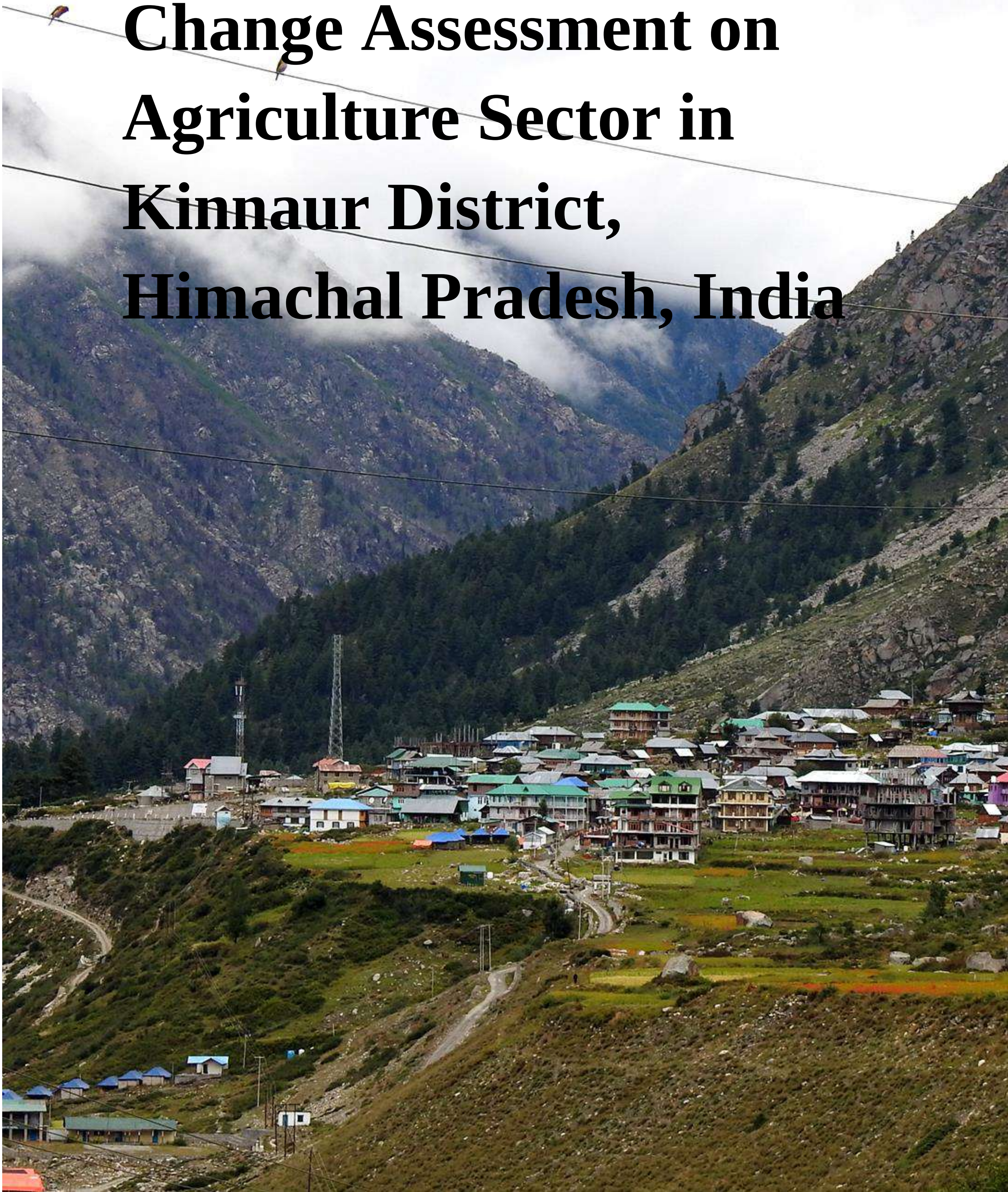
Impact of Climate Change Assessment on Agriculture Sector in Kinnaur District, Himachal Pradesh, India



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CONTENTS

LIST OF TABLES

LIST OF FIGURES

EXECUTIVE 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 unfavorable 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 Kinnaur. Seasonal trends on climatic variables i.e., minimum, maximum, and diurnal temperatures, and rainfall patterns were conjugated with a standardized 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 Kinnaur. 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 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. During Rabi crop season, Diurnal temperature registered statistically significant increase of 0.02 °C per year in District Kinnaur. For all assessed crop varieties *viz.*, Wheat, Barley, Rice, Maize, Ragi and Common millets only 12.6%, 12.8%, 35.6%, 15.4%, 8.2% and 9.0% of productivity variability could be explained from temperature and rainfall variations in the district respectively. With respect to individual crops, this means that the observed significant maximum variations in climatic parameters which is 35.6% for rice crop, 15.4% for maize and 9.0% for common millets. Non-significant variations were recorded for Wheat, Barley and Ragi.

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 analyzed 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 characterized 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 CO_2 concentration is expected to be on C_3 species i.e. *wheat, rice, and soybeans (accounting for more than 95% world's species)* more than on C_4 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. The figure 1 below gives a pictorial representation of direct and indirect interactions of climate change with agriculture production and anthropogenic induced vulnerability.

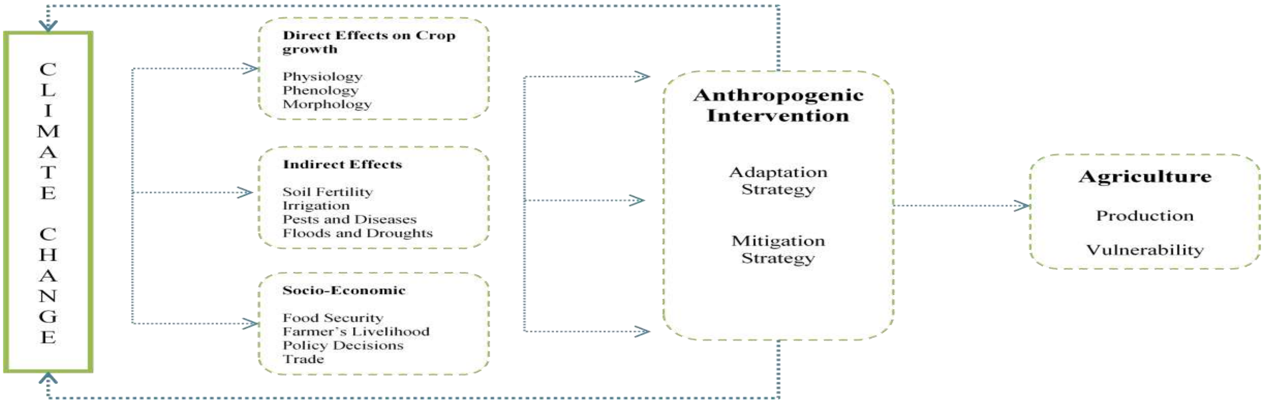


Figure 1: Agriculture and Climate Change Impact

Source: Indian Agriculture Research Institute, New Delhi

[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

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.

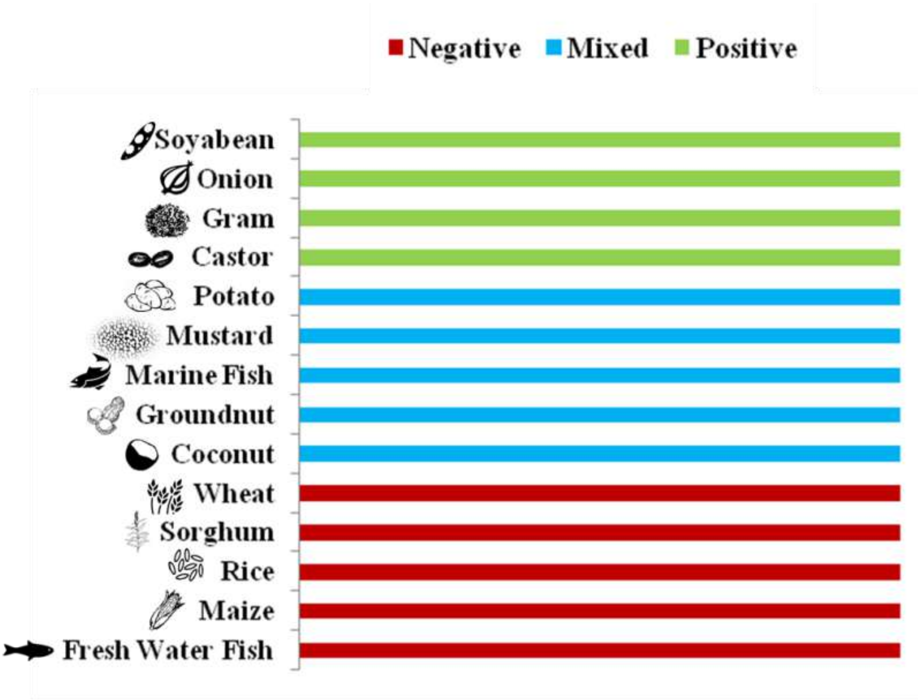


Figure 2: Commodity wise climate change impact, India (from modelling)

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

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.

