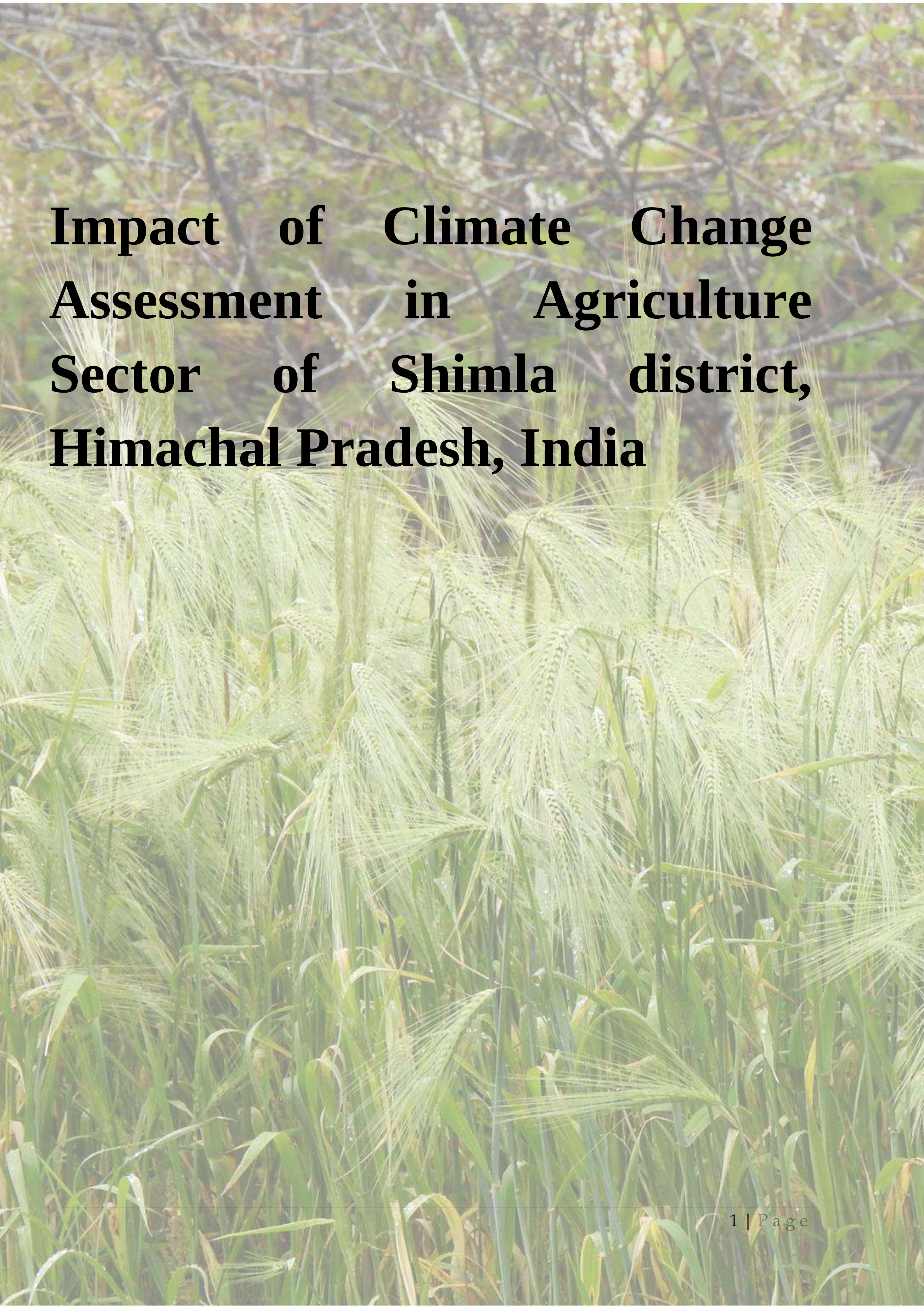
Impact of Climate Change Assessment in Agriculture Sector of Shimla district, Himachal Pradesh, India



Team Members of Climate Change

Sh. D.C. Rana, HPAS

Director (Env.) Govt of H.P. cum-Member Secretary [EC], HIMCOSTE

Dr. S.S. Randhawa

Principal Scientific Officer, State Centre on Climate Change, HIMCOSTE, Shimla

Team Members

Dr. YP Sharma, Dr. Pratima Vaidya (Consultant), Ms. Shubhra Randhawa, Dr. Priyanka Sharma

Ms. Kiran Lata and Mr. Ritesh Kumar (Scientific Professional)

STATE CENTRE ON CLIMATE CHANGE

STATE CENTRE ON CLIMATE CHANGE

Under the aegis of

Himachal Pradesh Council for Science, Technology & Environment (HIMCOSTE)

