Impact of Climate Change on Agriculture Sector in District Kangra Himachal Pradesh

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EXEUTIVE SUMMARY

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. Particularly, in the fragile Himalayan eco-system, where over 72 million people rely on access to species-rich forests, hill agriculture, fresh water sources, and bio-diversity for their survival; the increasing pressure from burgeoning population combined with global climate change is pushing the ecological hotspot to a dangerous point, thus creating unfavourable conditions for agrarian livelihood of mountain communities. 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.

To this effect, a status study was conducted with a view to ascertain the impact of climate change on agricultural activities in District Kangra. 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 Kangra.

During Kharif crop season, the maximum temperature and Diurnal T rose at the rate of 0.017°C and 0.041°C per year respectively (as exhibited by the Sen's slope).Meanwhile the minimum temperature exhibited a decreasing trend of 0.016 °C. And for Rabi crop season maximum temperature and diurnal temperature rose at the rate of 0.039°C and 0.039°C per year respectively. Rainfall, on the other hand, did not show any significant variation from 1971-2018.however in Ravi season there is less rainfall at the rate of (-0.051mm).

During Rabi crop season, Max Temperature and Diurnal temperature registered statistically significant increase of 0.039°C and 0.03°C per year respectively in District Kangra. Meanwhile, the minimum temperature and rainfall did not show significant changes from 1971-2018.

As per the outputs from SAI, maximum temperature showed a warming trend from 1994 onwards, except for dip in the year 2014 and 2015. Whereas no significant pattern was observed for minimum temperature and rainfall

As per the output from SAI, after 1992, maximum temperature remained above the long term average except for the years 1997, 2006 and 2008 indicating an overall warming trend. Meanwhile cooling trend was observed in case of minimum after 1992 temperature except for 2013 and 2014 years. Rainfall, on the other hand, also showed increase in rainfall from 1994 to 2018 except few years during the Kharif crop season.

For all assessed crop varieties viz. Wheat, Barley, gram, Rice, Maize, black gram, horse gram and only 20.7%, 7.7%, 8.0%, 19.7%, 18.1%, 9.3, %and 3.5% of productivity variability could be explained from temperature and rainfall variations in the district. With respect to individual crops, this means that the observed increase in productivity for Wheat, Barley, Rice, Gram, Black gram, and Horse gram from 1971-2009 is explained by the variations in climatic parameters only to the extent of 20.7% ,7.7%, 8.0%,19.7% ,9.3% and 3.5% respectively. Similar interpretation stands for the decline in productivity for maize and potato.

CHAPTER 1 - INTRODUCTION

CLIMATE AND AGRICULTURE

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)). Climate Change is *defined as climate variability induced by direct or indirect anthropogenic activities in addition to natural climate variations causing alterations in composition of global atmosphere observed over comparable time periods*. It holds inextricable interlinks with Agriculture through concurrent crop yields, biodiversity, water use, and soil conditions that has greater global relevance as the mismatch between world population and world food production continues to grow. As per FAO forecast, if world population were to reach 9.1 billion by 2050, the world food production should increase by 70 per cent (PI, 2009).

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). In this regard, a large number of exploratory studies have analysed the potential impact of climate variability on agricultural productivity and livestock alike, especially in context of developing countries. Rural landscapes and the equilibrium between the forest and the agrarian ecosystems is expected to be significantly impacted (Walker & Steffen, 1997) (Bruijnzeel, 2004) as would be the pressing concerns around food security due to unstable crop production, induced market changes, and supply chain infrastructures (Sanchez, 2000) (Siwar et al., 2013). Many studies also highlight agriculture's supplementary role as a provider of renewable natural resources, landscape protection, biodiversity conservation, and an avenue to maintain socio-economic activities in rural areas (Klein et al., 2014).

There are certain succinct factors linking climate change to agriculture that need to be understood to get a better grasp of their dependencies.

- *Precipitation*: Water cycle is critical to agricultural system and shifting seasonality in precipitation can impact the water availability for grasslands and cropping system.
- *Hydrologic*: Hydrologic cycle characterised by frequent and intense droughts and floods in many agricultural plains can be detrimental to crop yield and soil fertility.
- *Heat*: Anticipated temperature rise is expected to result in recurrent heat waves, fewer frost days, and longer growing season in temperate zones.
- *CO_2* : Concentration of CO_2 is predicted to increase within the range 463-1099 parts per million by 2100[1] and the response of higher CO2 concentration is expected to be on C3 species i.e. *wheat, rice, and soybeans (accounting for more than 95% world's species)* more than on C4 species (*Corn and Sorghum).*
- *Crop Biodiversity*: Adverse impact on distribution of wild crop relatives, an important genetic resource for crop breeding. Climatic changes directly govern physiological constraints on growth and reproduction of wild species, and indirectly drive the ecological factors of resource competition.
- *Economic Consequences*: Fluctuations in crop yield can lead to price rise for most important agricultural crops such as rice, wheat, maize, and soybeans that will have a spill-over surge in feed and meat prices.
- According to the Intergovernmental Panel on Climate Change (IPCC), temperatures in India are likely to rise by 3-4°C by the end of 21st century (2007). Without any adaptation measure, this temperature increase is expected keep the agriculture sector reeling with lower farm incomes by 15 per cent and 18 per cent for irrigated and un-irrigated areas respectively. 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 2 and table 1 below.

[1] Estimates of CO_2 concentration range from 478 ppm to 1099 ppm by 2100, given the range of emissions and uncertainties about the carbon cycle

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)

THE HIMALAYAS AND CLIMATE CHANGE VULNERABILITY

The Himalayan ecosystem in particular is positioned at high vulnerability with respect to pressing perils of looming climate change. While heightened focus of recent research and discussions have been around glacial retreat and its impact on downstream water discharge, nevertheless there are growing evidences for the potential cascading impact of climate change in the Himalayas on all connected and satellite regions. The fragile Himalayan ecosystem, owing to its geological history and structural rock set-up, is fast approaching a state of disequilibrium with apparent changes in its resources and environment.

The Indian Himalayan region is home to over 72 million people living in over 10 states covering 95 districts spread in an area of 5 lacs square km, representing around 16 per cent of country's geographical area. Due to its high biological and socio-cultural diversity, the Himalayan ecosystem is inherently susceptible to natural hazards that are prone to aggravated occurrence of floods, droughts, and landslides, caused by drastic changes in climatic conditions.

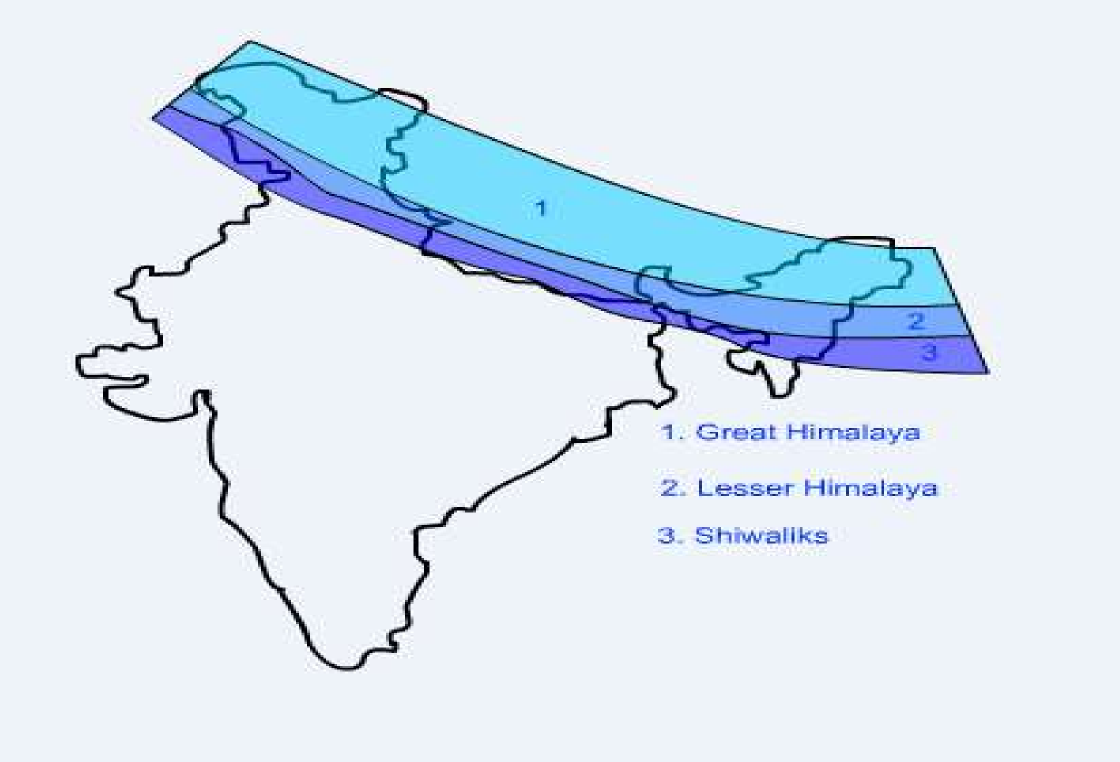


Figure 1: Geographical Representation of the Indian Himalayas
Source: Divecha Centre of Climate Change, Indian Institute of Science, Bengaluru (2018)