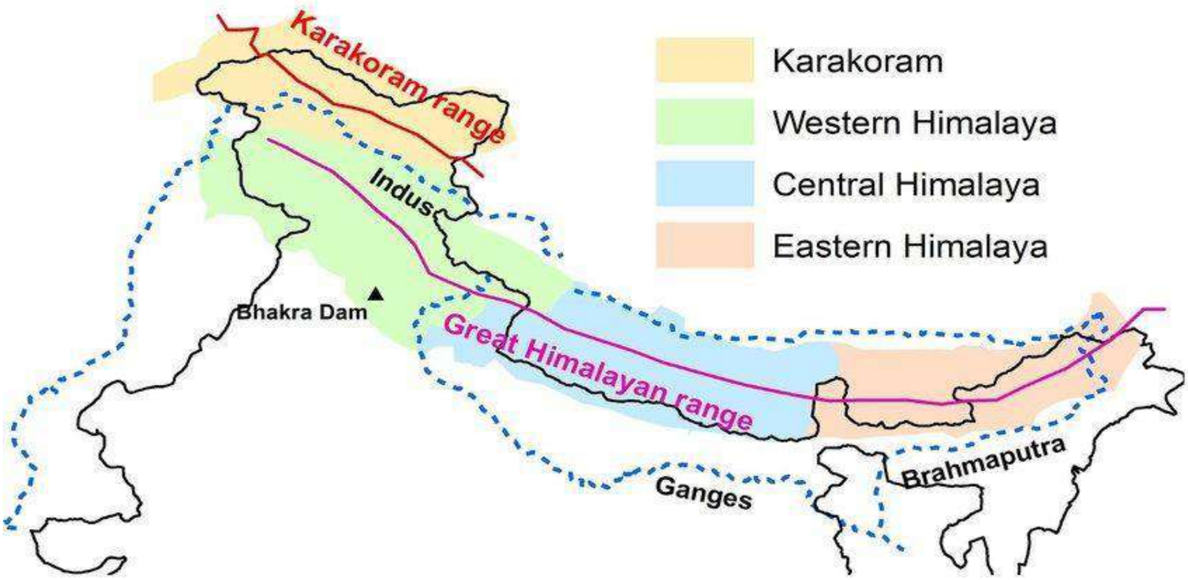


Figure 3: Geographical Representation of the Indian Himalayas

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 unfavorable 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, Sirmour, Solan), *Lesser Himalayas* (covering parts of District Mandi, Sirmour, Chamba, Kangra, Kinnaur), 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 become 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 characterized 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, Palampur: 3000mm)	1,000	**>1,500**
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, Sirmour	Parts of Chamba, Kangra, Mandi, Shimla, Sirmour, Kullu, Kinnaur, Hamirpur, Bilaspur	Kinnaur, Chamba, Kangra, Mandi, Kullu, Solan, Sirmour, Shimla, Lahaul & Spiti	Kangra, Lahaul & Spiti, Kinnaur, and Parts of Chamba, Mandi, Kullu, Sirmour, Shimla.

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)

