regression analysis, for all assessed crop varieties *viz.*, Wheat, Maize, Barley and Rice only 10.1%, 11.3%, 5.2%, 26.1% and 6.1% of productivity variability could be explained from temperature and rainfall variations in the district, respectively. With respect to individual crops, positive significant values were recorded for rice crop with 26.1% change and non significant values were recorded for Wheat, Barley Maize and Potato from 1970 to 2010.

Keywords: Climate, agriculture, global economic

1. Introduction

Agriculture is amongst the most vulnerable sectors to be affected by climate change owing to its sensitivity to variations in temperature and rainfall patterns, frequently occurring weather extremes and continued exposure to atmospheric carbon dioxide (CO_2). Moreover, it is one of the few sectors that both mitigates and supports sequestration of carbon emissions while maintaining a significant global carbon footprint (approximately 13 per cent in 2010 (WRI, 2014) [8]. Agriculture in itself exists as a complex milieu of interactions between a range of plants and animal commodities, linkages between exacting components governed by risk perceptions, personal experiences and preferences, knowledge and skill, and external influences from market demand, government policies, and the climate (Walthall *et al*., 2012) [7].

According to the Economic Survey 2018, the impact of climate change exhibited through temperature and rainfall variations is highly non-linear and is observed in extreme cases of increased temperatures and rainfall shortfalls. Furthermore, divergent observations are made for irrigated and un-irrigated and thus, respective crop varieties (rainfed crops such as pulses vis-à-vis cereals), with almost twice more for un-irrigated areas. Commodity wise impact of climate change as modelled by International Central Research Institute for Dryland Agriculture (CRIDA) is illustrated in figure 1 and table 1 below.



Source: Adapted by HPSCCC from Down to Earth, 2018 (Goswami, 2017)

Fig 1: Commodity wise climate change impact, India (from modelling)

In Himachal Pradesh, around 71 per cent of the 6.86 million people are dependent on the agriculture sector as an income source and employment, thus exhibiting a heightened exposure and vulnerability to climate induced variations in the sector. The agriculture practices in the Himalayan region are shifting from traditional cereal crops to cash crops such as fruits and vegetables.

To this effect, a status study was conducted with a view to ascertain the impact of climate change on agricultural activities in District Mandi. Seasonal trends on climatic variables i.e. minimum, maximum, and diurnal temperatures, and rainfall patterns were conjugated with a standardised anomaly index and a multivariate regression analysis was conducted to unearth the climate and crop yield relationship. The statistical assessment unearthed climate change as an instrumental component leading to significant shifts in cropping patterns and productivity in District Mandi.

Table 1: Impact of Weather Shocks on Agricultural Yields, India (% decline in response to temperature increase and rainfall decrease)

	Extreme Temperature Shocks	Extreme Rainfall Shocks
Average Kharif	4.0%	12.8%
Kharif, Irrigated	2.7%	6.2%
Kharif, Un-irrigated	7.0%	14.7%
Average Rabi	4.7%	6.7%
Rabi, Irrigated	3.0%	4.1%
Rabi, Un-irrigated	7.6%	8.6%

Source: Economic Survey, 2018, Ministry of Finance, Government of India (Economic Survey, 2018)

In Himachal Pradesh, around 71 per cent of the 6.86 million people are dependent on the agriculture sector as an income source and employment, thus exhibiting a heightened exposure and vulnerability to climate induced variations in the sector. The agriculture practices in the Himalayan region are shifting from traditional cereal crops to cash crops such as fruits and vegetables. To this effect, a status study was conducted with a view to ascertain the impact of climate change on agricultural activities in District Mandi. Seasonal trends on climatic variables i.e. minimum, maximum, and diurnal temperatures, and rainfall patterns were conjugated with a standardised anomaly index and a multivariate regression analysis was conducted to unearth the climate and crop yield relationship. The statistical assessment unearthed climate change as an instrumental component leading to significant shifts in cropping patterns and productivity in District Mandi.

2. Material and Methods

Within the context of collocation of climate variability and agriculture productivity in District Mandi, Himachal Pradesh, the study was designed to determine the statistical impact of variations in climatic parameters (temperature and rainfall) vis-à-vis agricultural crop productivity. This section elaborates on the applied methodology along with details on the data sources.

2.1 Secondary data sources and technique

The study employs three different statistical measures *viz.* trend analysis based on Mann Kendall Test, Standardized Anomaly Index, and Multivariate Linear Regression Analysis to ascertain the impact of variation in climatic parameters on agriculture.

2.2 Climate Datasets

The mean minimum, maximum, diurnal temperatures, and rainfall data for District Mandi was collected from India Meteorological Department (IMD), Shimla covering a time period of 1971-2015. This data was categorized for *Rabi* and *Kharif* crop seasons i.e. November to April for former, and May to October for latter. This dataset was used to conduct Mann Kendall Test and Standardized Anomaly Index assessments.

2.3 Agricultural Datasets

Wheat, Barley, Rice, Maize, and Potato crops acreage and production data was collected from the Department of Land Records, Shimla covering the time period 1966 to 2009. Wheat and Barley are *Rabi* crops while the remaining crops are categorized as *Kharif* crops. This dataset was used to conduct all three assessment techniques *viz.* Mann Kendall Test, Standardized Anomaly Index, and Multivariate Linear Regression Analysis.

2.4 Trend analysis

Seasonal trends were analyzed for climatic variables such as minimum, maximum, diurnal temperature and rainfall from 1971 to 2016. Yearly trends were worked out for productivity of wheat, barley, rice, maize and millets. Trend analysis was done by using Mann-Kendall test using XLSTAT 2017. Mann Kendall test was conducted to reject the null hypothesis stating that there is no trend in the dataset with the alternate hypothesis assuming that population follows a particular trend in the given period of time. Sen's slope method was used to quantify the trend (Sen, 1968).

2.5. Standardized Anomaly Index (SAI)

SAI is a commonly used index for regional climate change studies which can be premeditated by subtracting the long term mean value of temperature and rainfall data set from individual value and dividing by their standard deviation (Koudahe *et al.*, 2017) [9]. In this manner standardized temperature indices for mean minimum, maximum and diurnal temperature of rabi and kharif seasons were computed for the study area. Similarly standardized precipitation indices were also calculated for the cropping seasons.