Further, human reliance on mountain ecosystems is well established for its verve to provide ecological and social security. Mountains are regions of heightened economic importance and social relevance offering invaluable access to species-rich forests, hill agriculture, fresh water sources, bio-diversity and the traditional gen. Nevertheless, this fragile ecosystem is

undergoing dramatic changes that stand to impact the life and livelihood of those dependent on its products and services. In the western Himalayas, particularly, striking vegetative changes are observed where various plant species are migrating to higher altitudes due to warming trends (Padma, 2014), and other are in grave danger of extinction. Additionally, the Hindu-Kush-Himalayan region is witnessing early trends of greening while a habitat loss of around 30 per cent is expected for Snow Leopards owing to continuous forest losses (Panday & Ghimire, 2012) (Forrest et al., 2012). Further, the fragile Himalayan region is also experiencing a gradual increase in temperatures higher than the world average of 0.7º C in the last century. Increasing pressure from burgeoning population combined with global climate change is pushing the ecological hotspot to a dangerous point of no return that can be unfavourable to the agrarian livelihood of mountain communities.

SETTING THE SCENE

Himachal Pradesh is a mountainous state in the northernmost part of India, situated in the western Himalayas between latitude 30º 22’ 40” N to 33 º 12’ 40” N and longitude 75 º 45’ 55” E to 79 º 04’ 20” E. The State has a complex geological structure that dissects its topography in extreme altitudinal ranges from 350m to 6,975m above sea level. Owing to these extreme variations in elevations, it experiences varied climatic conditions, ranging from hot and sub-humid tropical in the southern tracts to cold, alpine and glacial in the northern and eastern mountain ranges with higher elevations. There are 6.86 million people in the State with almost 90 per cent residing in rural areas. There is incessant reliance on agriculture as a source of income and employment for around 71 per cent of the population and mixed farming, agro-pastoral, silvi-pastoral, and agro-horticulture are the predominantly adopted farming systems. Nevertheless, of the geographic area of 55.67 lacs hectares only 10 per cent of the State’s net area comes under cultivated land and 81 per cent of this cultivated area is rainfed. However, only one lac hectare of net sown area is with assured irrigation. Major food crops in the state are rice, maize, barley, jowar, pulses, millet, potato and many other off-season vegetables and a comprehensive profile of horticulture crops.

HIMACHAL PRADESH – CLIMATIC PROFILE

The State has wide-ranging exposure to climatic conditions on parameters of temperature and precipitation. Depending on the altitude, climatic conditions vary from hot and sub-humid tropical at 450m-900m in southern low tracts, warm and temperate at 900m-1,800m, cool and temperate climate at 1,900m-2,400m, and cool alpine and glacial in extreme northern and eastern mountain ranges at 2,400m-4,800m. The state’s climatic profile can be better understood with respect to its division in three physiographic regions – *Outer Himalayas* (covering District Bilaspur, Hamirpur, Kangra, Una, and lower parts of Mandi, Sirmaur, Solan), *Lesser Himalayas* (covering parts of District Mandi, Sirmaur, Chamba, Kangra, Kangra), and *the Greater Himalayas or the Alpines* (covering District Kinnaur, Lahaul & Spiti, Chamba).

Climate change does not have even and uniform impact on any region and with these topographical and varied climate classifications in Himachal Pradesh, the vulnerability and risk quotient becomes significant with regional variance. There is substantial literature and research to support the expected varied impact of climate change in Himachal Pradesh. Based on the findings of short-term analysis at different altitudes, Bhutiyani et al. (2007) observed a significantly higher temperature variation in the north-western Himalayan region when compared to the global averages in the last century, and concluded that rate of increase in maximum temperature changes is directly linked to the changes in altitudes. Bhan and Singha (2011) predicted a shortening of seasons by 10-12 days earlier per decade based on assessment of precipitation data for 20 years. Kumar et al. (2009) and Shrestha et al. (2012) reported an average increase of 1.52 °C in annual minimum temperature (Kullu Valley, 1962-2004), and 1.5 °C in annual mean temperature (25 years) in the State. With reference to precipitation, Himachal Pradesh is witnessing a period of uncertain and untimely rainfalls and snowfalls, which is likely to impact water availability and replenishment of snow fed gravity channels (kuhls), thus affecting irrigation support to agriculture. As per the estimates from Himachal Pradesh State Action Plan on Climate Change (2012), a 40 per cent reduction in rainfall has been observed in last 25 years. In nutshell, annual temperatures are expected to rise for all seasons with significant decline in snowfall in mid-hills temperate wet agro-ecological zones. The frequency of rains is expected to increase but with diminished average intensity creating drought conditions in some pockets and accelerated summer flows in the north-western part of the State.

STATE'S AGRO-ECOLOGICAL PROFILE

Himachal Pradesh is divided into four agro-ecological zones based on characterised precipitations, altitude, cultivated and irrigated area. Table 2 below highlights the details for four zones with information on district coverage. A further magnified and bifurcated agro-ecological classification is illustrated in figure 4.

Table 2: Agro-ecological (new) Classification, Himachal Pradesh

	Zone I	**Zone II**	**Zone III**	**Zone IV**
Ecology	Sub Montane & Low Hill Sub-tropical	Mid Hills Sub-humid	High Hills Temperate Wet	High Hill temperate dry
Geographic Area (%)	18.43	8.37	16.54	56.61
Cropped Area (%)	40	37	21	2
Irrigated Area (%)	17	18	8	5
Altitude (m)	240-1,000	1,001-1,500	1,501-3250	Above 2501
Mean Annual Temp	15 ºC - 23ºC	14ºC - 22ºC	9.1ºC – 20.6ºC	9ºC - 20ºC
Rainfall (mm)	1,100	1,500 (except Dharmshala,	1,000	>1,500

		Palampur : 3000mm)		
Soil	Shallow, Light textured, low fertility	Loamy to Clay loam deficient in Nitrogen and Phosphorus	Shallow, acidic, silt loam to loam, deficient in Nitrogen and Phosphorus	Sandy loam, neutral to Alkaline, Low fertility
Major crops	Wheat, Maize, Paddy, Pulses, Oilseeds, Barley, Sugarcane, Potato Citrus fruits, Mango, Litchi	Wheat, Paddy, Barley, Pulses, Oilseeds Off-season vegetables Citrus Fruits	Wheat, Barley, Millets, Pseudo-Cereals (Buckwheat, Amaranthus), Maize, Potato, Oilseeds Off-season vegetables Apple and other temperate fruits and nuts	Wheat, Potato, Barley, Pseudo- Cereals (Buckwheat and Amaranthus), Peas, Minor Millets, Kuth and Temperate vegetables Apples, Grapes, Almonds, Walnuts, Apricot Zeera, Hops, Cumin, Saffron
Districts	Kangra, Una, Hamirpur, Bilaspur, Solan, and Parts of Chamba, Sirmaur	Parts of Chamba, Kangra, Mandi, Kangra, Sirmaur, Kullu, Kinnaur, Hamirpur, Bilaspur	Kangra, Chamba, Kangra, Mandi, Kullu, Solan, Sirmaur, Kinnaur, Lahaul & Spiti	Kangra, Lahaul & Spiti, Kinnaur, and Parts of Chamba, Mandi, Kullu, Sirmaur, Kangra

Source: Agro-Ecological Zonation of Himachal Pradesh – Agricultural System Information Development at micro-level, Centre of Geo-informatics, CSK Himachal Pradesh Agriculture University, Palampur (Bhagat et al., 2006)