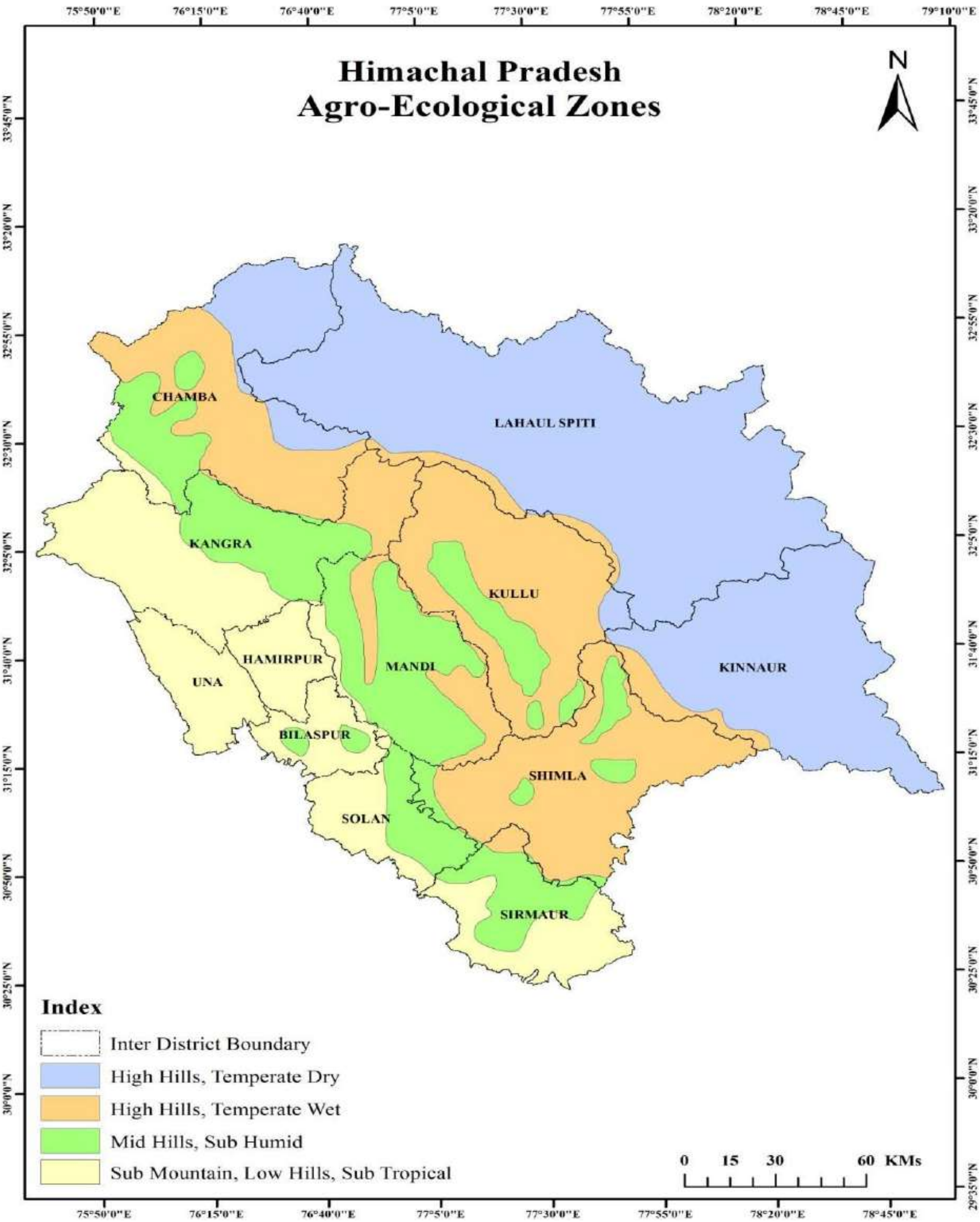


Figure 4: **Himachal Pradesh Agro-Ecological Zones**

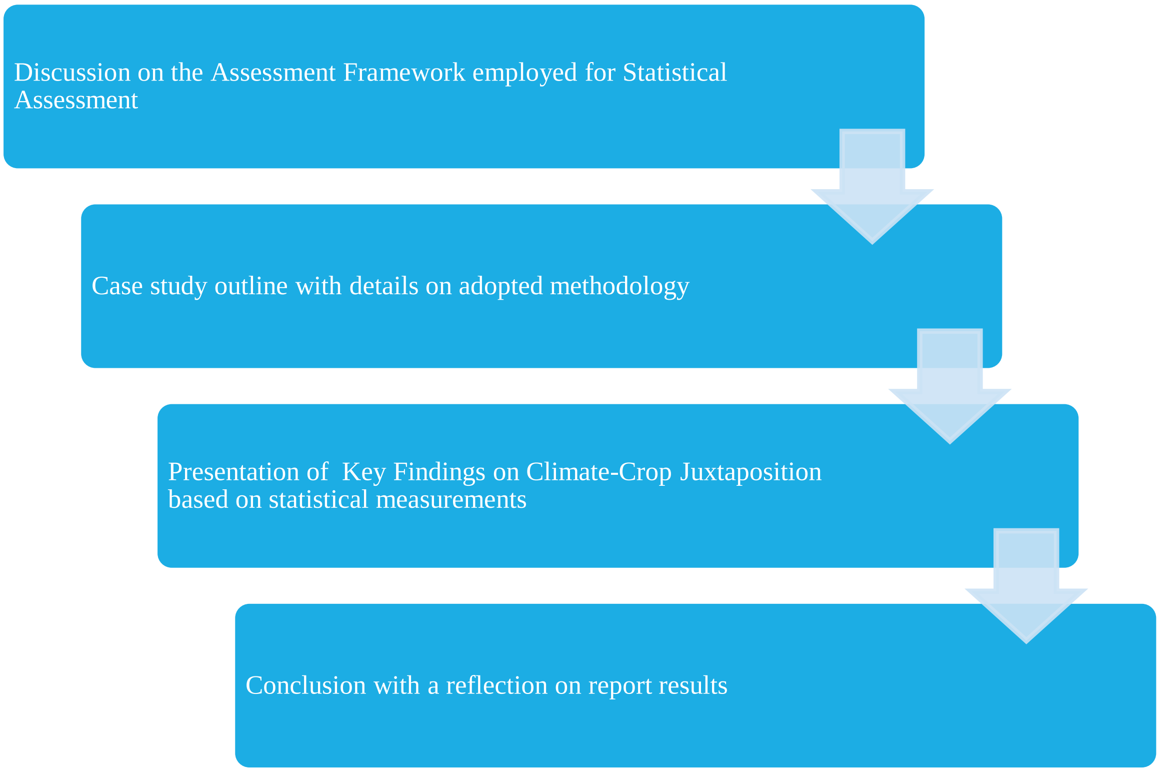
Source: Adapted by HPSCCC from Agro-Ecological Zonation of Himachal Pradesh – Agricultural System Information Development at micro-level, Centre of Geo-informatics, CSK Himachal Pradesh Agriculture University, Palampur (Bhagat *et al.*, 2006)

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 are characterized 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 Kinnaur. Seasonal trends on climatic variables of minimum, maximum, and diurnal temperatures, and rainfall patterns were conjugated with a standardized 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 Kinnaur, and is organized as:



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 statistic 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 XLSTAT2017. 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 variables (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 (1970- 2016).

CHAPTER 3 - PILOT CASE AND METHODS

DISTRICT KINNAUR – A BACKGROUND

District Kinnaur is located between 77°45' and 70° 00'35" East longitude and 31°05'50" to 32° 05'15" north latitude About 80 kms long and 55 kms wide located in the north eastern part of Himachal Pradesh, it runs in a north east and southwest direction and the habitable part seldom exceeds 13 kms in breadth. It is a secluded, rugged and mountainous region in an extra ordinary degree. The district is endowed with enchanting natural beauty in its picturesque snow-clad peaks, thick natural forests, meandering river courses through deep gorges, streams cascading down the hills with great fury, hanging ropeways across the rivers, alpine meadows, rare wild fauna, clear blue skies, high altitude lakes and rich cultural heritage of people, that give thrilling and memorable experience to trekkers and tourists from within and outside the country.

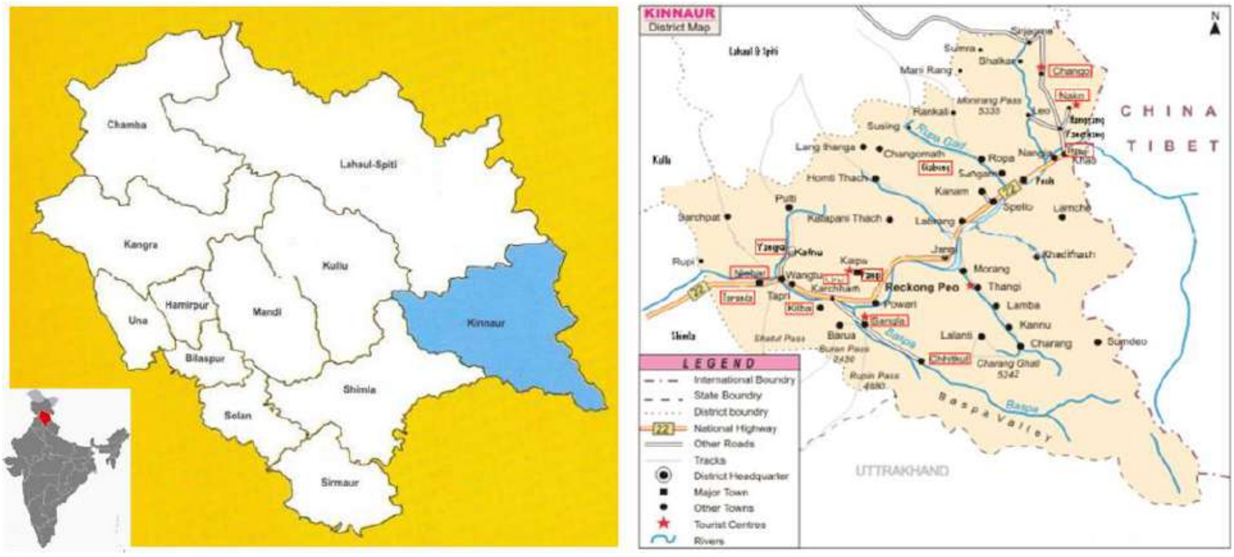


Figure 5: Map of District Kinnaur, Himachal Pradesh

Climate: Kinnaur is located between 77°45’ and 70° 00’35” East longitude and 31°05’50” to 32° 05’15” north latitude and bounded by Tibet and Uttaranchal on the east, Shimla district in south-west, Kullu and Lahaul-Spiti district in the north-west, about 235 km from the state capital, Shimla. Most of Kinnaur enjoys a temperate climate due to its high elevation, with long winters from October to May and short summers from June to September. The lower parts of the Sutlej valley and the Baspa valley receive monsoon rains. The Baspa valley receives highest rainfall in July month. The upper areas of the valleys fall mainly in the rain-shadow area. Kinnaur situated in Trans Himalayan Zone of Himalayas having high mountain ranges, altitude from 1600 m to 6816 m; considered to be a sedimentary wedge between colliding plate margins of Indian and Asian plates and having deep narrow valleys/gorges of River Satluj and its numerous tributaries, having their origin in the glaciated ridge. Kinnaur has three high mountains ranges namely, Zanskar, Himalayas and Dhauladhar that enclose valleys of Sutlej, Spiti, Baspa and their tributaries. The tropical monsoon climate involves an annual rainfall in excess of 1000 mm, occurring mostly in the months of June to October. Winters are severe with heavy snowfall causing Glaciers and Avalanches. Summers are mild with the rainy season in most of the Kapla and Nichar Sub-Divisions of the district. Pooh Sub-Division of this district forms part of ‘Indian Cold Desert’ and receives scanty rainfall as it falls in rain-shadow zone of the Himalaya. Satluj is the main river of Kinnaur district. Probability of Cloudburst, flood/flash flood and landslide in Kinnaur district is very high.