2.6. Climate-crop yield relationship

Climate crop relationship was analysed by using correlation coefficient and multivariate regression analysis using SPSS-20. Pearson's correlation coefficient was used to measure the strength of association between climatic variables and crop productivity. Multivariate regression analysis was performed to confirm the contribution of anomalies of studied climatic parameters on crop productivity which can be explained by following linear model: $\Delta P = \text{constant} + (\alpha \times \Delta T\text{min}) + (\beta \times \Delta T\text{max}) + (\gamma \times \Delta T\text{dt}) + (\delta \times \Delta R)$ where, ΔP is the observed change in the productivity due to minimum, maximum, diurnal temperature and rainfall in the respective cropping season of the crop and α, β, γ and δ are the coefficients of minimum, maximum, diurnal temperature and rainfall, respectively. ΔTmin, ΔTmax, Tdt and ΔR are the observed changes in minimum, maximum, diurnal temperature and rainfall respectively of the cropping seasons during the study period.

3. Result and Discussion

Changes in climatic variables of kharif and rabi season in Mandi district from 1971 to 2015 have been illustrated in Figs. 1(a-d). Standardized Anomaly Index for minimum, maximum, diurnal temperature and rainfall has been depicted in Figs. 1(e-h). Using Mann Kendall test, it has been observed that minimum and diurnal temperature has undergone a significant change in Kullu district during kharif season over past 45 years (Table 1). 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, Mann Kendall trend test, the maximum and diurnal temperature showed significant changes during the *Kharif* crop season for the study period spanned across 23 years, while for Rabi crop season, only the diurnal temperature underwent statistically significant changes. Table 4 exhibits the results of Mann Kendall test at 95 per cent confidence level for minimum, maximum, and diurnal temperate, and rainfall for the time period 1995-2018.

Table 4: Mann Kendall Test Results – Climatic Trends for Kharif and Rabi Season (1995-2018)

	Mean	Sen's slope	p-value
Kharif			
Max T	27.911	0.035	0.017
Min T	9.795	-0.012	0.237
Diurnal T	10.16	0.057	0.005
Rainfall	191.1	1.123	0.245
Rabi			
Max T	18.827	0.039	0.007
Min T	2.493	-0.008	0.398
Diurnal T	10.334	0.030	0.001
Rainfall	80.222	-0.061	0.756

During Kharif crop season, the maximum temperature rose at the rate of 0.035 °C per year (as exhibited by the Sen's slope). Meanwhile the diurnal temperature exhibited a increasing trend of 0.057 °C per year. Rainfall, on the other hand, did not show any significant variation from 1970-2018. During Rabi season diurnal temperature increases at the rate of 0.030 °C per year, on the other hand maximum temperature and minimum temperature did not show any significant variations. Abbas, S., Mayo, Z.A, 2020 showed that maximum temperature negatively affects rice plant resulting in decrease in the number of plants at replantation stage. The positive impact of minimum temperature on rice production is also observed that may cause growth of plant, which affects the rice crop at replantation stage during vegetative phase. Results revealed that number of tillers and rice plant diet increase with the positive impact of rainfall at tillering stage.

The analysis of seasonal and annual surface air temperatures (Pant & Kumar, 1997) [] has shown a significant warming trend of 0.57 ˚C per hundred years. Mall and Singh (2000) observed that small changes in the growing season temperature over the years appeared to be the key aspect of weather affecting yearly wheat yield fluctuations.

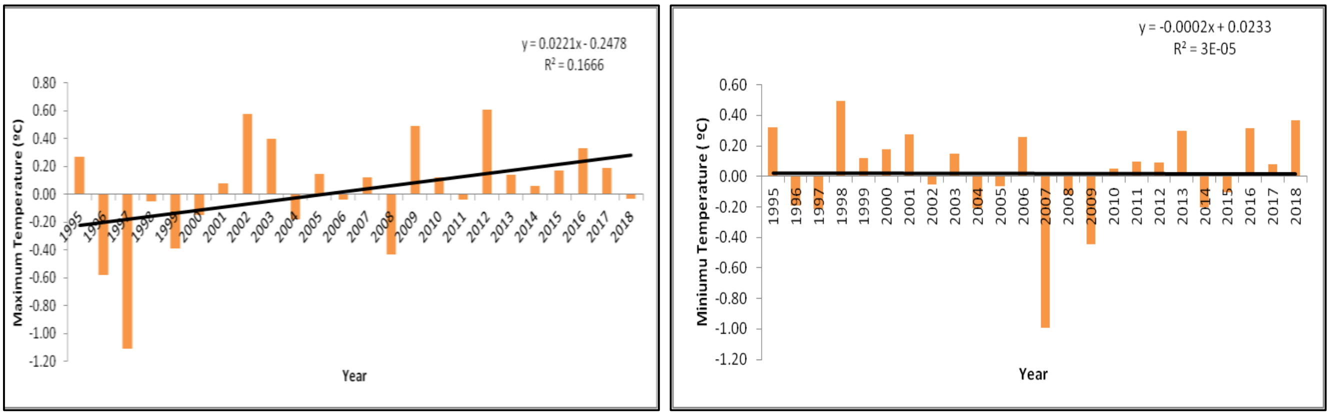
The minimum and maximum temperature shows a rising trend both in summer or 'Kharif' growing season (June – October) as well as winter or 'rabi' growing season starts after summer monsoon. The accompanied increase in minimum temperatures increases maintenance respiration requirement of the crops and thus further reduces net growth and productivity (Aggarwal, 2003).

Recent trends of a decline or stagnation in the yield of rice-wheat cropping system in Indo-Gangetic plain and north western India have raised serious concern about the regions food supply (Aggarwal *et al*., 2000; Mall and Srivastava, 2002; Pathak *et al*., 2003). This trend clearly indicates the reduced factor of productivity in case of the rice-wheat cropping systems. These variations in trends of productivity indicate the effects of other biophysical and socio-economic components, which needs to be eliminated before embarking on assessing the impacts of climate change and its variability on growth and yield of crops.