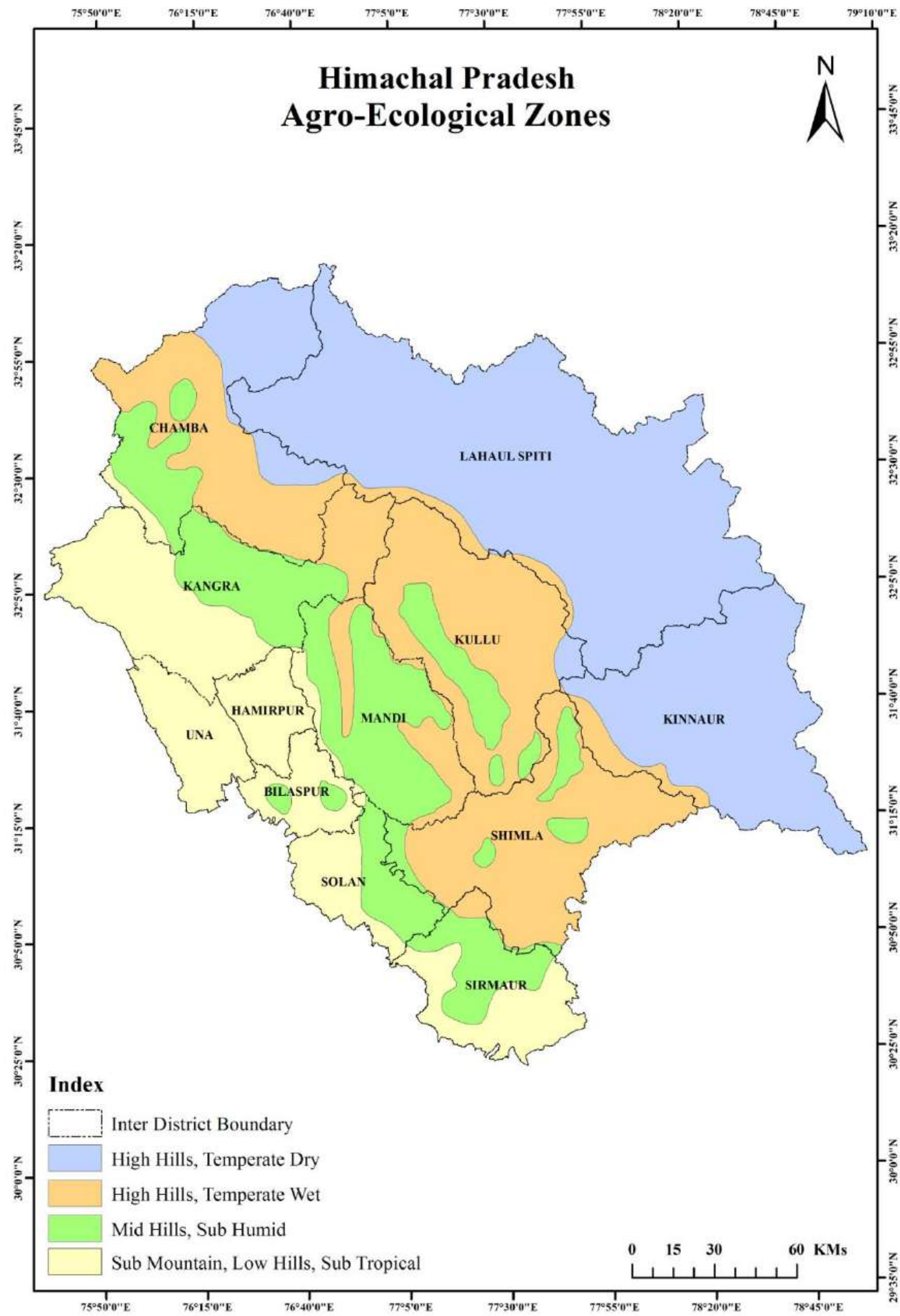


Figure 2: Himachal Pradesh Agro-Ecological Zones

Source: Adapted by HPSCCC from Agro-Ecological Zonation of Himachal Pradesh – Agricultural System Information Development at micro-level, Centre of Geo-informatics, CSK Himachal Pradesh Agriculture University, Palampur (Bhagat et al., 2006)

As noticeable from above, a majority of agriculture exposure is spread across Zone II and III in the State. Nevertheless, each zone and each district is characterised with different soil, climatic, and precipitations pattern. As per IPCC estimates, high confidence negative impacts of climate change on crop yields are observed across crop categories than positive impacts. Human managed ecosystems such as food production and livelihood sustenance are found to be highly vulnerable to climate change 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 change in climatic patterns of temperature, precipitation, and humidity on yields of *rabi* and *kharif* crops.

To that effect a status study was conducted to ascertain the impact of climate change on agricultural activities in the state focusing on District Kangra. Seasonal trends on climatic variables of minimum, maximum, and diurnal temperatures, and rainfall patterns were conjugated with a standardised anomaly index and a multivariate regression analysis was conducted to establish the climate and crop yield relationship during Rabi and Kharif seasons.

ORGANISATION OF STATUS REPORT

The status report designed to provide a snapshot view of statistical impact of climate change on agriculture in the state with an astute focus on District Kangra, and is organised as:

1. Case study outlines with a details on adopted methodology
2. Presentation of Key Findings on Climate-Crop Juxtaposition based on statistical measurements
3. Conclusion with a reflection on report results for future adaptation planning, and government interventions

CHAPTER 2 – ASSESSMENT FRAMEWORK

CLIMATE TREND ASSESSMENT

To better understand the impact of climate change variable of temperature and precipitation (rainfall) vis-à-vis parameters of agriculture productivity the following statistical measures were employed.

TREND ANALYSIS

Seasonal trends on climatic variables of minimum, maximum, and diurnal temperatures were conducted using the Mann Kendall Test – a widely accepted statistical test for analysis of trend in climatologic and hydrologic time series (Pohlert, 2018). This statistical test comes with two-fold advantages – first, being a non-parametric test it does not require the master data to be normally distributed. Second, the test shows low sensitivity to abrupt data breaks and inhomogeneous time series. Therefore, data gaps are plugged by assigning a common value smaller than the smallest measure value in the master data set. The Mann Kendall Test works on the basic null hypothesis H_o of no trend i.e. data is independent with a random order that is tested against the alternative hypothesis $H_{1.}$

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

In the ordered time series, each data point is compared with the subsequent data point, and in case the subsequent data point is of higher value, the statistic *S* is incremented by 1, for a lower value of subsequent data point, S gets decremented by 1. The net results of all iterations give the final value of *S i.e. Mann Kendall S statistic*

$$S = \sum_{i=1}^{n-1} \sum_{j=i+1}^{n} sign\ (T_j - T_i)$$

$$Sign\ (T_j - T_i) = \begin{cases} 1\ if\ T_j - T_i > 0 \\ 0\ if\ T_j - T_i = 0 \\ -1\ if\ T_j - T_i < 0 \end{cases}$$

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

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

Magnitude of the trend is determined by *Sen's Slope,* which essentially computes the linear rate of change and intercept. First, a set of linear slopes is ascertained, then the Sen's Slope is calculated as the median from all linear slopes that gives the magnitude of the observed seasonal trend. Another statistics linked to the Mann Kendall test is the *p-value.* Smaller the p-value (smaller than 0.05), greater is the weight of evidence against the null hypothesis of no trend.

For this study, the statistical Mann Kendall test is carried on software XLSTAT 2017. The null hypothesis is tested at 95% confidence level for minimum, maximum, and diurnal temperate, and rainfall for the time period 1971-2016. Further, annual trends were conducted for productivity of wheat, barley, rice, maize, and millets.

STANDARDIZED ANOMALY INDEX (SAI)

SAI is a commonly used index used for regional climate change studies that 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). 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, the standardized precipitation indices were also calculated for the cropping seasons.

MULTIVARIATE LINEAR REGRESSION MODEL

To ascertain the climate-crop yield relationship, linear multivariate regression statistical measure is selected. In multivariate linear regression model, a dependent variable is guided by multiple independent variables and hence, multiple coefficients are determined. Key to a successful outcome is associated with a careful selection of independent variables for which a correlation matrix is created. In this study, Pearson's correlation coefficient was used to measure the strength of association between climatic variables and crop productivity. For interpretation purposes, a correlation coefficient of -1 indicates perfectly negative linear relation; a correlation of 0 indicates no linear relationship between the two variable (but possibly a non-linear relationship); and, a correlation coefficient of 1 shows a perfectly positive linear relation. The value of correlation coefficient can never be less than -1 or more than 1.

Here, the regression analysis helped to confirm the contribution of anomalies in studied climatic parameters on crop productivity, which can be explained by following linear model:

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

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. Coefficients α, β, γ and δ are the coefficients of minimum, maximum, diurnal temperature and rainfall, respectively. ΔT_{min}, ΔT_{max}, T_{dt}, ΔR, ΔRd are the observed changes in minimum, maximum, diurnal temperature, rainfall and rainy days respectively for the cropping seasons during the study period (1971- 2016).