Agriculture:

Agriculture is the main Occupation of the people of Himachal Pradesh. It has an important place in the economy of the state. The economy of Kinnaur is predominantly agriculture based where as large as 67.09 per cent of the total working force is engaged in tilling the cultivable land. The space of arable land is small and the cultivation is common on narrow strips along the browse of the mountains. The crops for the most part are poor and a great scarcity of grain pervades. In time of scarcity, horse chestnuts are dried and ground into flour; apricot and walnut also form the part of food of people. But these days with plenty of wheat and rice available through PDS, the people no longer are forced to resort to such distress measures as were common in Gerard's time. The standard grains are barley, phaphra (*Fagopyrum esculentum*); barely is sown in March-April and harvested in July after which the fields are prepared for the phaphra which are harvested in October. At the places of one cropping season, the important crops grown are oat, wheat, phaphra and barley which are sown in April and harvested in August-September. The other grains are Bathu, cheena and koda. Generally, the local millets are grown as cereals. A long and typical winter season is responsible for low production. The crop season is limited to only six months due to intensive cold and snowfall. However, the economy of the district is highly agro-pasturage. Land holdings are generally small and scattered; almost every family has a piece of land. Soils generally consist of sand, sandy-loam, clay-loam, sandy and gravel. Wheat, barley, maize, potato, vegetables and pulses are the main crops of the district.

Table 3: District Kinnaur: Agriculture Profile

Agriculture Profile – District Kinnaur					
Agricultural Land Use	**Total Geographical Area ('000 ha) : 624.3**	**Net Sown Area ('000 ha): 7.55**		Cropping Intensity: 119 Per cent	
Agro-Ecological Zone	**Western Himalayan Region (I)**				
Agro Climatic Zone (NARP)*	**1. High Hills Temperate Dry Zone (HP-4)**				
Irrigation	**Net Irrigated Area ('000 ha) : 4.8**	**Gross Irrigated Area ('000ha): 5.7**		Rainfed Area ('000 ha): 2.7	
	Sources of Irrigation:		***Number***	***Area ('000 ha)***	*Irrigated Area (%)*
		Tanks	72	0.0043	**0.08**
		Other sources (please specify) Flow irrigation schemes	158	4.868	**99.02**

		(Glaciers melts) through Kuhls			

Major Crops	*Grain Crops:* Wheat, Maize, Rice, Barley, Pulses, millets *Fruit Crops:* Apple, Pear, Walnut, Apricot, Other fruit. *Veg.:* (Cauliflower, French- bean and Capsicum)
Major cropping window	

Sowing window for 5 major field crops	Maize	Paddy	Wheat	Barley	Potato	Pulses
Kharif- Rainfed	1st week of April				2nd Week of April	2nd week of April
Kharif-Irrigated		1st week of April				
Rabi- Rainfed			1st week of Nov	2nd week of October - 2nd week of November		1st week of October
Rabi-Irrigated			1st week of Nov			

Major field crops cultivated	Area ('000 ha)							
	Kharif			*Rabi*				
	Irrigated	Rainfed	Total	Irrigated	Rainfed	Total	Summer	Grand total
Maize		0.32	0.321					0.32
Paddy	0.02							0.02
Wheat					0.32	0.32		0.32
Barley					1.02	1.02		1.0
Pulses			1.99					1.9
Minor millets								1.5

District Kinnaur, Himachal Pradesh (AGRICOOP, 2013)

METHODS

Within the context of 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) 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 Kinnaur was collected from India Meteorological Department (IMD), Kinnaur covering a time period of 1970-2017. 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.

AGRICULTURAL DATASETS

Wheat, Barley, Rice, Maize, and common millets and ragi crops acreage and production data was collected from the Department of Land Records, Kinnaur covering the time period 1970 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 KINNAUR

CURRENT CLIMATE TRENDS –DISTRICT KINNAUR

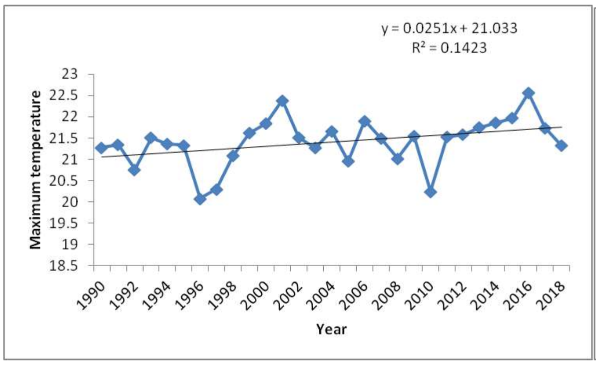
To capture the nerve of climatic changes in the district, temperature (min, max, diurnal), and rainfall parameters are considered as explanatory indicators. Based on the statistical analysis, Mann Kendall trend test**,** the maximum and diurnal temperature showed significant changes during the *Kharif* crop season for the study period spanned across 28 years, while for Rabi crop season, only the diurnal temperature underwent statistically significant changes. Table 3 exhibits the results of Mann Kendall test at 95% confidence level for minimum, maximum, and diurnal temperate, and rainfall for the time period 1990-2018.

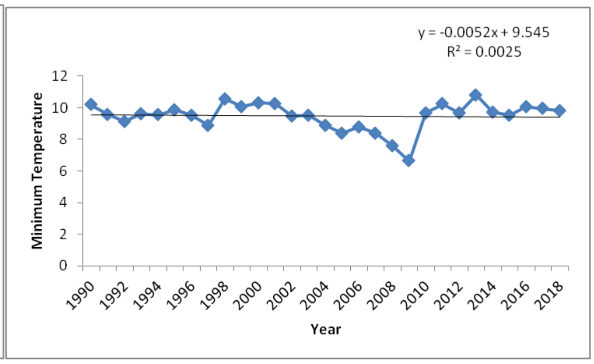
Table 3: Mann Kendall Test Results – Climatic Trends for Kharif and Rabi Season (1990-2018)

	Mean	Sen'^{S} slope	p-value
Kharif			
Max T	21.414	**0.02**	**0.01**
Min T	12.09	**0.04**	**1.000**
Diurnal T	0.066	0.46	0.307
Rainfall	108.56	0.78	0.312
Rabi			
Max T	10.740	1.07	0.724
Min T	-0.423	-0.42	0.307
Diurnal T	11.163	**0.02**	**0.00**
Rainfall	73.883	-14.69	0.423

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 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.

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 (figure 6) 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 few dips like 1992, 1998, 2004, 2006, 2008 and 2010, 17years were showing a warming trend which is above long-term average during the minimum temperature. Rainfall, on the other hand, showed variation in 10 years which are above the long term average these years are, 1991,1993, 1994,1998,2003,2009,2010,2011,2013 and 2018 during the Kharif crop season.





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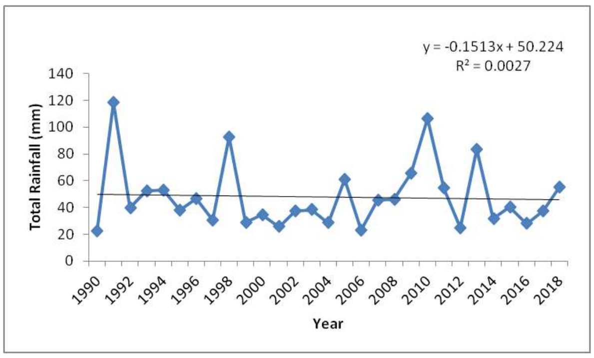
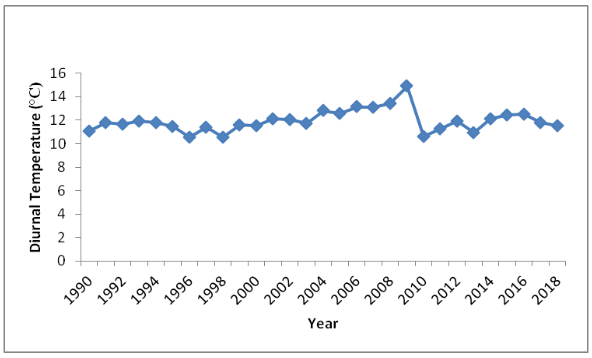