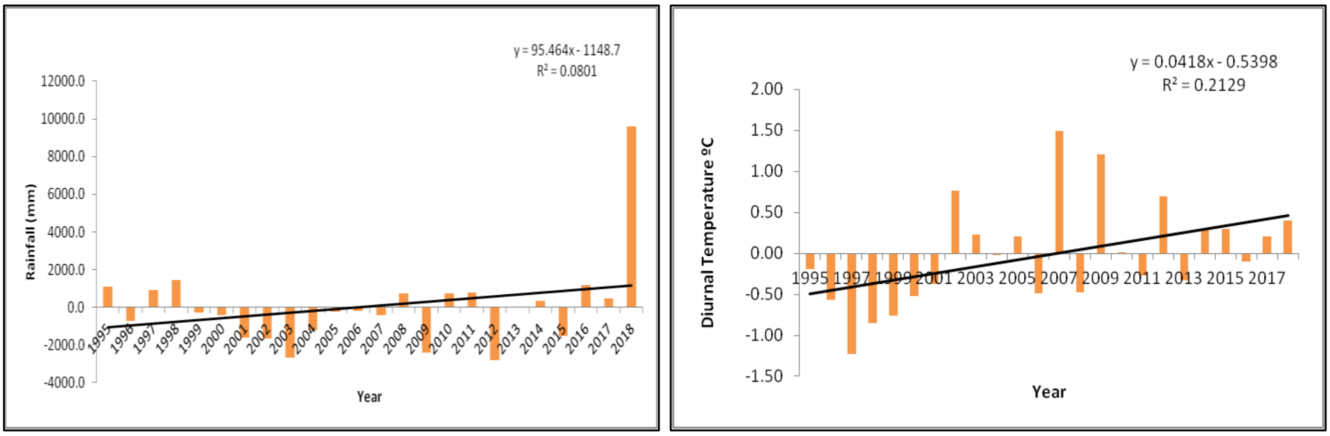
Saini and Nanda (1986) reported 0.5 ˚C increase in winter temperature would reduce wheat crop duration by seven days and reduce yield by 0.45 ton/hectare. An increase in winter temperature of 0.5 ◦C would thereby translate into a 10% reduction in wheat production in the high yield states of Northern India.

As per the output from SAI, after 2001, maximum temperature remained above the long term average except for the years 2004 and 2008 indicating an overall warming trend. A continued warming trend was observed in case of minimum temperature except for few years (2007, 2008, 2009, 2014 and 2015). Rainfall, on the other hand, did not show any significant variation from 1995 to 2018 during the Kharif crop season.

Fig 6: Variations in Climatic Parameters- Minimum T, Maximum T, Diurnal T and Rainfall during *Kharif Crop* season (1995-2018), District Mandi, H.P.



(A) (B)



(C) (D)

Fig 7: SAI for Climatic Parameters- Minimum T, Maximum T, Diurnal T and Rainfall, during *Kharif Crop* season (1995-2018), District Mandi, HP

During Rabi crop season, Diurnal temperature registered statistically significant increase of 0.030 °C per year in District Mandi. Meanwhile, the maximum and minimum temperature and rainfall did not show significant changes from 1995-2018. As per the outputs from SAI, maximum temperature showed a warming trend from 2004 onwards, except for dip in the year 1998, 2000, 2005 and 2008 for maximum temperature. Whereas for minimum temperature from 2004 onwards there was a warming trend except for the years 1997, 2000, 2001, 2003, 2011 and 2013. Whereas no significant pattern was observed for diurnal temperature and rainfall.

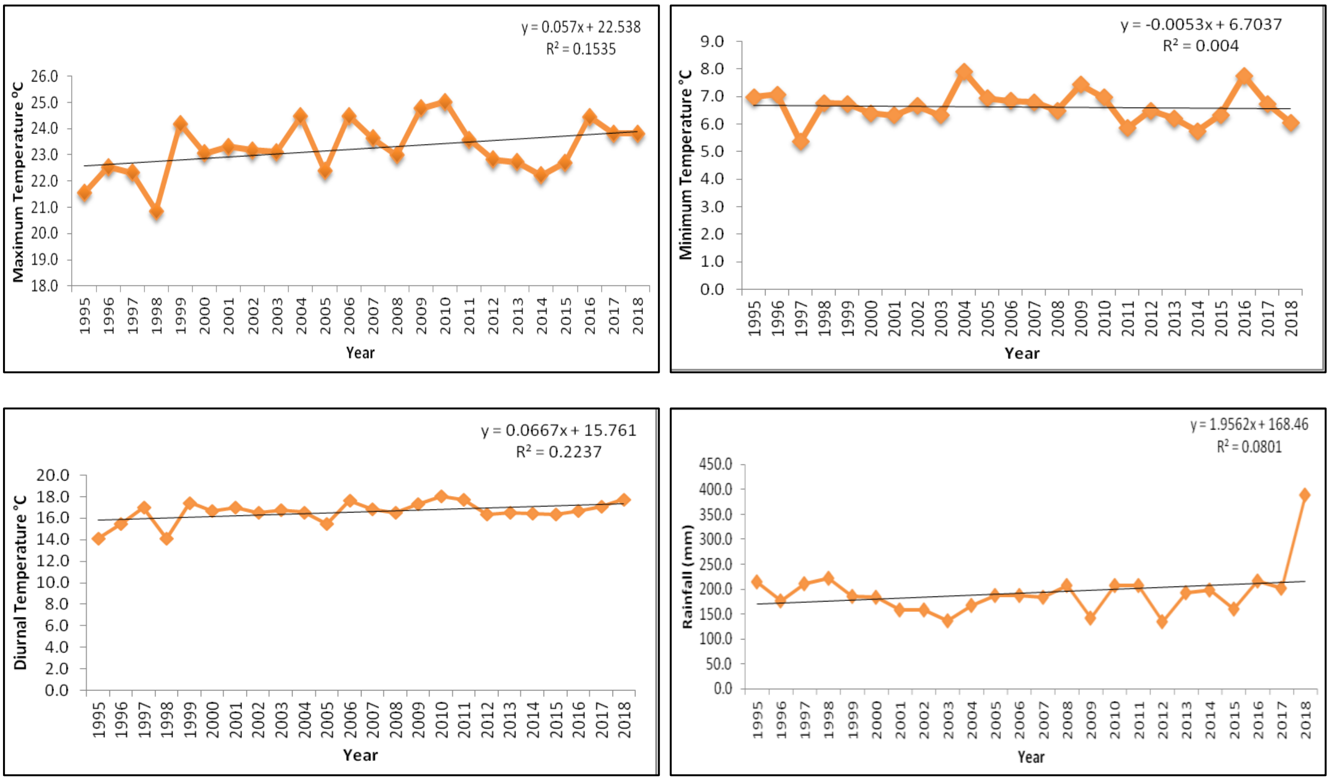


Fig 8: Variations in Climatic Parameters- Minimum T, Maximum T, Diurnal T and Rainfall during *Rabi Crop* season (1995-2018), District Mandi, HP