CHAPTER 3 - PILOT CASE AND METHODS

DISTRICT KANGRA – A BACKGROUND

It is situated in Western Himalayas between latitude 31°2'-32°5' N, longitude 75°-75°45' E. The elevation above the sea level of Kangra district is in the range of 427 to 6,401 meters. The district is spread over 5,739 km² having about 216643 hectare of land, out of which 195738 hectare is under cultivation. In this district, river Beas flows through distance of 94.00 km. The soil characteristic is both sandy & loamy. The climate of district is pleasant around the year except in plains like Nurpur, Indora, Fatehpur areas where temperature may raise up to 40° C in the month of May/June. Monsoon sets in the first week of July and continues till mid September. It is extremely cold in winter. Various agricultural crops, vegetables and fruits are grown in different parts of district Kangra. Agriculture forms the backbone of the district economy.

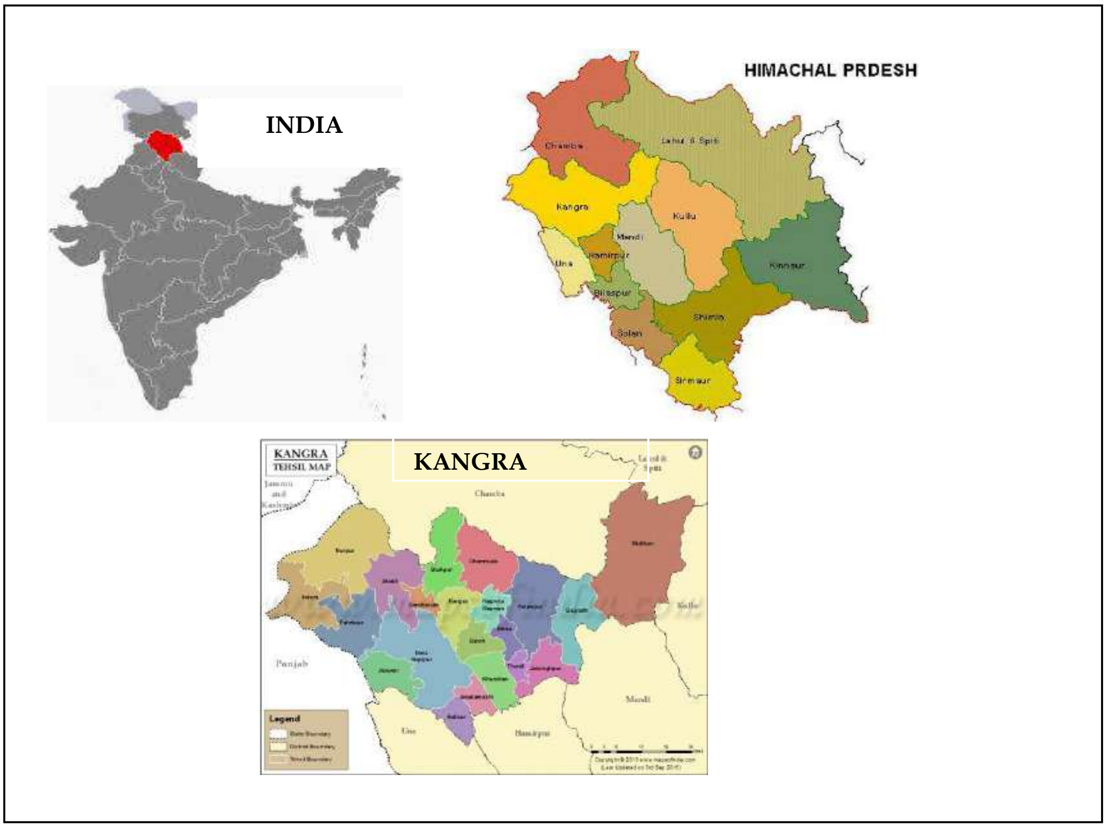


Figure 3: Map of District Kangra, Himachal Pradesh

Climate: It is situated in Western Himalayas between latitude 31°2′-32°5′ N,longitude 75°-75°45′ E. The elevation above the sea level of Kangra district is in the range of 427 to 6,401 meters. The district is spread over 5,739 km2 having about 216643 hectare of land, out of which 195738 hectare is under cultivation. In this district, river Beas flows through distance of 94.00 km. The soil characteristic is both sandy & loamy. The climate of district is pleasant around the year except in plains like Nurpur, Indora, Fatehpur areas where temperature may raise up to 40 °C in the month of May/June. Monsoon sets in the first week of July and continues till mid September.

Agriculture: Agriculture remains the primary occupation for the populace in District Kangra. Conducive agro-climatic conditions and favourable soil profile, enables cultivation of a varied types cereals, off season vegetables, temperate and stone fruits, and other cash crops in the district. Lower elevations are suitable for the production of cereal crops, citrus fruits.

Table 3: District Kangra: Agriculture Profile

Agriculture Profile – District Kangra					
Agricultural Land Use	**Total Geographical Area ('000 ha)** : 577.7	**Net Sown Area ('000 ha):** 116.3		**Cropping Intensity:** 184%	
Agro-Ecological Zone	Western Himalayas, Warm Subhumid (To Humid With Inclusion Of Perhumid) Eco-Region.				
Agro Climatic Zone (NARP)*	1. Sub-Mountain and low hills sub-tropical zone (HP-1)				
Irrigation	**Net Irrigated Area ('000 ha)** : 35.6	**Gross Irrigated Area ('000ha):** 66.5		**Rainfed Area ('000 ha):** 107.2 (69.4% of total cultivable area, 154.417)	
	Sources of Irrigation:		***Number***	***Area ('000 ha)***	***Irrigated Area (%)***
		Tanks	141	0.3	2.3
		Lift Irrigation Scheme	77	2.2	14.4
		Kuhls	88	5.8	36.7
		Tube wells	156	1.7	10.8
Major Crops	*Grain Crops:* Wheat, Maize, Rice, Barley, Pulses(black gram, gram and other)				

	Fruit Crops: Mango,Apple, Pear, Litchi ,Guava, papaya, Citrus, Other fruit *Veg.:* Tomata,Okra ,Onion,Cauliflower, French- bean, Capsicum .
Crop Sowing Window	***Kharif – rainfed:*** Maize – 3rd week of May – 3rdweek of June Paddy - 3rd week of May – 3rd week of June ***Kharif – irrigated:*** Paddy - 3rd week of May – 3rd week of June ***Rabi – rainfed:*** Wheat – 1st week of October to 4th week of December Barley – 3rd week of October to 2nd week of November ***Rabi – irrigated:*** Wheat – 1st week of November to 4th week of December

Source: Agriculture Contingency Plan, District Kangra, Himachal Pradesh (AGRICOOP, 2012)

METHODS

Within the context of collocation of climate variability and agriculture productivity in District Kangra, Himachal Pradesh, and 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.

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.

CLIMATE DATASETS

The mean minimum, maximum, diurnal temperatures, and rainfall data for District Kangra was collected from India Meteorological Department (IMD), Kangra covering a time period of 1971-2015. This data was categorised 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.

AGRICULTURAL DATASETS

Wheat, Barley, Rice, Maize, and Potato crops acreage and production data was collected from the Department of Land Records, Kangra 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.

CHAPTER 4 – CLIMATE TREND AND AGRICULTURE: DISTRICT KANGRA

CURRENT CLIMATE TRENDS –DISTRICT KANGRA

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* and rabi crop season for the study period spanned across 47 years. Table 4 exhibits the results of Mann Kendall test at 95% confidence level for minimum, maximum, and diurnal temperate, and rainfall for the time period 1971-2018.

Table 4: Mann Kendall Test Results – Climatic Trends for Kharif and Rabi Season (1971-2018)

	Mean	Sen's slope	p-value
Kharif			
Max T	27.911	**0.017**	**0.005**
Min T	18.795	-0.016	0.237
Diurnal T	9.116	**0.041**	**0.038**
Rainfall	358.416	4.167	<0.0001
Rabi			
Max T	19.827	**0.039**	**0.001**
Min T	9.493	-0.008	0.398
Diurnal T	10.334	**0.030**	**0.029**
Rainfall	80.222	-0.051	0.756

During Kharif crop season, the maximum temperature and Diurnal T rose at the rate of 0.017°C and 0.041°C per year respectively (as exhibited by the Sen's slope). Meanwhile the minimum temperature exhibited a decreasing trend of 0.016 °C and for Rabi crop season maximum temperature and diurnal temperature rose at the rate of 0.030°C per year respectively. Rainfall, on the other hand, did not show any significant variation from 1971-

2018. However in RaBi season there is less rainfall at the rate of (-0.051mm).As per the output from SAI, after 1992, maximum temperature remained above the long term average except for the years 1997, 2006 and 2008 indicating an overall warming trend. Meanwhile cooling trend was observed in case of minimum after 1992 temperature except for 2013 and 2014 years. Rainfall, on the other hand, also showed increase in rainfall from 1994 to 2018 except few years during the Kharif crop season.