In collaboration with

CSKHPKV, PALAMPUR

Dr. Ranbir Singh Rana
Principal Scientist (Agronomy)Centre for Geoinformatics, Research and Training
CSK Himachal Pradesh Agriculture University
Palampur Himachal Pradesh - 176 062

CONTENTS

TABLE OF FIGURES

TABLE OF TABLES

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 Shimla. 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 Shimla. The 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. Moreover, the Standardized Anomaly Index of minimum temperature depicted a warming trend from 1992 onwards except for dips in 1996, 1997, and 2004. During the Rabi crop season, the diurnal temperature increased by 0.02 °C per year. Maximum and minimum temperature and Rainfall did not register any statistically significant result. Meanwhile, the Standardized Anomaly Index (SAI) of minimum and maximum temperature showed a warming trend from 1993 onwards between 1971 and 2016.

As per the output from the multivariate regression analysis, for all assessed crop varieties viz. Wheat, Potato, Maize, Barley, and Rice only 16.8%, 9.6%, 7.3%, 6.7%, and 4.6% 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 increase in productivity for Maize and Potato from 1965-2011 is explained by the variations in climatic parameters only to the extent of 7.3% and 9.6% respectively. Similar interpretation stands for the decline in productivity for Wheat, Barley and Rice.

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.

The figure 1 below gives a pictorial representation of direct and indirect interactions of climate change with agriculture production and anthropogenic induced vulnerability.

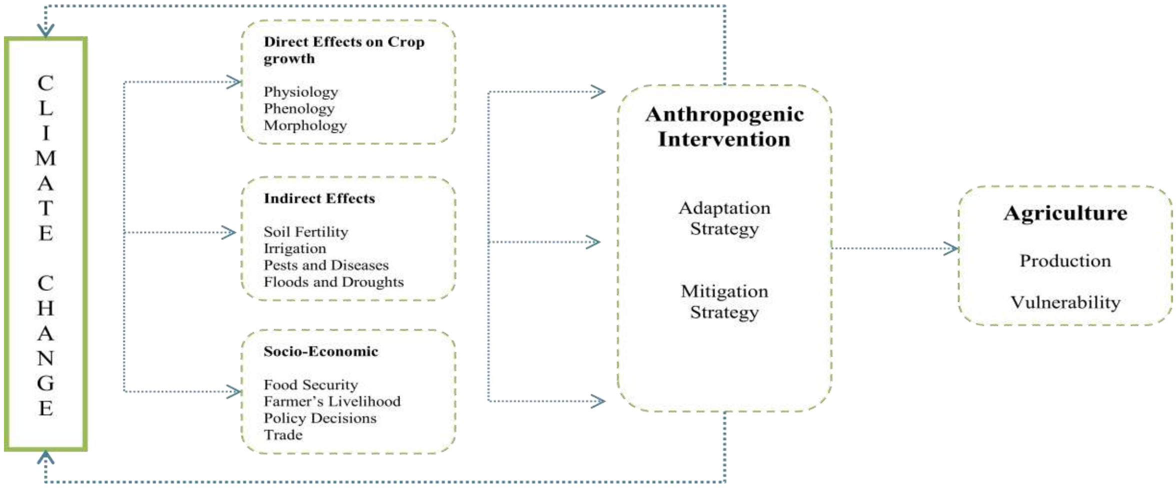


Figure 1: Agriculture and Climate Change Impact
Source: Indian Agriculture Research Institute, New Delhi

[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.