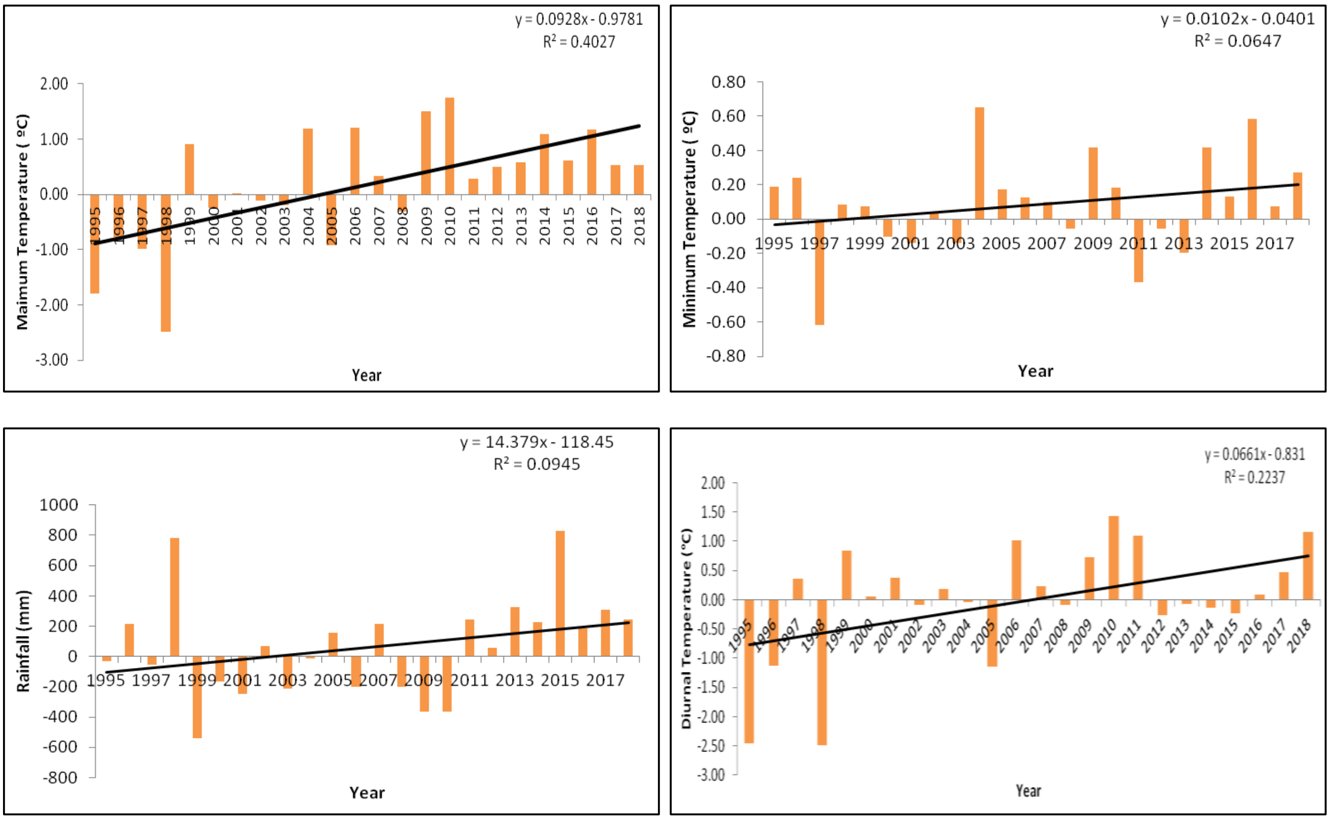


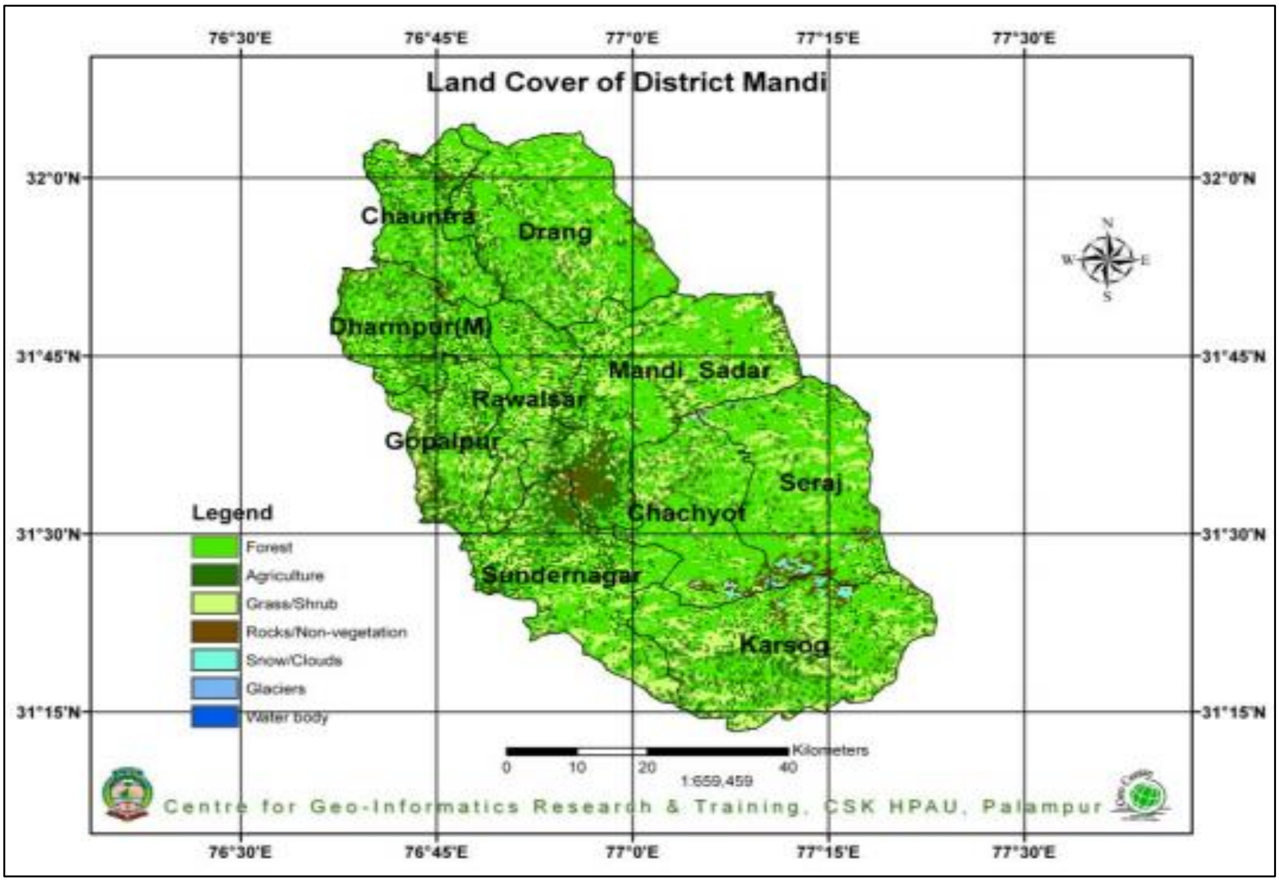
Fig 9: SAI for Climatic Parameters- Minimum T, Maximum T, Diurnal T and Rainfall during *Rabi Crop* season (1995-2018), District Mandi, HP