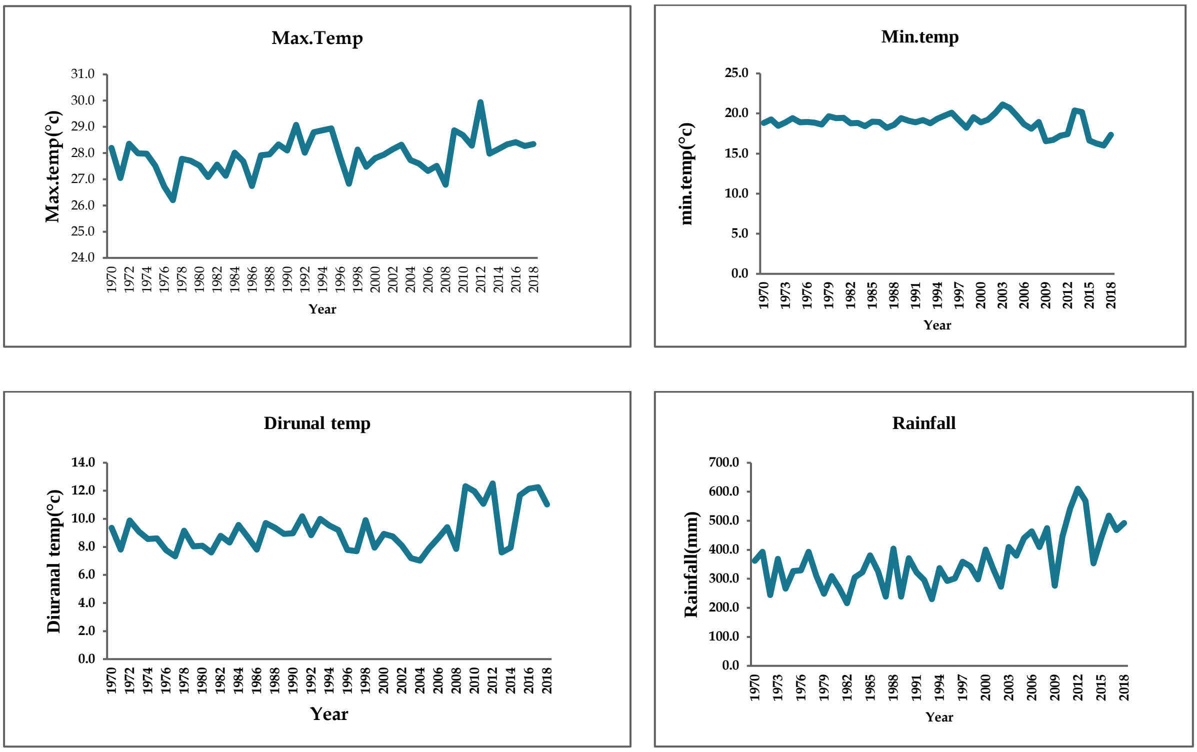
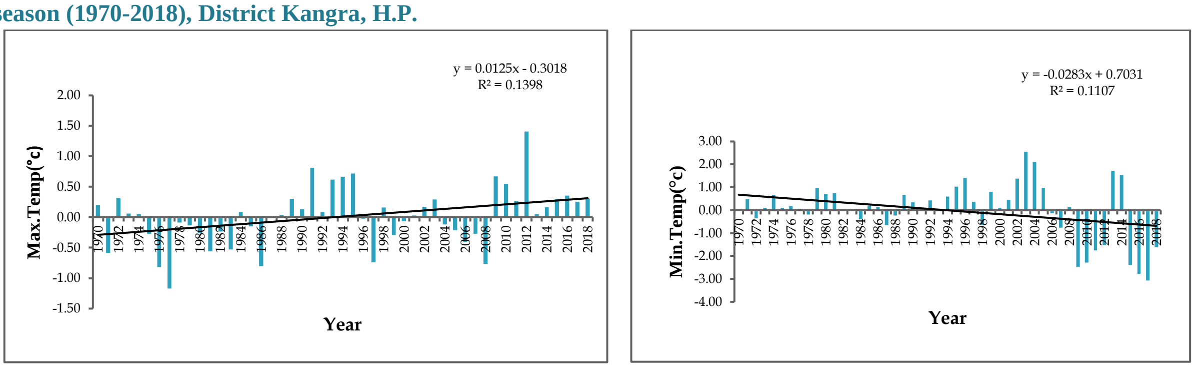


Figure 6: Variations in Climatic Parameters- Minimum T, Maximum T, Diurnal T and Rainfall during *Kharif Crop* season (1970-2018), District Kangra, H.P.



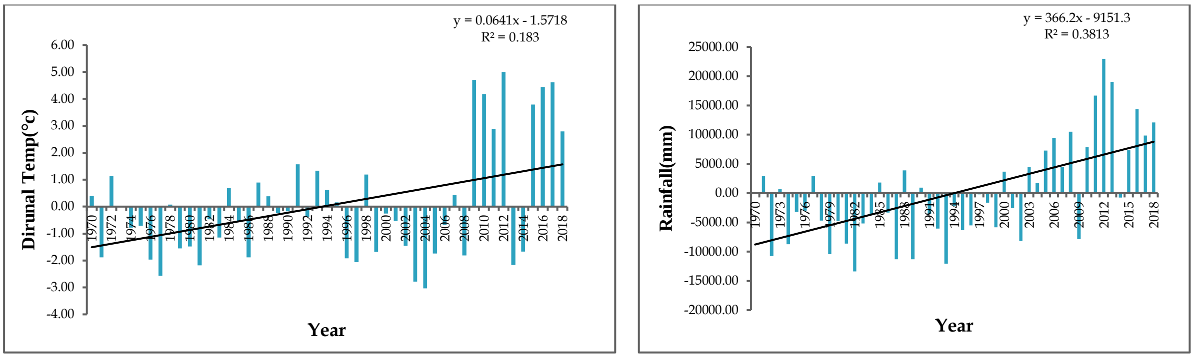


Figure 7: SAI for Climatic Parameters- Minimum T, Maximum T, Diurnal T and Rainfall, during *Kharif Crop* season (1970-2018), District Kangra , HP

During Rabi crop season, Max Temperature and Diurnal temperature registered statistically significant increase of 0.039°C and 0.03°C per year respectively in District Kangra. Meanwhile, the minimum temperature and rainfall did not show significant changes from 1971-2018.

As per the outputs from SAI, maximum temperature showed a warming trend from 1994 onwards, except for dip in the year 2014 and 2015. Whereas no significant pattern was observed for minimum temperature and rainfall for Rabi crops.

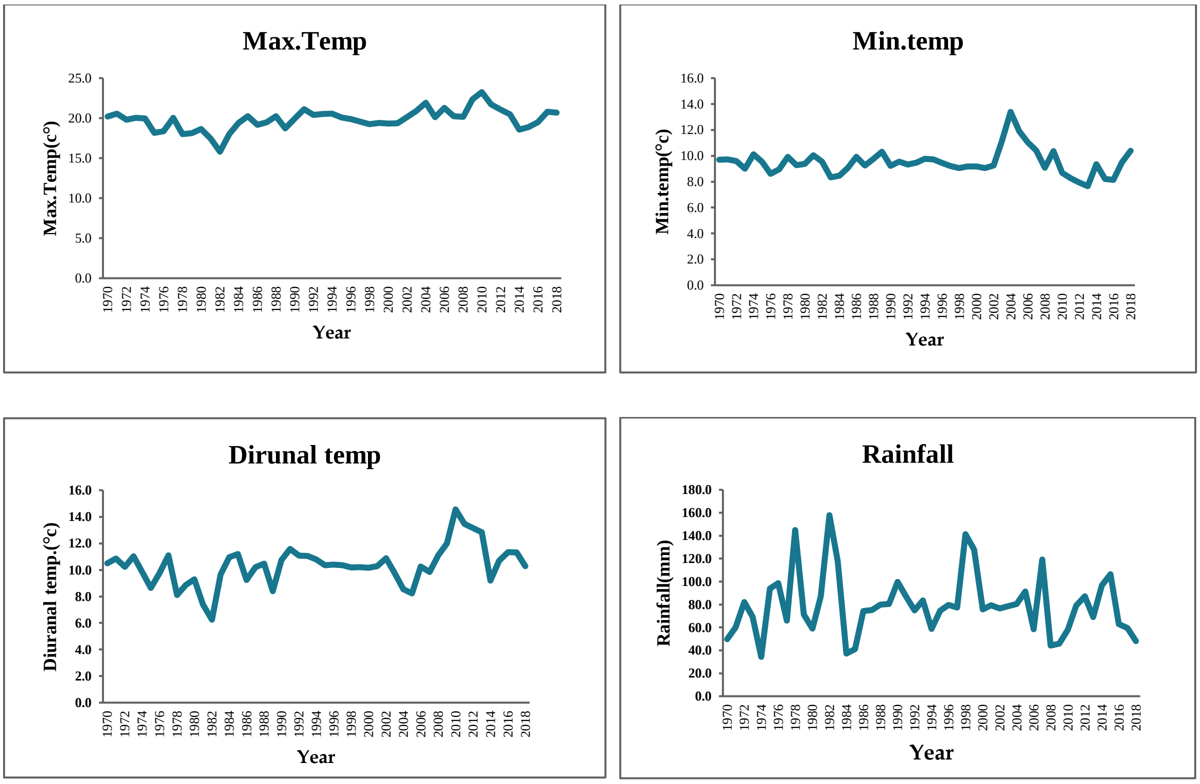


Figure 8: Variations in Climatic Parameters- Minimum T, Maximum T, Diurnal T and Rainfall during *Rabi Crop* season (1970-2018), District Kangra, HP