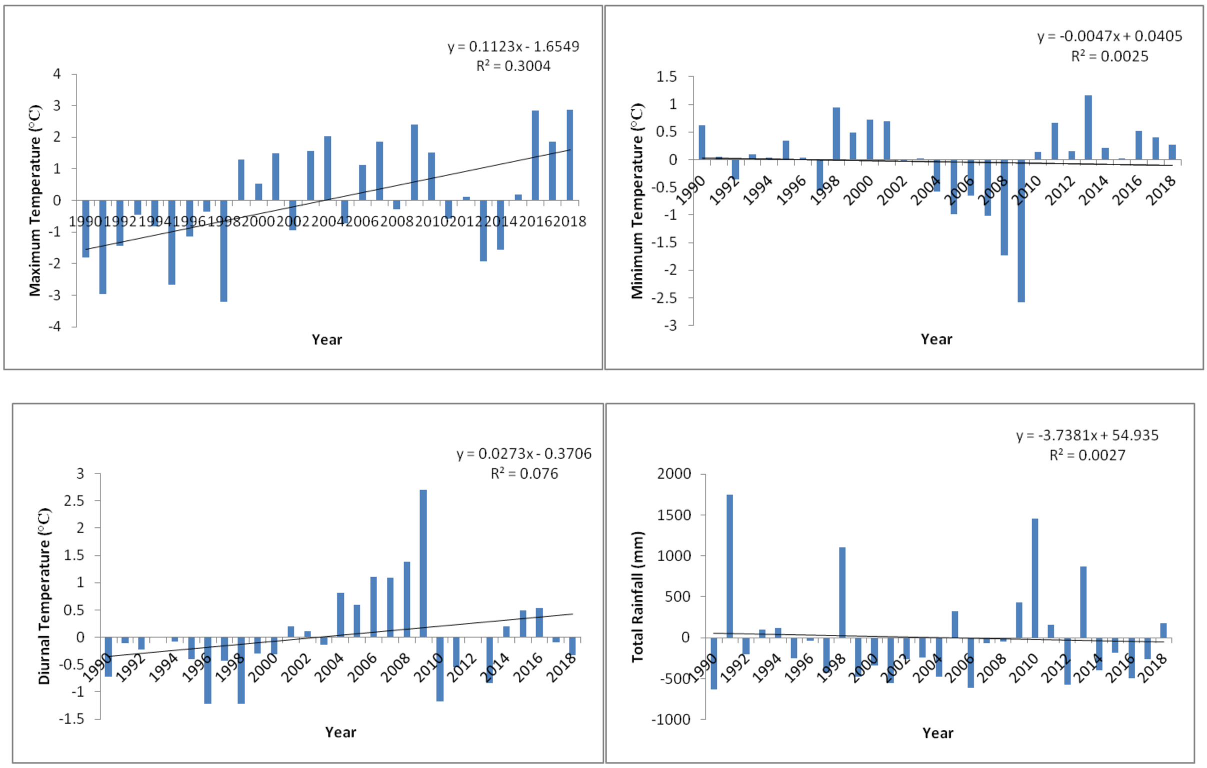
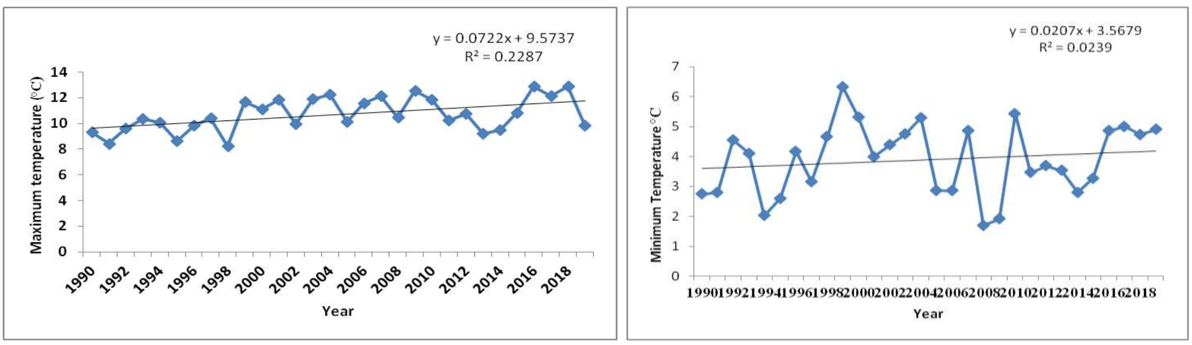


Figure 6: Variations in Climatic Parameters- Minimum T, Maximum T, Diurnal T and Rainfall during Rabi Crop season (1990-2018), District Kinnaur, HP.

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.

As per the outputs from SAI, a continuous dip from the year 1990 to 1999 after that maximum temperature remained above the long-term average in the year 2000, 2001, 2003, 2004,2006, 2008 and 2010. In case of minimum temperature 13years out of 28 years were registered above the long-term average. Whereas during rainfall few dips 1994,1996,1998, 1999,2000,2001,2004,2006,2008,2010,2011 and 2012 with some years above the long-term average (1990,1991,1992,1995,2002,2003,2005,2007 and 2014).



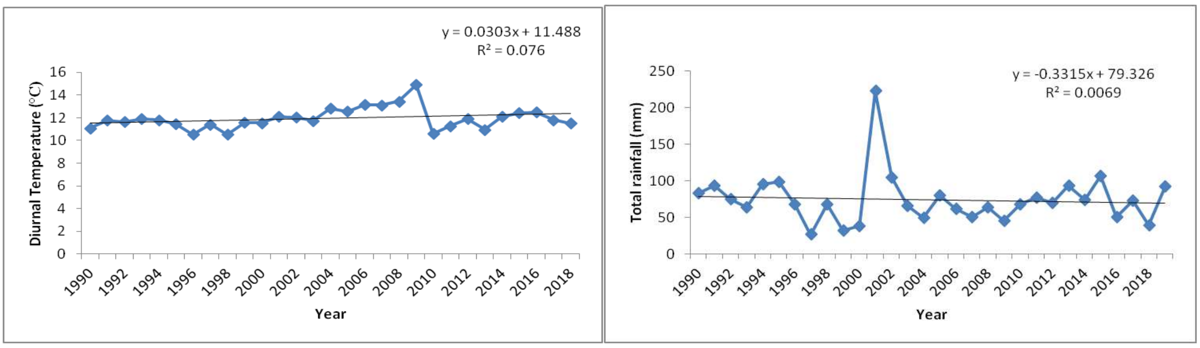
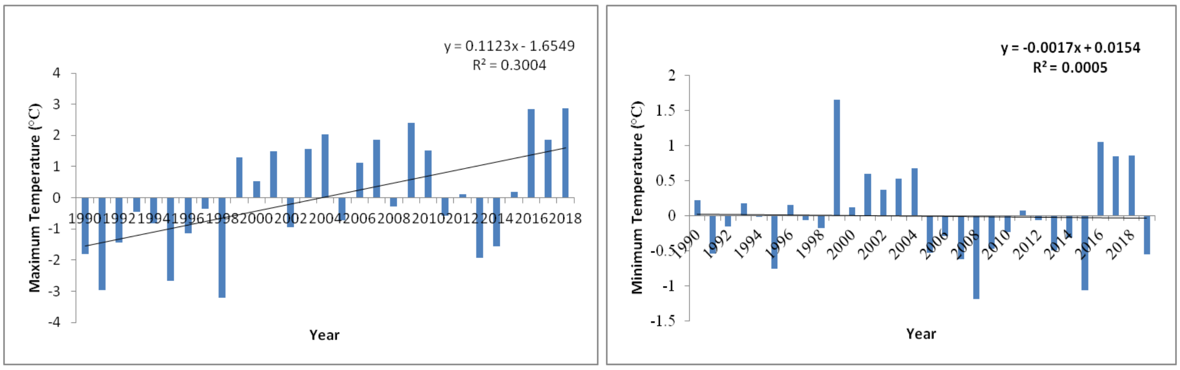


Figure 7: Variations in Climatic Parameters- Minimum T, Maximum T, Diurnal T and Rainfall during Rabi Crop season (1990-2018), District Kinnaur, HP.