The discussed variations in temperature and rainfall patterns are not confined to District Mandi but are corroborated by various observations from other studies in the Himalayan region. Poudel and Shaw (2016) [10] observed an increase of 0.07 °C in minimum temperature and 0.02 °C in maximum temperature from 1980 to 2010 in Nepal bound Himalayan region, while comparing minimum annual temperatures with maximum temperatures. Recent increases in climate variability may have affected crop yields in countries across Europe since around the mid-1980s (Porter & Semenov 2005) causing higher inter-annual variability in wheat yields. (added new literature to mandi)

Meanwhile, Bhutiyani *et al*. (2007) [1] reported a significant increase in temperature in the north-west Himalayas by about 1.6 °C with faster pace of winter warming. Specifically in Himachal Pradesh, the rate of increase in maximum temperature was observed to vary with altitudinal zones (higher altitudes registered higher rate of increase). Rainfall patterns have been observed to remain steady in the Himalayan region (Joshi *et al*., 2011), as also observed in our study.

3.1 Crop Productivity

District is situated between 31^0 13'' to 32^0 04' N and 76^0 36' to 77^0 23' E in the centre of Himachal Pradesh having total 2-D area 3949.96 sq. km. The elevation ranges between 516 m to 4030 m above sea level. The three dimensional surface area of the district is 5402.766 sq.km. Hence an additional area of 1443.162 sq. km has been reported as veiled in the district. The district has the highest area under forest cover (52 per cent) followed by grass/shrub (23 per cent). Agriculture is also practised in 22 per cent of the total area. North –East and South-East part of the districts are having the high mountain ranges. Rocks/Non vegetation comprises 2 percent of the total area whereas glaciers and water bodies collectively cover only 0.5 percent area of the district. According to the department of Land Records, Himachal Pradesh the total area under agriculture use is 1008 sq km (26%) which is 4% higher than mapped and estimated area. The defined forests are 1860 sq km (47%) of total geographical area which is 5% less than estimated. The total geographical area of the district is 3951.



Source: Report on District wise Centre for Geo-informatics, Research and Training CSK Himachal Pradesh Agricultural University.

Land Cover of District Mandi

3.2 Acreage and Production Assessment of Major Agricultural Crops

Major food crops of the district are Paddy, Maize, Wheat, Barley and Potato. Acreage under these crops has also witnessed a change over the time. Temporal trends of change in area, production and productivity of different food crops in District are illustrated in figure 12 to 17. Rice crop acreage witnessed a drastic decrease of 43.9 per cent from 33958 to 1,9019 ha during 1970 to 2010, while production decreased 30.11 per cent from 2,271 MT to 1,587 MT in 2010. Area and production of Maize exhibited a increasing trend, from 66954 ha to 126176 ha 1970-2018; whereas the production decreased by 19.31% from 27,662 MT in 1966 to 22,318 MT in 2010. Similarly, Wheat experienced a decreasing trend in acreage from 11,943 ha in 1966 to 9,338 ha in 2010; whereas production of wheat increased by 36.42% from 8,207 MT to 11,196 MT in 2010. However, Barley also showed a decrease in the production during the study period. Barley crop acreage witnessed a drastic increase by 226.81 per cent where as production increased by 477.3 per cent.

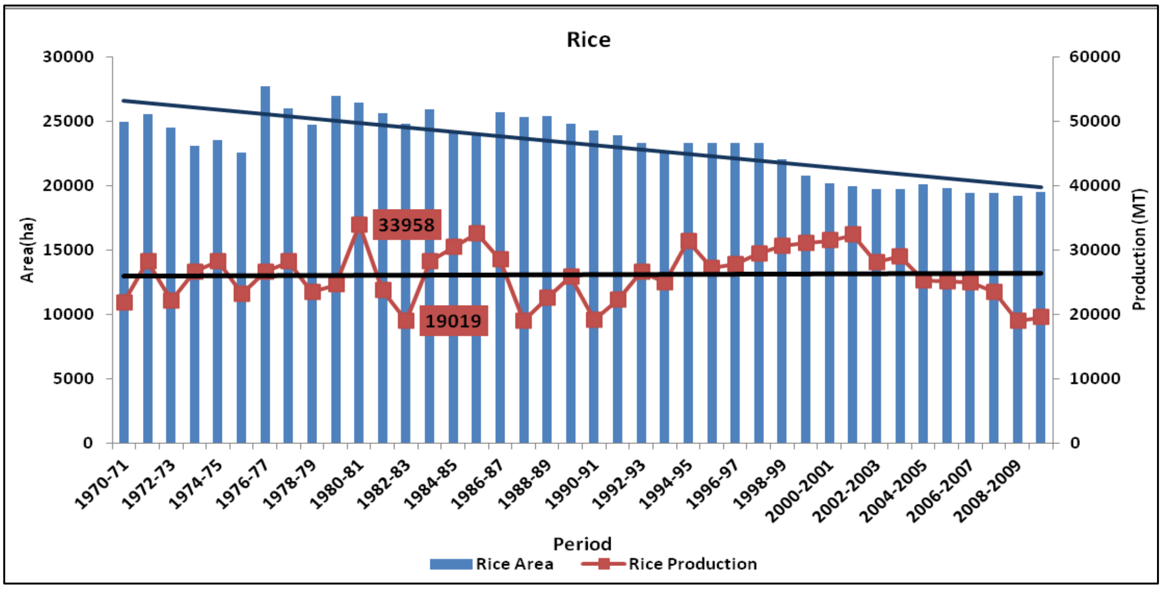


Fig 12: Variations in Area and Annual Production of Rice (1970-2010), District Mandi, HP