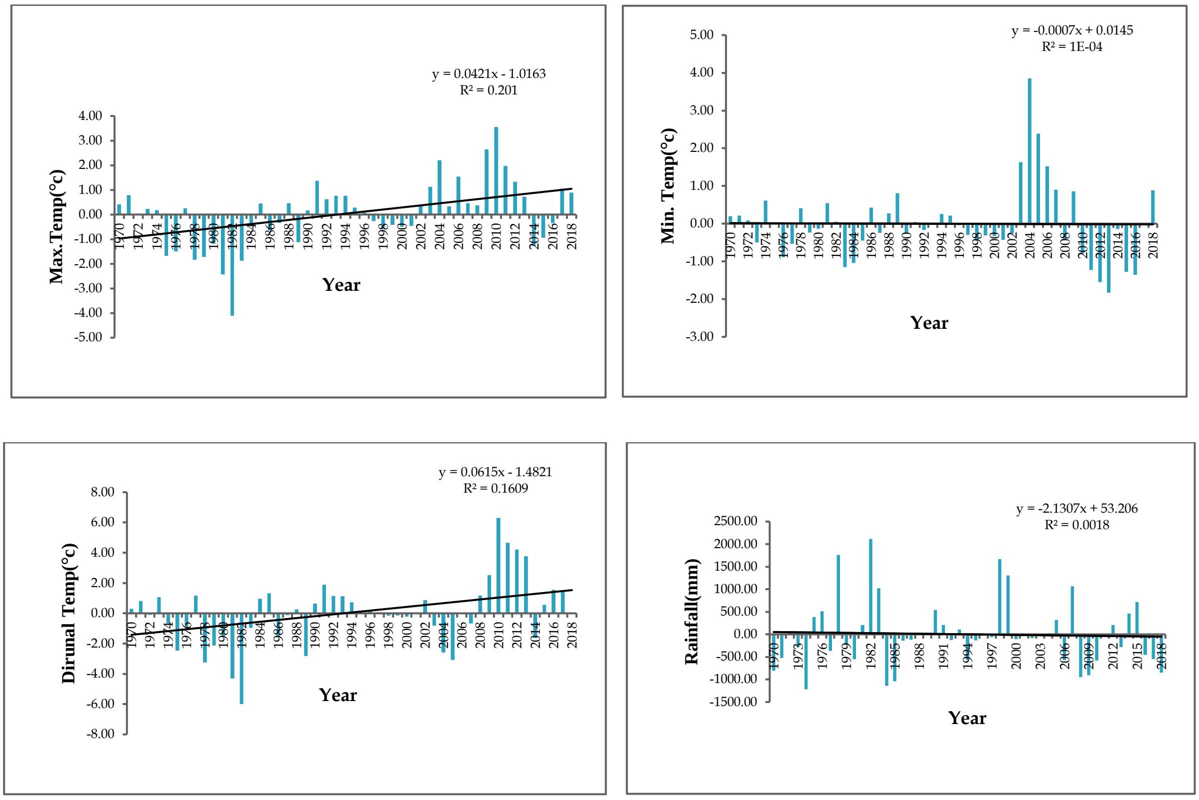


Figure 4: SAI for Climatic Parameters- Minimum T, Maximum T, Diurnal T and Rainfall during *Rabi Crop* season (1970-2018), District Kangra, HP

CROP PRODUCTIVITY – DISTRICT KANGRA

ACREAGE AND PRODUCTION ASSESSMENT OF MAJOR AGRICULTURAL CROPS

Major food crops of the district are Paddy, Maize, Wheat, Barley Potato Gram, Black gram and Horse Gram. 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 Kangra are illustrated in figure 12 to 17. Rice crop acreage witnessed a drastic decrease of from 47,338 to 36,888 ha during 1967 to 2010, while production increased from 35,181 MT to 55,836 MT in 2010. Area and production of Maize exhibited a decreasing trend, from 91685 ha in 1967 to 58455 ha in 2010; whereas the production from 1, 14,770 MT in 1967 to 93,531 MT in 2010. Similarly, Wheat experienced a decreasing trend in acreage from 1, 02,124 ha in 1966 to 93,859 ha in 2010; whereas production of wheat increased from 55,658 MT to 1, 40,418 MT in 2010. Barley crop acreage witnessed a decrease of from 4,456 to 2,871 ha during 1967 to 2010, while production increased from 2,819 MT to 3,075 MT in 2010. However, Potato showed slight increase in acreage 1392 ha to 1400ha. And the production increased during the study period. However pulses i.e. Gram, Black Gram and Horse Gram showed drastic decrease in acreage 5,874ha to 268ha, 10,096 to 2,210ha and 4,354 to 182ha respectively from 1967 to 2010 and its production also showed decrease 1,762MT to 157MT, 2,776MT to 869MT and 1,197MT to 79 MT respectively.

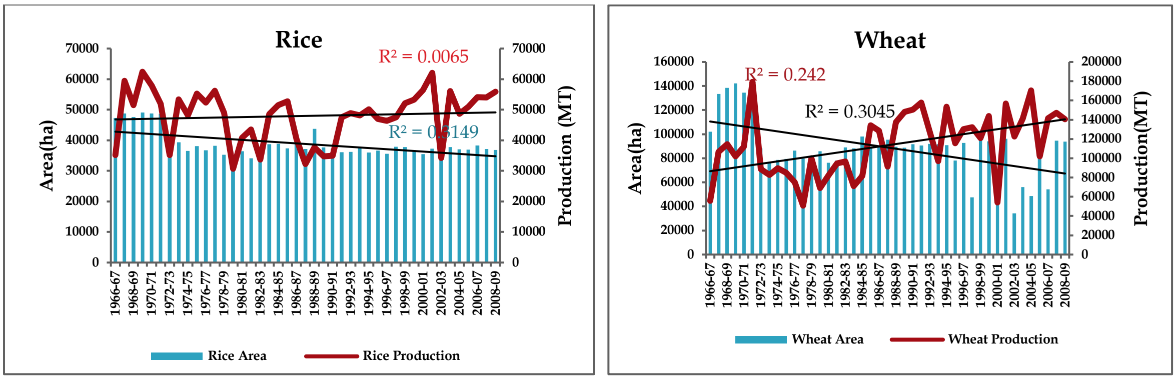


Figure 5: Variations in Area and Annual Production of Rice (1966-2009), District Kangra, HP