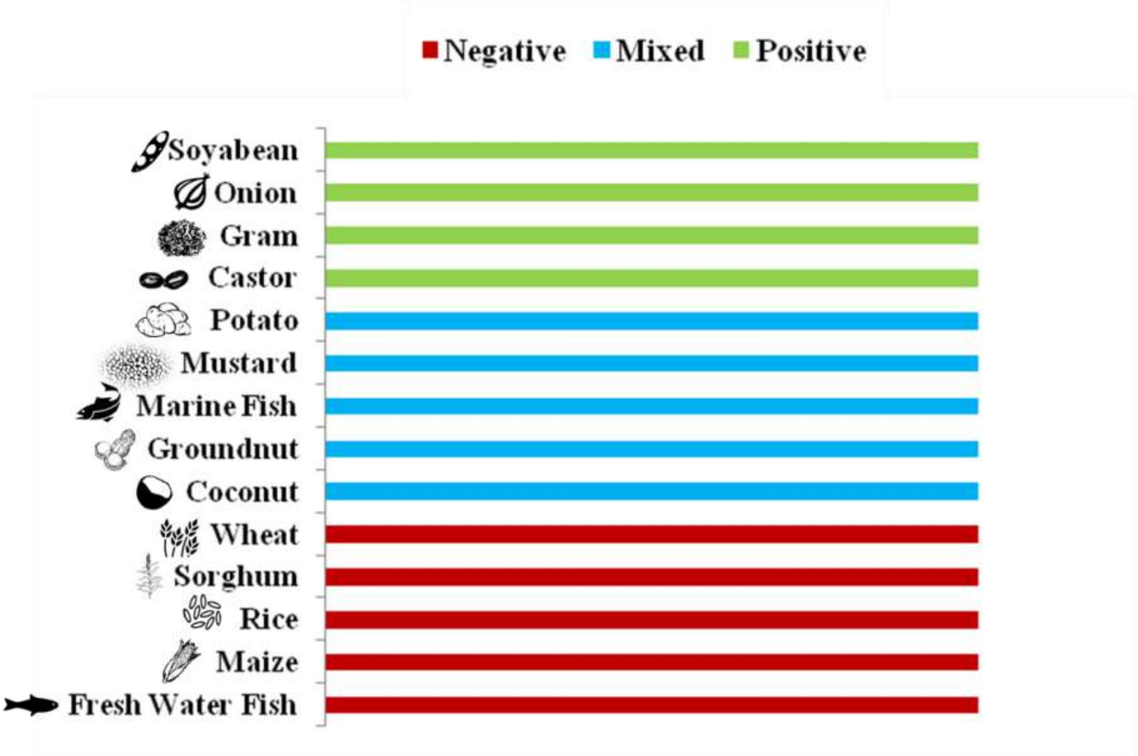


Figure 2: Commodity wise climate change impact, India (from modelling)
Source: Adapted by HPSCCC from Down to Earth, 2018 (Goswami, 2017)

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.

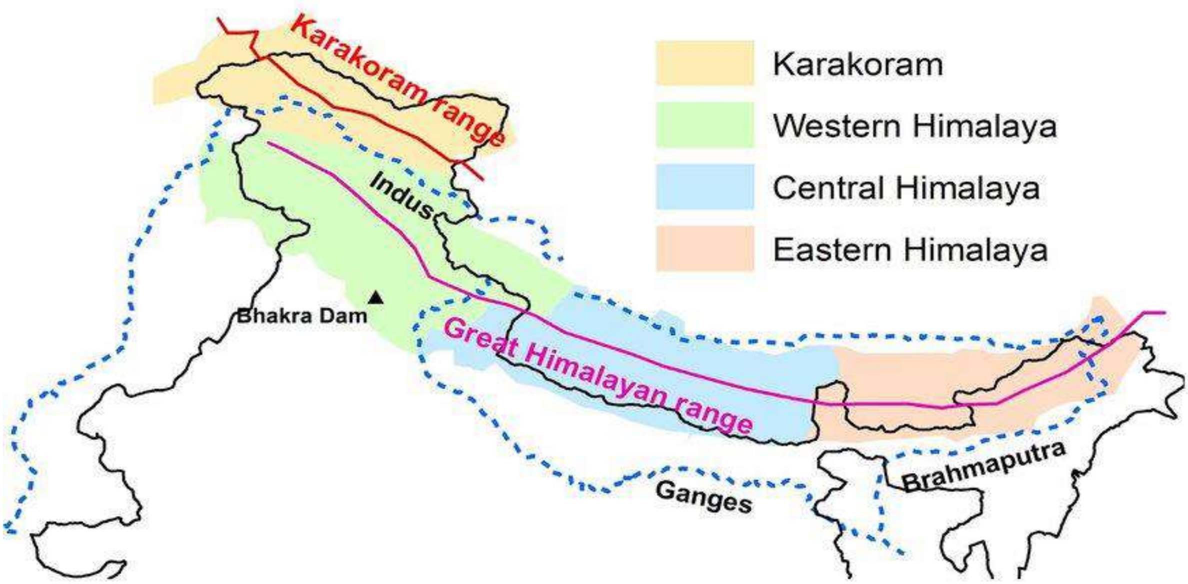


Figure 3: Geographical Representation of the Indian Himalayas
Source: Divecha Centre of Climate Change, Indian Institute of Science, Bengaluru (2018)

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 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, Shimla*)*, 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, 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, Sirmaur	Parts of Chamba, Kangra, Mandi, Shimla, Sirmaur, Kullu, Kinnaur, Hamirpur, Bilaspur	Shimla, Chamba, Kangra, Mandi, Kullu, Solan, Sirmaur, Kinnaur, Lahaul & Spiti	Kangra, Lahaul & Spiti, Kinnaur, and Parts of Chamba, Mandi, Kullu, Sirmaur, 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)