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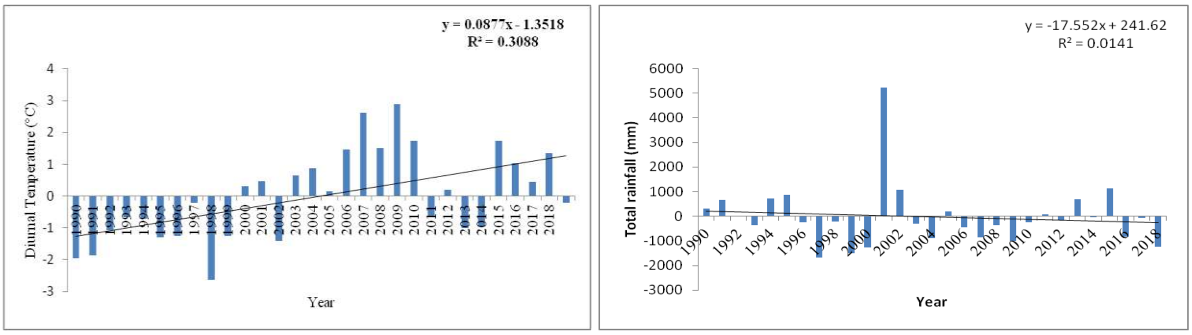

Figure 8 SAI for Climatic Parameters- Minimum T, Maximum T, Diurnal T and Rainfall during Rabi Crop season (1990-2018), District Kinnaur, HP.

The discussed variations in temperature and rainfall patterns are not confined to District Kinnaur but are corroborated by various observations from other studies in the Himalayan region. Poudel and Shaw (2016) 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. Abdul *et al* (2016) reported that monthly and annually mean temperature, mean maximum temperature and mean minimum temperature have increased during the period of time.

Meanwhile, Bhutiyani et al. (2007) 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.

CROP PRODUCTIVITY – DISTRICT KINNAUR

LAND USE CHANGES IN DISTRICT KINNAUR:

According to the Block Development indicators of Kinnaur district 2007 it Land use showing total of cultivable and the irrigated area. As observed, all the inhabited villages numbering 234 in 2001, had total area of 5, 68,780 ha of which only 7,602 ha (1.34 per cent) was cultivable and of this 4,768 ha or 62.72 per cent was served by irrigational facility. It is seen that 66 villages of Kalpa cover an area of 1, 40,405 ha of which only 2,798 ha was cultivable which was incidentally the highest, and of this 79.66 per cent or 2,229 ha was under irrigation. Though area wise Pooh is the biggest block, only 1.04 per cent of its total area or 2, 446 ha was under plough, having irrigation facility to over ninety per cent. The cropping intensity across the blocks varied from 115 per cent in Kalpa to 124 per cent in Pooh block with the overall intensity of 119 per cent. Changes in land utilization pattern have been shown in Table below which clearly shows that the percentage of net sown area and the forest land have declined sharply since 1990-91.

Block	Inhabited villages (No.)	Area as per village papers (Ha.)	Net sown area (Ha) and % age of total area	Net sown area (Ha/agril . worker)	Net irrigated area (Ha) and %age of net sown area	Total cropped area (Ha)	Cropping intensity (%)
Pooh	80	234830	2446 (1.04)	0.33	2238 (91.50)	3027	124
Kalpa	66	140450	2798 (1.99)	0.35	2229 (79.66)	3212	115
Nichar	88	193500	2358 (1.22)	0.26	301 (12.77)	2778	118
District	234	568780	7602 (1.34)	0.31	4768 (62.72)	9017	119

Source: Block Development Indicators of Kinnaur, 2007

Figure 9 : Distribution of net sown area and irrigated area in Kinnaur district

The cropping pattern of district Kinnaur and Himachal Pradesh over different years is given in Table below. It is evident from the table that in the district and state as a whole, the per cent area under food grains has declined mainly due to crop diversification, that is, the area under fruit and vegetables and others high value cash crops like flowers and spices (ginger, garlic, turmeric) has increased. The diversification was more in Kinnaur than the state as a whole.

Particular	Maize	Rice	Wheat	Barley	Pulses	Food-Grains	Cropped area ('000' ha)
Kinnaur							
1990-91	5.41	0.33	8.73	17.98	8.78	75.76	9.11
1995-96	4.81	0.28	5.06	15.44	9.65	63.19	9.78
2000-01	4.11	0.25	5.14	15.81	15.47	66.18	9.33
2005-06	3.53	0.24	3.50	11.20	16.43	53.03	9.01
Himachal Pradesh							
1990-91	32.44	8.63	38.26	2.98	3.69	88.59	983.60
1995-96	32.58	8.74	38.04	2.84	3.80	87.43	949.89
2000-01	31.46	8.65	38.27	2.71	3.28	85.98	947.54
2005-06	30.97	8.32	37.58	2.65	2.88	83.66	953.60

Note: Percentages have been worked out on the basis of total cropped area
Source: Annual Season and Crop Report (Various Issues)

Table 3: Change in land use pattern (per cent of Geographical area) District Kinnaur, H.P.

ACREAGE AND PRODUCTION OF MAJOR AGRICULTURAL CROPS

Figure (11-15), Major 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 the time. Temporal trends of change in area, production and productivity of different food crops in District Kinnaur are illustrated in figure 12 to 17. Rice crop acreage witnessed a drastic decrease from 66 ha to 3 ha form the year 1990 to 2018, while production decreased from 57 MT in 2016 to 2 MT in 2014. During the year 1970 to 2017 acreage of Wheat decrease from 1911ha to 201ha and production decreases from 2457MT to 185MT. Area and production of the maize crop decreases from the year 1970 to 2017, the area decreases from 550ha to 83ha and production decreases from 1057 MT to 209MT from 1970 to 2017. In case of barley crop the area decreases from 2828 ha to 627ha and production also showed decreasing trend from 5140MT to 83MT. Ragi also showed the decreasing trend from the year 1970 to 2017.

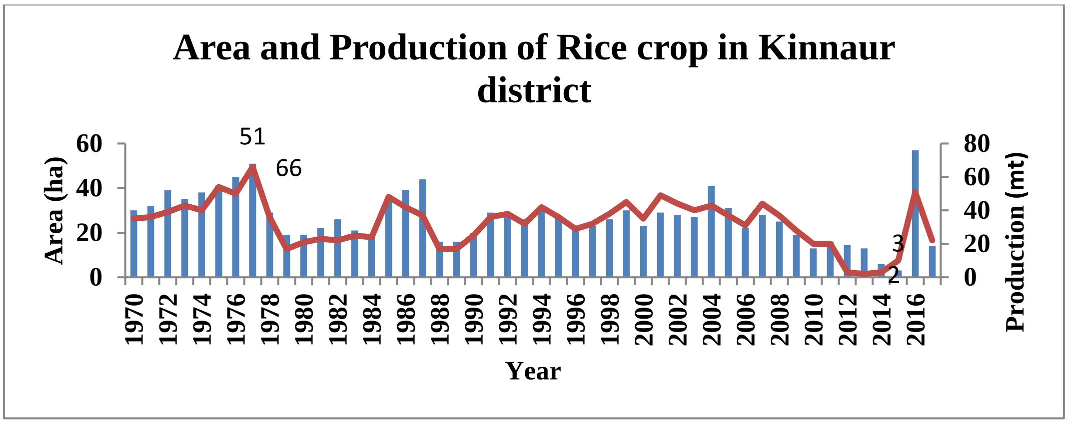

Figure 10: Area and Production of Rice crop in Kinnaur district from 1970-2017.