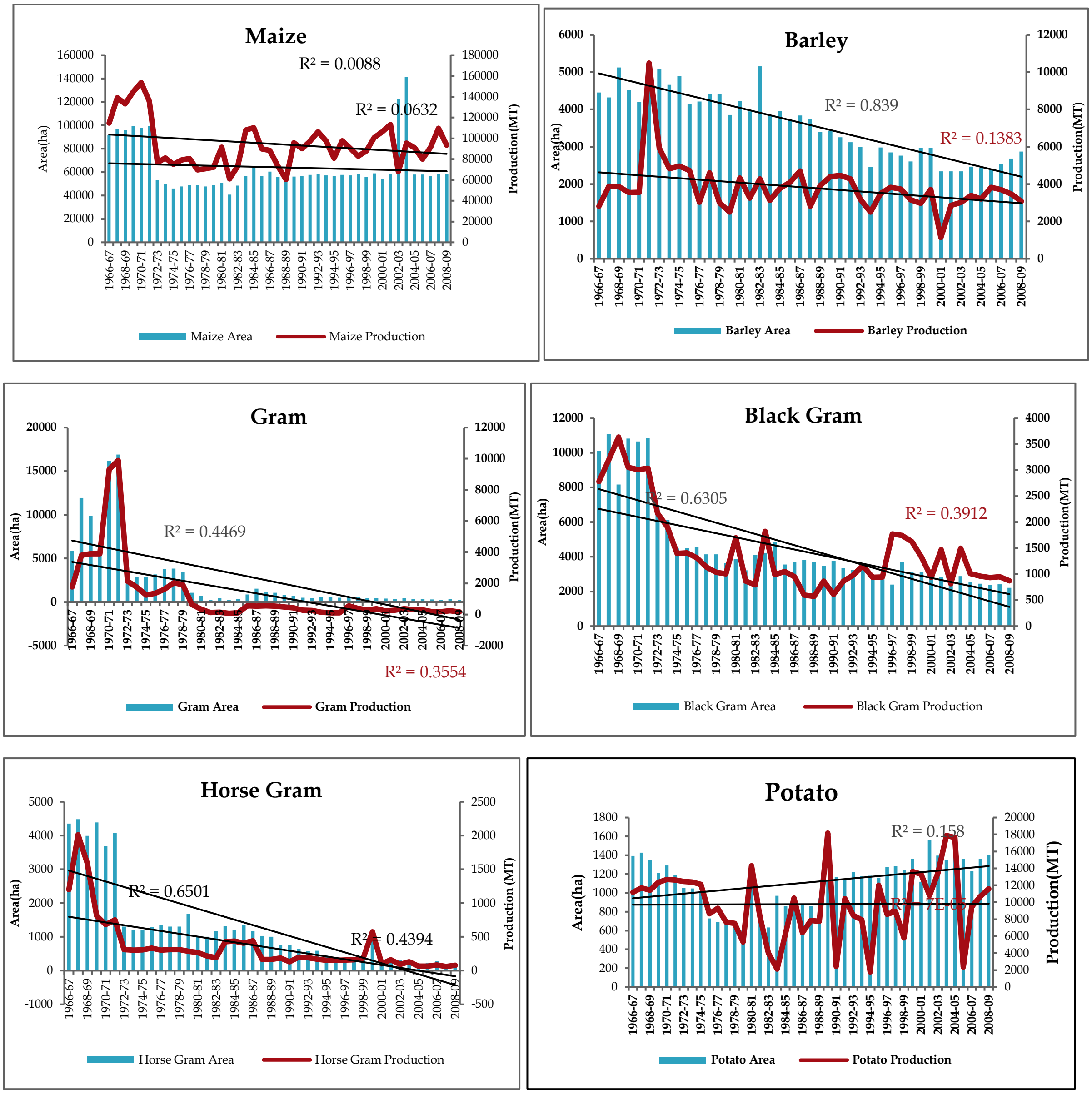
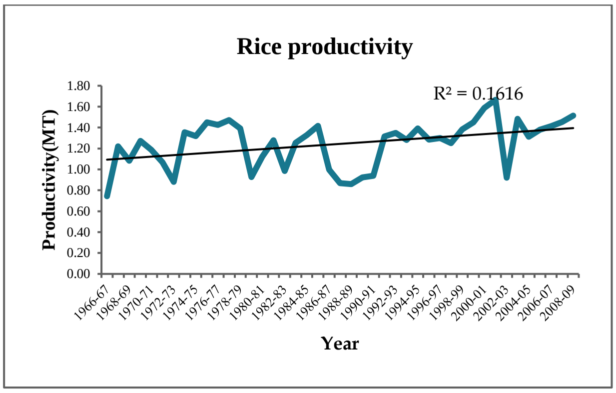
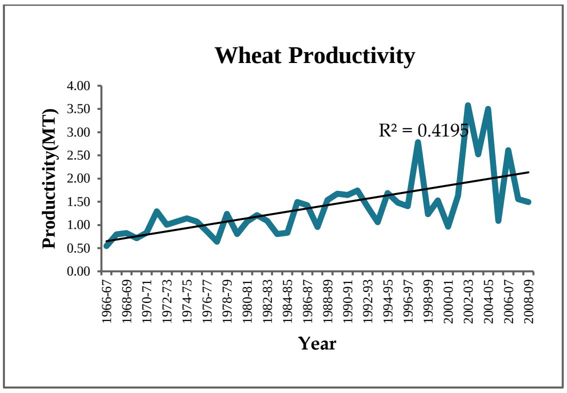
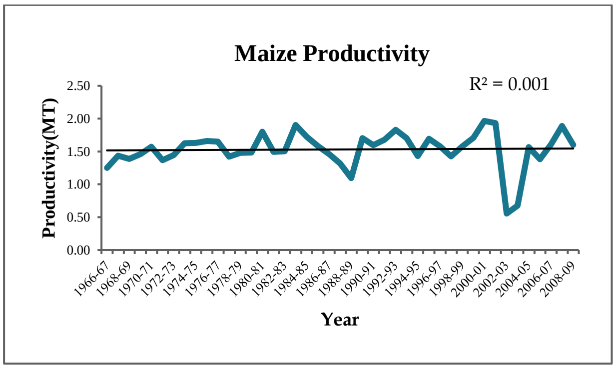


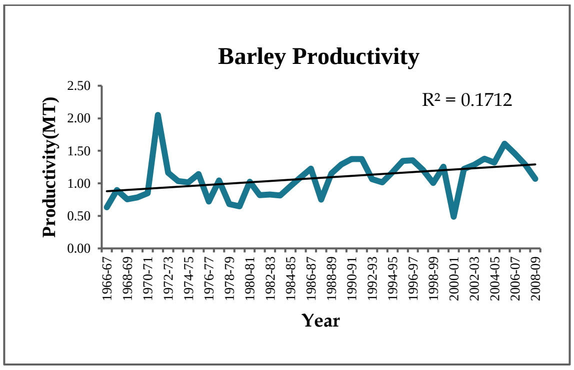
Figure 19: Variations in Area and Annual Production of different crops (Rice, Wheat, Potato, Maize, Barley, Gram and black gram (1966-2009), District Kangra, HP

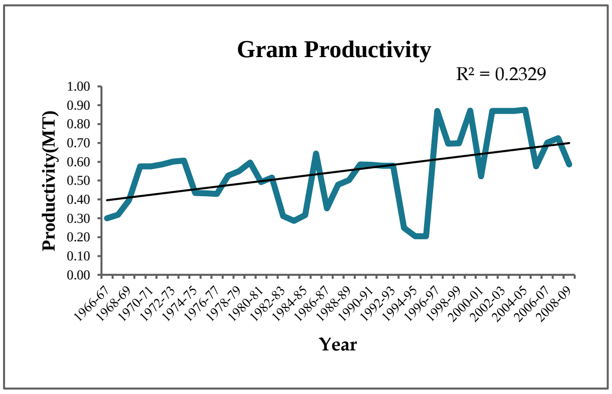
Analysis of productivity trends for maize and potato crops showed significantly changing yields during 1967-2010 time periods while Rice, barley, Wheat, gram, black gram and horse gram shows non significance change in yield. (Illustrated in figure 17).

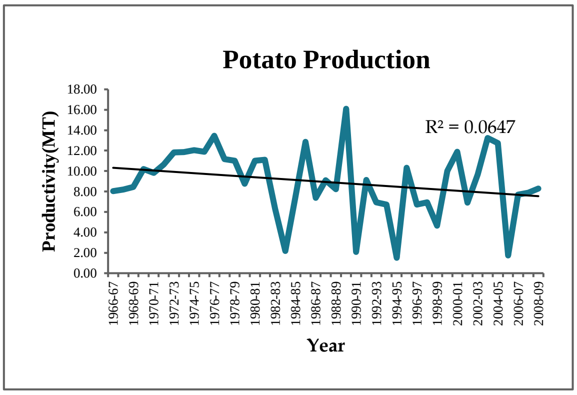


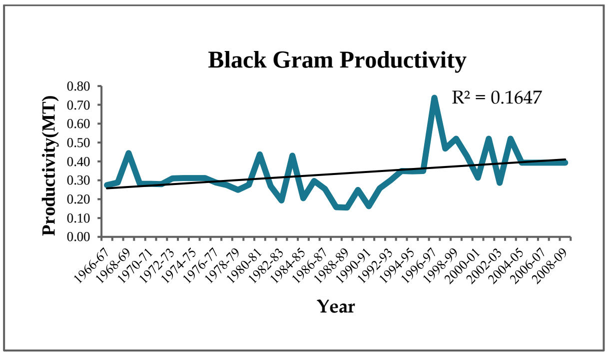












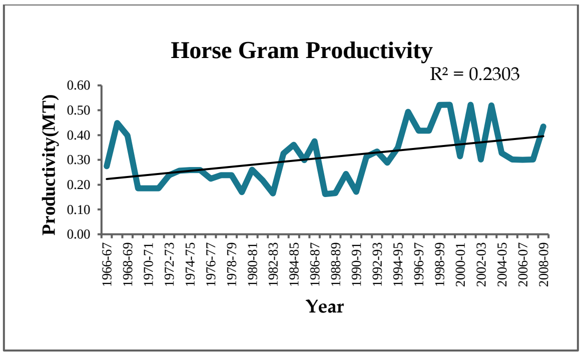


Figure 6: Variations in Productivity - Rice, Wheat, Maize, Barley, Potato, gram, black gram, horse gram, (1966-2009), District Kangra, HP

As per the outputs from Mann Kendal Tests, an overall increased productivity trend is recorded for Wheat, barley, rice, gram, black gram and horse gram (see table 5), wherein wheat crop had the lowest p-value (0.001) exhibiting significant changes in productivity compared to the other crops. Only potato crop registered a decline in productivity by 0.056 t ha^{-1} $year^{-1}$.