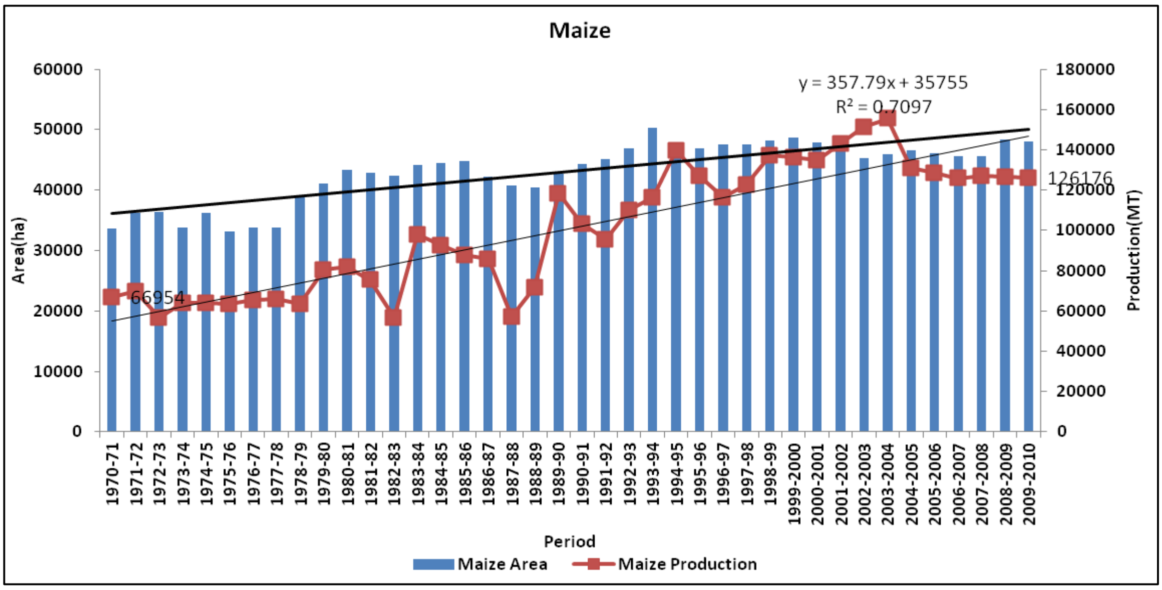


Fig 13: Variations in Area and Annual Production of Maize (1970-2010), District Mandi, HP

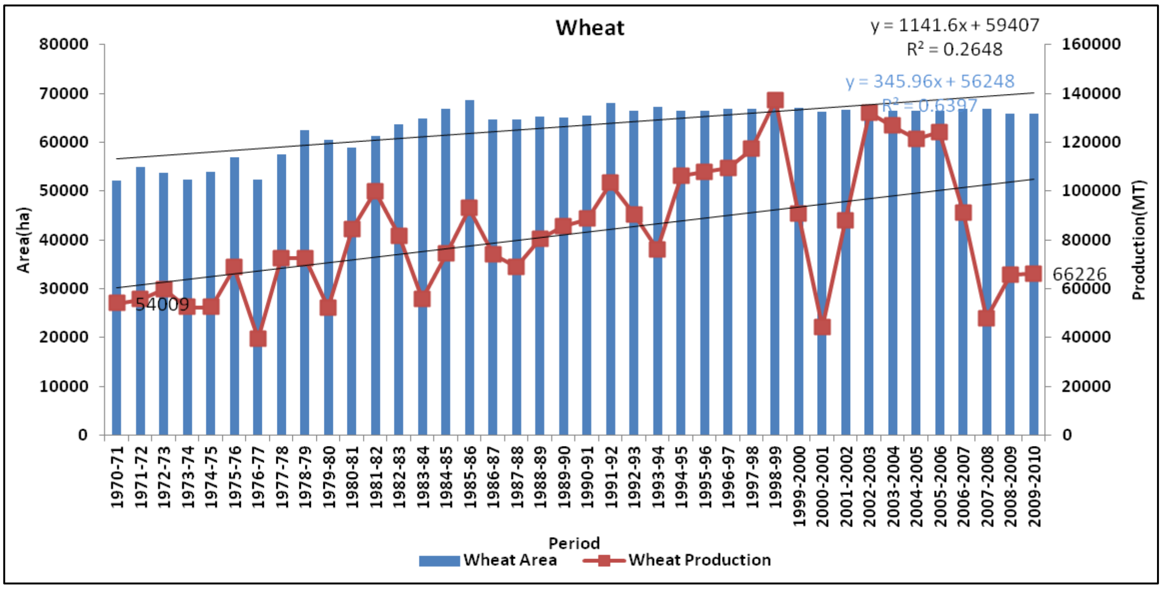


Fig 14: Variations in Area and Annual Production of Maize (1970-2010), District Mandi, HP

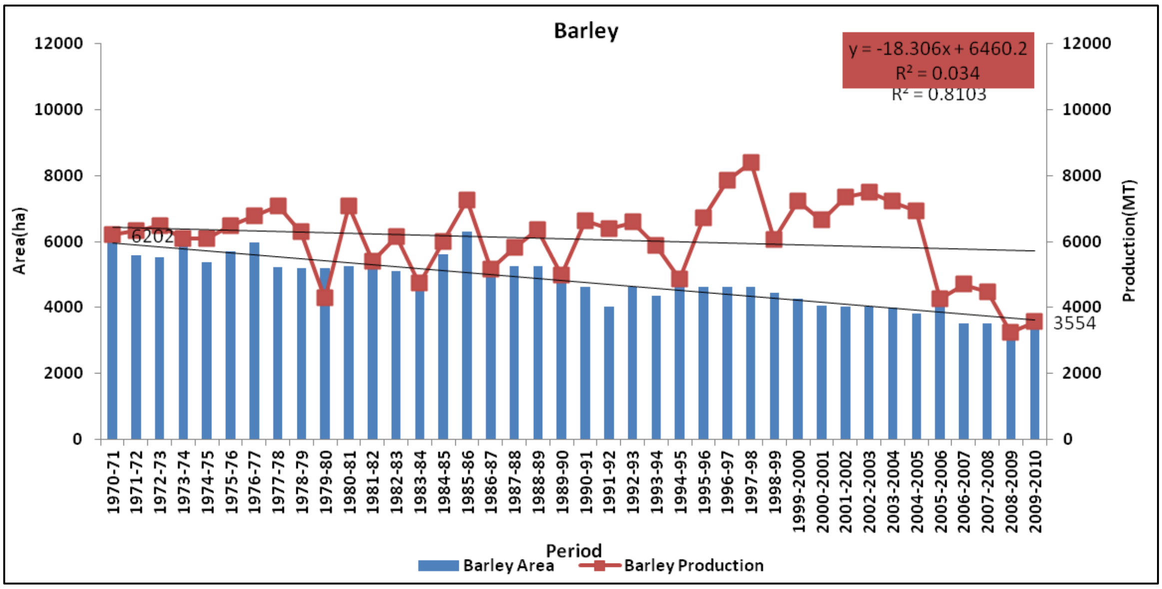


Fig 15: Variations in Area and Annual Production of Barley (1970-2010), District Mandi, HP