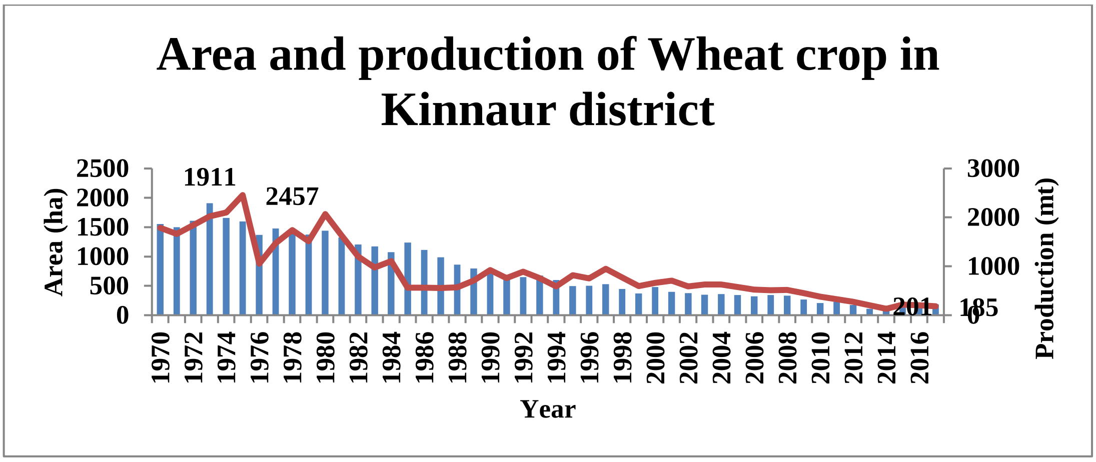

Figure 11: Area and Production of Wheat crop in Kinnaur district from 1970-2017.

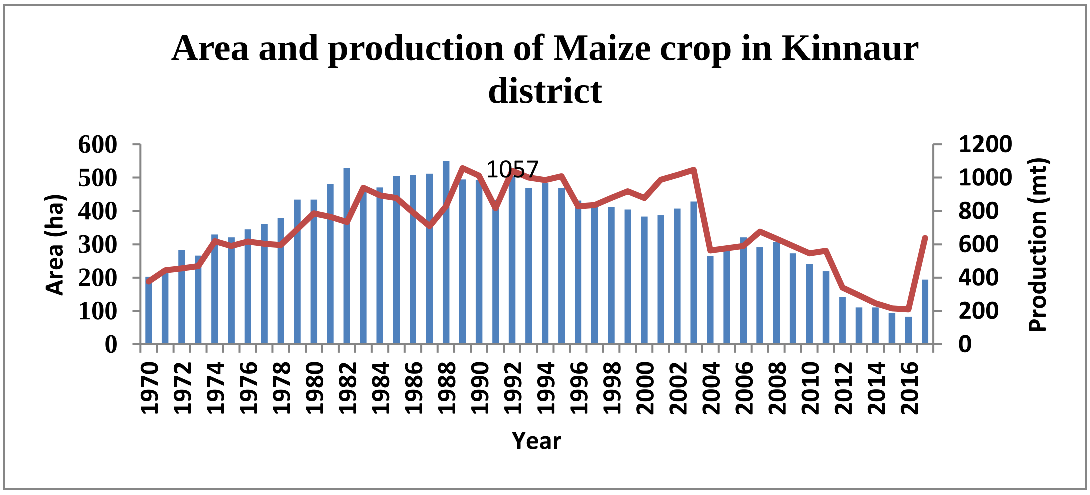

Figure 12 : Area and Production of Maize crop in Kinnaur district from 1970-2017.

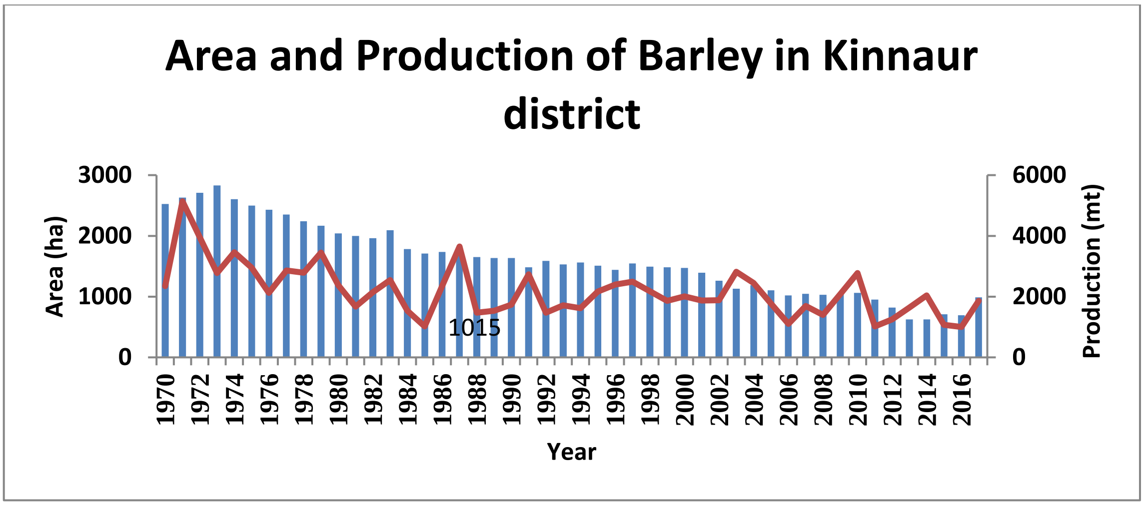

Figure 13 : Area and Production of Barley crop in Kinnaur district from 1970-2017.

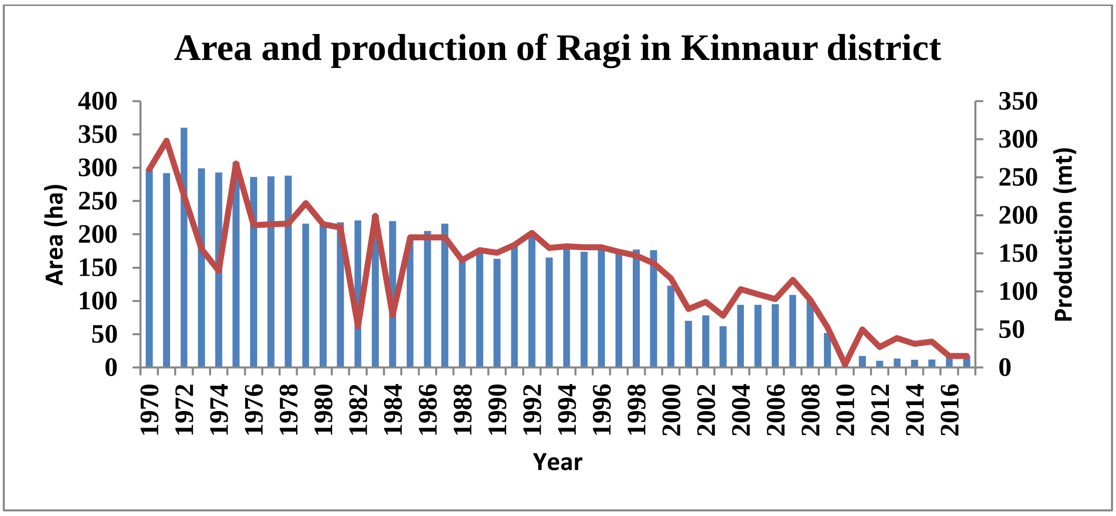

Figure 14: Area and Production of Ragi crop in Kinnaur district from 1970-2017.

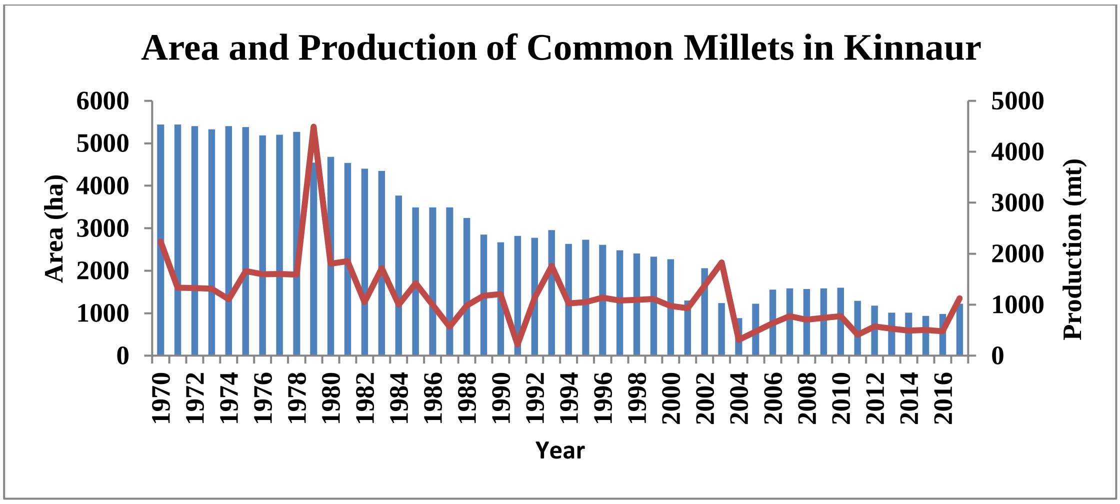

Figure 15 Area and Production of Common millets crop in Kinnaur district from 1970-2017.