Table 3: Mann Kendall Test Results – Crop Yields for Kharif and Rabi Season (1971-2009)

Crops	Mean	Sen's slope	p-value
Wheat	1.411	0.028	**<0.0001**
Barley	1.096	0.012	**0.000**
Rice	1.256	0.006	**0.013**
Maize	1.538	0.004	0.165
Potato	10.695	-0.056	0.274
Gram	0.553	0.007	**0.005**
Black gram	0.335	0.003	**0.019**
Horse gram	0.310	0.004	**0.002**

From the table above it can be seen that Wheat, barley, rice, gram, black gram and horse gram showed significant variations in productivity (as per interpretation of p-values at 95% confidence intervals). 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) (Kumar & Parikh, 2001) (Mendelsohn et al., 2011). 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).

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*. By testing the effects of variability in maximum temperature, a negative correlation coefficient (-0.298 and-0.291) was observed for rice and black gram crop productivity (with a p-value of 0.031, and 0.034) respectively. *i.e.*, an increase in maximum temperature is expected to result in decline their productivity as corroborated from Mann Kendall trend test result. While the minimum temperature and rainfall does not show significant relationship. Secondary literature also supports these findings in certain cases. Singh et al. (2015), Mishra et al. (2015), and Gammans et al. (2017) reported similar trends for wheat, barley, maize, and paddy crops. Rainy days variations did not hold statistically significant relationship with variability in productivity for any of the crops during the study period.

Table 6 illustrates the regression outcome of detrended[2] climatic variables of minimum, maximum, diurnal temperature and rainfall with the productivity of selected crops. For all assessed crop varieties *viz.*, Wheat, Barley, gram, Rice, Maize, black gram, horse gram and only 20.7%, 7.7%, 8.0%, 19.7%, 18.1%, 9.3% and 3.5% of productivity variability could be explained from temperature and rainfall variations in the district. With respect to individual crops, this means that the observed increase in productivity for Wheat, Barley, Rice, Gram, Black gram, and Horse gram from 1971-2009 is explained by the variations in climatic parameters only to the extent of 20.7%, 7.7%, 8.0%, 19.7%, 9.3% and 3.5% respectively. Similar interpretation stands for the decline in productivity for maize and potato. 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).

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

Table 6: Multivariate Linear Regression Analysis – Crop Yields and Climatic Parameters, (1970-2009)

Crop	Variable / Statistics	Maximum temperature	Minimum temperature	Diurnal temperature	Rainfall	R^2	Change (%)
Wheat	Coefficient	0.037	0.122	0.309	0.821		**20.7%**
	p-value	0.410	0.321	0.010	0.342		
Barley	Coefficient	0.192	0.555	0.654	0.011		**7.7%**
	p-value	0.118	0.432	0.100	0.321		
Gram	Coefficient	0.037	0.876	0.212	-.765		**8.0%**
	p-value	0.411	0.908	0.666	0.222		
Rice	Coefficient	**-0.298**	0.432	-0.322	-0.26		**19.7%**
	p-value	**0.031**	0.123	**0.001**	0.321		
Maize	Coefficient	-0.133	0.321	0.098	0.212		**18.1%**
	p-value	0.206	**0.031**	0.111	0.222		
Black gram	Coefficient	**-0.291**	0.543	-0.123	0.137		**9.3%**
	p-value	**0.034**	0.213	0.009	0.432		
Horse gram	Coefficient	-0.013	0.321	0.321	0.322		**3.5%**
	p-value	0.469	0.234	0.654	0.786		

CONCLUDING POINTERS

Crop Variations:

As per the outputs from Mann Kendal Tests, an overall increased productivity trend is recorded for Wheat, barley, rice, gram, black gram and horse gram (see table 5), wherein wheat crop had the lowest p-value (0.001) exhibiting significant changes in productivity compared to the other crops. Only potato crop registered a decline in productivity by 0.056 t ha^{-1} year^{-1}.

Climatic Variations:

During Kharif crop season, the maximum temperature and Diurnal T rose at the rate of 0.017°C and 0.041°C per year respectively (as exhibited by the Sen's slope).Meanwhile the minimum temperature exhibited a decreasing trend of 0.016 °C. And for Rabi crop season maximum temperature and diurnal temperature rose at the rate of 0.039°C and 0.039°C per year respectively. Rainfall, on the other hand, did not show any significant variation from 1971-2018. However in Rabi season there is less rainfall at the rate of (-0.051mm).

Climate Crop Juxtaposition:

By testing the effects of variability in maximum temperature, a negative correlation coefficient (-0.298 and-0.291) was observed for rice and black gram crop productivity (with a p-value of 0.031, and 0.034) respectively. i.e. an increase in maximum temperature is expected to result in decline their productivity as corroborated from Mann Kendall trend test result.

CHAPTER 5 –CONCLUSION& RECOMMENDATIONS

The status report was designed to elucidate statistical impact of climate change on productivity of agriculture crops in Himachal Pradesh with a study focused on District Kangra. Based on the statistical analysis, Mann Kendall trend test, the maximum and diurnal temperature showed significant changes during the *Kharif* and rabi crop season for the study period spanned across 47 years for the time period 1971-2018. During Kharif crop season, the maximum temperature and Diurnal T rose at the rate of 0.017°C and 0.041°C per year respectively (as exhibited by the Sen's slope). Meanwhile the minimum temperature exhibited a decreasing trend of 0.016 °C, and for Rabi crop season maximum temperature and diurnal temperature rose at the rate of 0.039°C and 0.039°C per year respectively. Rainfall, on the other hand, did not show any significant variation from 1971-2018. However in Rabi season there is less rainfall at the rate of (-0.051mm).

As per the output from SAI, after 1992, maximum temperature remained above the long term average except for the years 1997, 2006 and 2008 indicating an overall warming trend. Meanwhile cooling trend was observed in case of minimum after 1992 temperature except for 2013 and 2014 years. Rainfall, on the other hand, also showed increase in rainfall from 1994 to 2018 except few years during the Kharif crop season. As per the outputs from SAI, maximum temperature showed a warming trend from 1994 onwards, except for dip in the year 2014 and 2015.Whereas no significant pattern was observed for minimum temperature and rainfall.

As per the outputs from Mann Kendal Tests, an overall increased productivity trend is recorded for Wheat, barley, rice, gram, black gram and horse gram, wherein wheat crop had the lowest p-value (0.001) exhibiting significant changes in productivity compared to the other crops. Only potato crop registered a decline in productivity by 0.056 t ha^{-1} $year^{-1}$. From the table above it can be seen that Wheat, barley, rice, gram, black gram and horse gram showed significant variations in productivity (as per interpretation of p-values at 95% confidence intervals).

To ascertain the relationship between climatic variability and crop productivity, a correlation analysis was performed using the statistical tool – *Pearson's coefficient*. By testing the effects of variability in maximum temperature, a negative correlation coefficient (-0.298 and-

0.291) was observed for rice and black gram crop productivity (with a p-value of 0.031, and 0.034) respectively. I.e. an increase in maximum temperature is expected to result in decline their productivity as corroborated from Mann Kendall trend test result. Secondary literature also supports these findings in certain cases. Singh et al. (2015), Mishra et al. (2015), and Gammans et al. (2017) reported similar trends for wheat, barley, maize, and paddy crops. Rainy days variations did not hold statistically significant relationship with variability in productivity for any of the crops during the study period.

For all assessed crop varieties viz. Wheat, Barley, gram, Rice, Maize, black gram, horse gram and only 20.7%, 7.7%, 8.0%, 19.7%, 18.1%, 9.3, %and 3.5% of productivity variability could be explained from temperature and rainfall variations in the district. With respect to individual crops, this means that the observed increase in productivity for Wheat, Barley, Rice, Gram, Black gram, and Horse gram from 1971-2009 is explained by the variations in climatic parameters only to the extent of 20.7% ,7.7%, 8.0%,19.7% ,9.3% and 3.5% respectively. Similar interpretation stands for the decline in productivity for maize and potato. 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)

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