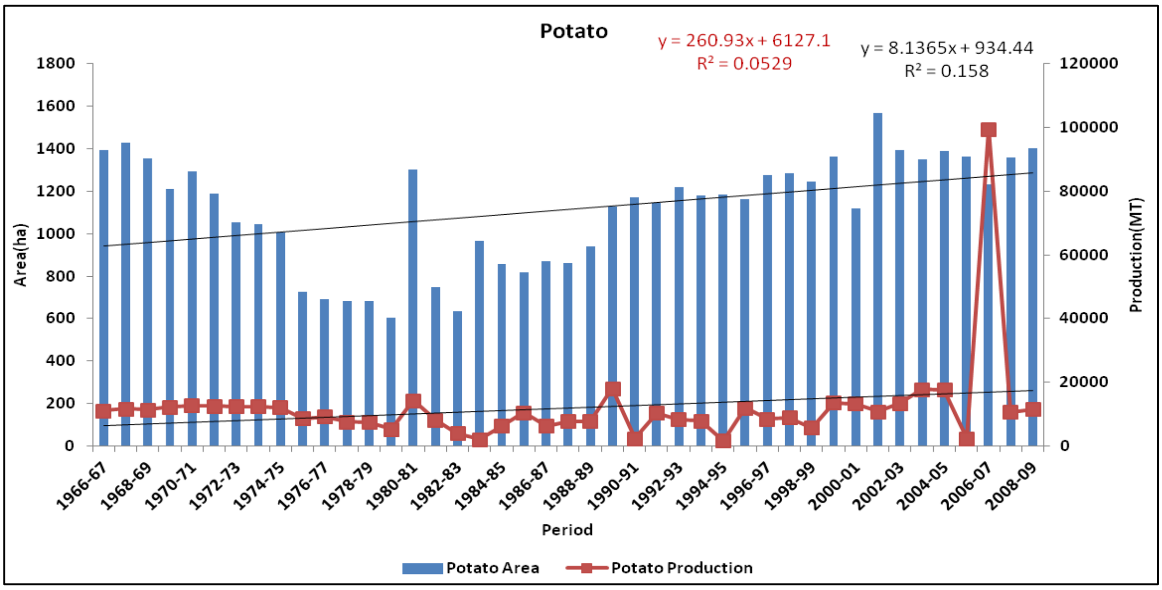
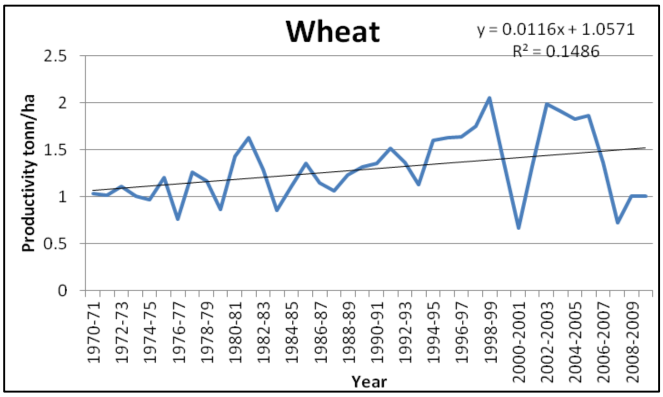
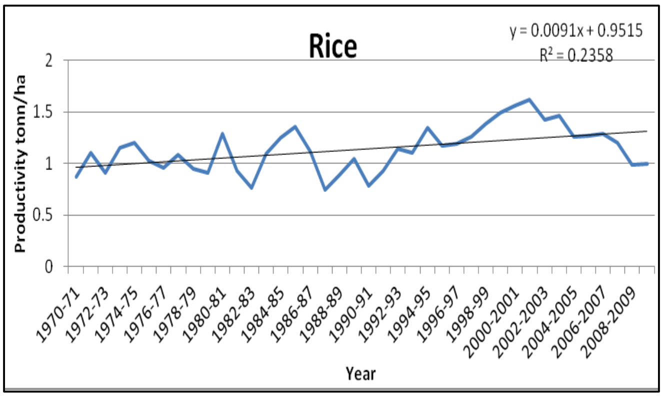


Fig 15: Variations in Area and Annual Production of Potato (1970-2010), District Mandi, HP

Analysis of productivity trends for Rice, Maize, Potato, Millets, and Wheat crops showed significantly changing yields during 1970-2009 time periods, except for Barley (illustrated in figure 17).





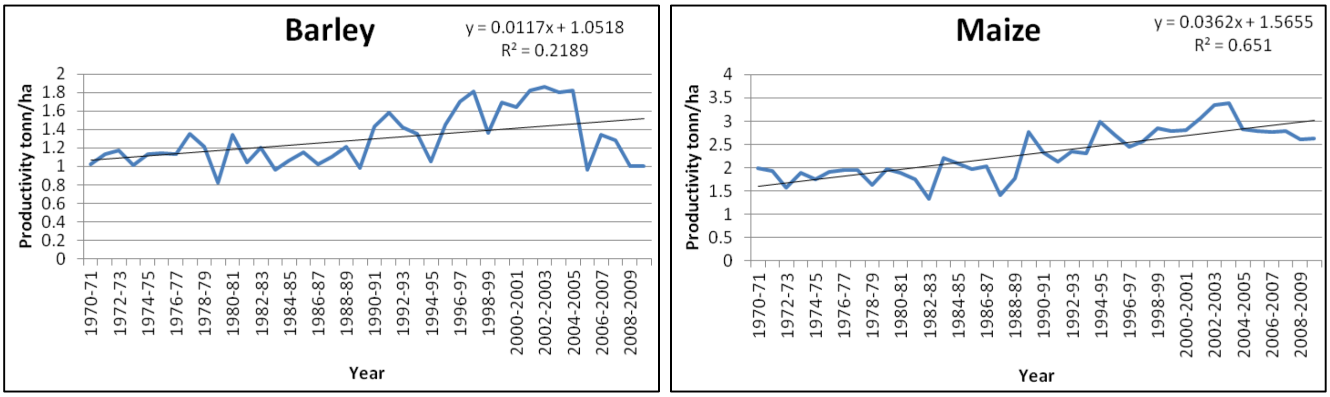


Fig 17: Variations in Productivity - Rice, Wheat, Maize, Barley, District Mandi, HP

As per the outputs from Mann Kendal Tests, an overall increased productivity trend is recorded for Maize (see table 5), wherein exhibiting significant decrease in productivity trend recorded in rice crop as compared to the other crops. Maize showed an increased crop yield of 0.035 t ha^{-1} year $^{-1}$ respectively. Only rice crop registered a decline in productivity by -0.01 t ha^{-1} $year^{-1}$. Barley crop showed increase in the productivity at the rate of 0.017 t ha^{-1} $year^{-1}$ but it is non significant value.