As per the outputs from Mann Kendal Tests, an overall increased productivity trend is recorded for Maize, Barley and Common millets (see table 4), wherein wheat showed the decreasing trend of -0.014t $ha^{-1}year^{-1}$ Maize showed an increased crop yield of 0.019t $ha^{-1}year^{-1}$ common millet, barley and total vegetable showed increasing trend of 0.006, 0.015 and 0.338t $ha^{-1}year^{-1}$ respectively.

Table 4: Mann Kendall Test Results – Crop Yields for Kharif and Rabi Season (1971-2009) Kinnaur (HP).

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
Total vegetables	**0.338**	0.001	0.442

From the table above it can be seen that only Maize and Common millets crops 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*. The results revealed a strong relationship between climate variability and productivity of *Rabi* crop such as Wheat whereas negligible association was observed for the *Kharif* crops (Rice and Maize) in District Kinnaur (Table 6). While testing the effects of variability in maximum temperature, diurnal temperature, and rainfall, a significant and positive trend (0.587) was observed for Rice crop productivity (with a p-value 0.001). The effects of variability in maximum temperature, diurnal temperature, and rainfall, a significant and positive trend (coefficient value 0.587 with p-value 0.001 for rice), with coefficient value 0.357 and p-value 0.031 for maize and 0.56, -0.53 with p-value 0.001, 0.002 for Common millets.

Table 5 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, Rice, Maize, Ragi and Common millets only 12.6%, 12.8%, 35.6%, 15.4%, 8.2% and 9.0% 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 maximum variations in climatic parameters which is 35.6% for rice crop, 15.4% for maize and 9.0% for common millets. Non significant variations were recorded for Wheat, Barley and Ragi. Similar interpretation stands for the decline in productivity for Wheat, Barley and Rice. 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).

With respect to rainfall variations, divergent but non statistically significant outcomes were observed for rice yield, with coefficients of correlation -0.86 with p-value 0.33 -0.34. One possible reason for the decline in crop productivity can be attributed to the occurrence of *neck blast* and *shoot borer* diseases during heavy rainfall or high moisture conditions. *Neck Blast* is found to affect the panicle directly leading to high and significant losses in rice yields. This inconclusive output can be attributed to inherent variations and gaps in data that were unable to capture minute changes in rainfall frequency and intensity. In absence of scientific evidence and field-based experiments conclusion on direct sensitivity to rainfall cannot be drawn.

Table 5: Multivariate Linear Regression Analysis – Crop Yields and Climatic Parameters, (1971-2011)

Crop	Variable / Statistics	Maximum temperature	Minimum temperature	Diurnal temperature	Rainfall	R^2	Change (%)
Wheat	Coefficient p-value	0.171 0.192	-0.178 0.182	0.208 0.145	0.008 0.484	0.126	**12.6%**
Barley	Coefficient p-value	0.137 0.243	-0.224 0.126	0.217 0.134	-0.076 0.351	0.128	**12.8%**
Rice	Coefficient p-value	0.141 0.237	0.587 **0.001**	-.042 0.416	-.086 0.332	0.356	**35.6%**

Maize	Coefficient p-value	0.193 0.162	**0.357** **0.031**	-0.130 0.255	-0.26 0.448	0.154	**15.4%**
Ragi	Coefficient p-value	0.024 0.452	0.257 0.097	0.026 0.447	-.121 0.269	0.082	**8.2%**
Common Millets	**Coefficient** **p-value**	**0.568** **0.001**	**0.242** **0.107**	**-0.538** **0.002**	**0.130** **0.235**	**0.090**	**9.0%**

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

CONCLUDING POINTERS

Crop Variations:

Rice, Maize, and common millets crops showed significantly changing yields during **1970- 2017** time periods, except for Barley, wheat and ragi.

Climatic Variations:

Mean maximum temperature increased by 0.05 °C per year during Kharif crop season. Meanwhile, the diurnal temperature exhibited a decreasing trend of 0.007 °C per year. Rainfall did not register any statistically significant result during the study period.

As per the outputs from Mann Kendal Tests, an overall increased productivity trend is recorded for Maize, Barley and Common millets (see table 3), wherein wheat showed the decreasing trend of -0.014t ha-1year-1 Maize showed an increased crop yield of 0.019t ha-1year-1 common millet , barley and total vegetable showed increasing trend of 0.006, 0.015 and 0.338t ha-1year-1 respectively.

Climate Crop Juxtaposition:

The results revealed a strong relationship between climate variability and productivity of the Kharif crops (Rice and Maize) whereas negligible association was observed Rabi crop such as Wheat for in District Kinnaur.

Strong relationship between climate variability and productivity of Kharif crops (Rice and Maize) whereas negligible association observed for Rabi crop such as Wheat in District Kinnaur. The effects of variability in maximum temperature, diurnal temperature, and rainfall, a significant and positive trend (0.587with p-value 0.001for rice), with coefficient value 0.357 and p-value 0.031 for maize.

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 Kinnaur. 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 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.During Rabi crop season, Diurnal temperature registered statistically significant increase of 0.02 °C per year in District Kinnaur. Rahman *et al*. 2017 reported similar effect of temperature, both maximum and minimum on rice crop, trends were reported to increase and monthly normalized anomalies and minimum temperature anomalies also note a significant ($P < 0.05$) positive trend. P. Miedema 1982 reported that Maize is sensitive to frost in all phases of its growth cycle except as dry seed. Freezing injury depends on the temperature, the duration of freezing, the water status of the plant, and the stability of supercooled water. Temperatures below and around the minimum temperature for germination and growth cause various types of physiological damage in maize. These low-temperature effects are referred to as chilling injury. Low-temperature chlorosis occurs at temperatures above the chilling range. Seeds and seedlings are sensitive to various types of injury.

As per the outputs from Mann Kendal Tests, an overall increased productivity trend is recorded for Maize, Barley and Common millets (see table 3), wherein wheat showed the decreasing trend of -0.014t ha-1year-1 Maize showed an increased crop yield of 0.019t ha-1year-1 common millet, barley and total vegetable showed increasing trend of 0.006, 0.015 and 0.338t ha-1year-1 respectively.

For all assessed crop varieties *viz.*, Wheat, Barley, Rice, Maize, Ragi and Common millets only 12.6%, 12.8%, 35.6%, 15.4%, 8.2% and 9.0% of productivity variability could be explained from temperature and rainfall variations in the district respectively. With respect to individual crops, this means that the observed significant maximum variations in climatic parameters which is 35.6% for rice crop, 15.4% for maize and 9.0% for common millets. Non significant variations were recorded for Wheat, Barley and Ragi.

With respect to rainfall variations, divergent but non statistically significant outcomes were observed for rice yield, with coefficients of correlation -0.86 with p-value 0.33 -

0.34. One possible reason for the decline in crop productivity can be attributed to the occurrence of *neck blast* and *shoot borer* diseases during heavy rainfall or high moisture conditions. *Neck Blast* is found to affect the panicle directly leading to high and significant losses in rice yields. This inconclusive output can be attributed to inherent variations and gaps in data that were unable to capture minute changes in rainfall frequency and intensity. In absence of scientific evidence and field-based experiments conclusion on direct sensitivity to rainfall cannot be drawn.

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