Table 5: Mann Kendall Test Results – Crop Yields for Kharif and Rabi Season (1971-2009).

Crops	Mean	Sen's slope	p-value
Wheat	1.284	0.016	0.017
Barley	1.289	0.017	0.000
Rice	1.169	-0.01	0.000
Maize	2.266	0.035	<0.000
Potato	9.045	-0.064	0.164

From the table above it can be seen that only rice (-0.01) and maize (0.035) crops showed significant variations in productivity (as per interpretation of p - values at 95% confidence intervals). Other crops showed non significant variation in the changes in climate system are quite complex to show immediate impact on any sector. Agriculture stands to witness exacting economic impact of climate change, especially with the continuous passage of time under 'as is' scenario. Various studies aimed to predict future course of climatic impact on agriculture have forecast for decline in grain yields with warming temperatures in many developing countries, even though they may be witnessing growth as per recent census data (Mendelsohn & Dinar, 1999) [4] (Kumar & Parikh, 2001) [3] (Mendelsohn *et al.*, 2011) [5]. Further, it is estimated that while an overall increase in mean temperature is certain, its impact on agricultural productivity remains highly subjective to magnitude and timing of extreme temperatures (Gornall *et al.*, 2010) [2].

3.3 Climate-Crop Juxtaposition

To ascertain the relationship between climatic variability and crop productivity, a correlation analysis was performed using the statistical tool – *Pearson's coefficient*. The results revealed a strong relationship between climate variability and productivity of Kharif crop such as rice whereas negligible association was observed for the *rabi* crops (wheat and barley) in District Mandi (Table 5). While testing the effects of variability in maximum temperature, diurnal temperature, and rainfall, a significant and positive trend (0.200, 0.310 and -0.54) was observed for rice crop productivity (with a p-value of 0.04, 0.001 and 0.02).

Table 6 illustrates the regression outcome of detrended [1] climatic variables of minimum, maximum, diurnal temperature and rainfall with the productivity of selected crops.

For all assessed crop varieties *viz.*, Wheat, Barley, Rice, Maize and Potato only 10.1%, 5.2%, 26.1%, 11.3% and 6.1% of productivity variability could be explained from temperature and rainfall variations in the district. With respect to individual crops, this means that the observed significant changes in the productivity of rice and non significant changes in maize from 1970-2010 is explained by the variations in climatic parameters only to the extent of 26.1 and 11.3% respectively. Factors of access to improved seed varieties, extensive fertilizer application, and better farm practices are touted to be the explanatory reasons for remainder variations in crop yield (Sharma, 2011) [6].

Table 6: Multivariate Linear Regression Analysis – Crop Yields and Climatic Parameters, (1970-2010)

Crop	Variable / Statistics	Minimum temperature	Maximum temperature	Diurnal temperature	Rainfall	R^2	Change (%)
Wheat	Coefficient p-value	0.07 0.37	0.12 0.28	0.09 0.33	0.07 0.35	0.101	10.1%
Barley	Coefficient p-value	-0.02 0.45	-0.29 -0.08	-0.29 0.08	0.29 0.07	0.052	5.2%
Rice	Coefficient p-value	0.01 0.09	0.20 0.04	0.31 0.001	-0.54 0.02	0.261	26.1%
Maize	Coefficient p-value	0.07 0.39	0.02 0.46	-0.03 0.45	-0.35 0.09	0.113	11.3%
Potato	Coefficient p-value	0.07 0.37	0.12 0.28	0.09 0.33	0.07 0.35	0.061	6.1%

4. Conclusion

The mean maximum temperature increased by 0.035 °C per year during Kharif crop season. Meanwhile, the diurnal temperature exhibited a increasing trend of 0.057 °C per year. Rainfall did not register any statistically significant result during the study period. Moreover, the Standardized Anomaly Index of maximum temperature depicted a warming trend from 2002 onwards except for dips in 2004 and 2008. During the Rabi crop season, the diurnal temperature increased by 0.030 °C per year. Maximum and minimum temperature and Rainfall did not register any statistically significant result. Meanwhile, the Standardized Anomaly Index (SAI) of maximum temperature showed a warming trend from 2006 onwards whereas minimum temperature showed warming trend from 2005 onwards. A 1 °C rise in maximum temperature in Rabi season reduces the yield of wheat crop significantly by around 10%, while a similar rise in minimum temperature leads to a significant in the yield by 6% (Ritambhara Singh *et al*, 2017) [11]. For all assessed crop varieties *viz.*, Wheat, Barley, Rice, Maize and Potato only 10.1%, 5.2%, 26.1%, 11.3% and 6.1% of productivity variability could be explained from temperature and rainfall variations in the district. With respect to individual crops, this means that the observed significant changes in the productivity of rice and non-significant changes in maize from 1970-2010 is explained by the variations in climatic parameters only to the extent of 26.1 and 11.3% respectively. With respect to individual crops, this means that the observed increase in productivity for Maize and Potato from 1970-2010 is explained by the variations in climatic parameters only to the extent of 11.3% and 6.1% respectively but it was non-significant. Similar interpretation stands for the decline in productivity for rice production climate change will reduce grain yield declined by 10% for each 1 °C increase in growing-season minimum temperature in the dry season, whereas the effect of maximum temperature on crop yield was insignificant. This report provides a direct evidence of decreased rice yields from increased nightime temperature associated with global warming, Shaobing Peng *et al.*, 2004 [12].

Ry (2071-2100) under medium emission scenario indicating an overall reduction in rice production from the current level by 2.5 to 5% during these periodsImpact of higher precipitation on Wheat production also depends strictly on geographical area. In general, higher precipitation in arid and semi-arid regions affects Wheat production positively. However, in regions with already high rainfall, more precipitation can reduce wheat crop productivity by nutrient leaching and water logging (Ludwig and Assent, 2006).

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