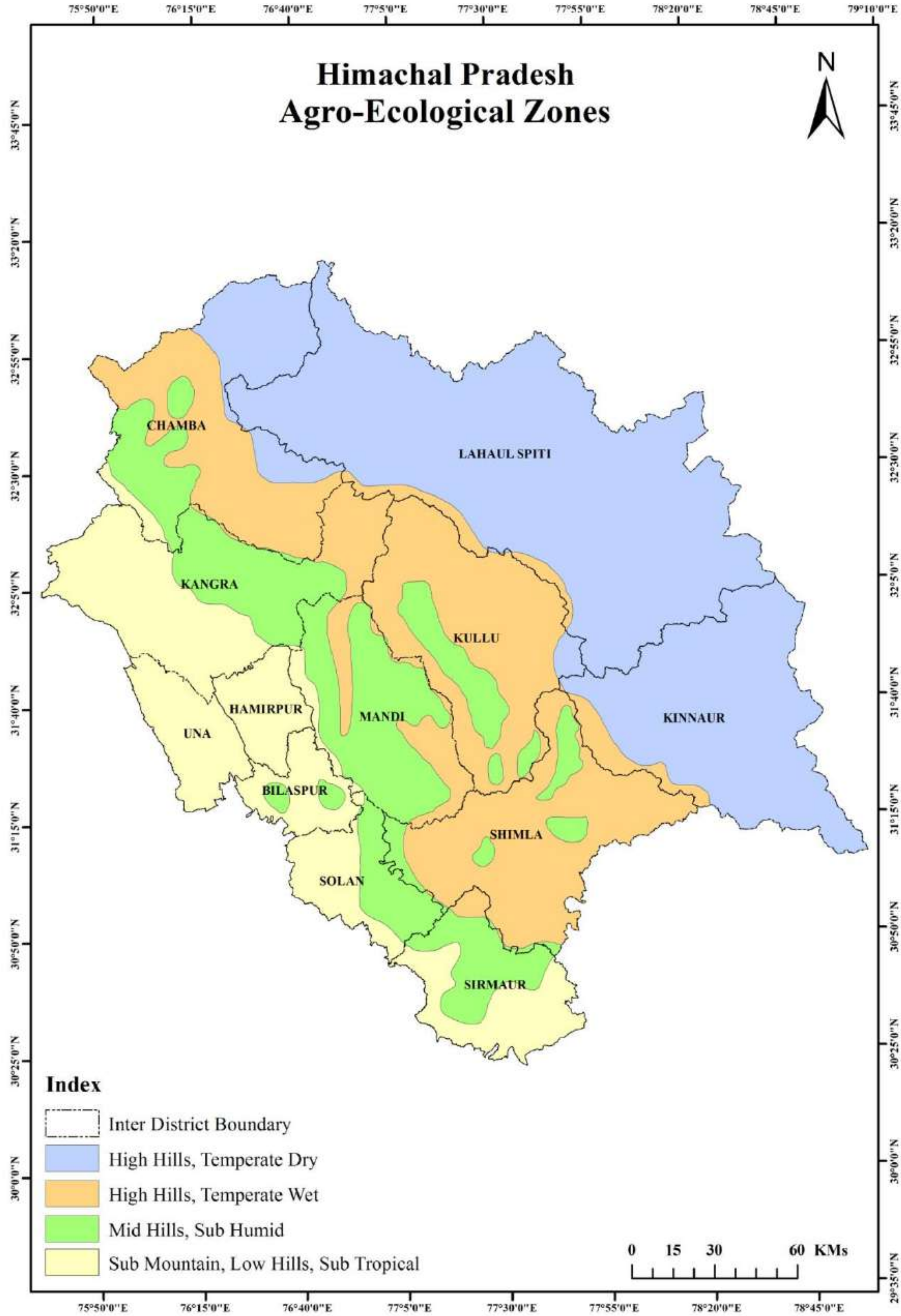


Figure 4 Himachal Pradesh Agro-Ecological Zones

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 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 Shimla. 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 Shimla, and is organised 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,…, n-1 and j = i+1, i+2, i+3, …, 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 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:

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

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, Δ*Rd* 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 SHIMLA – A BACKGROUND

District Shimla of Himachal Pradesh lies between longitude 77.00" and 78.19" east and latitude 30.45" and 31.44" north. It is surrounded by Mandi and Kullu in the north, Kinnaur in the east, Uttarakhand in the southeast, Solan to the southwest and Sirmaur in the south. The elevation of the district ranges from 300 metres (984 ft) to 6,000 metres (19,685 ft). As of 2011 it is the third most populous district of Himachal Pradesh (out of 12), after Kangra and Mandi and the most urbanized district as well. Tourism and agriculture/horticulture sector are the major sources of income.

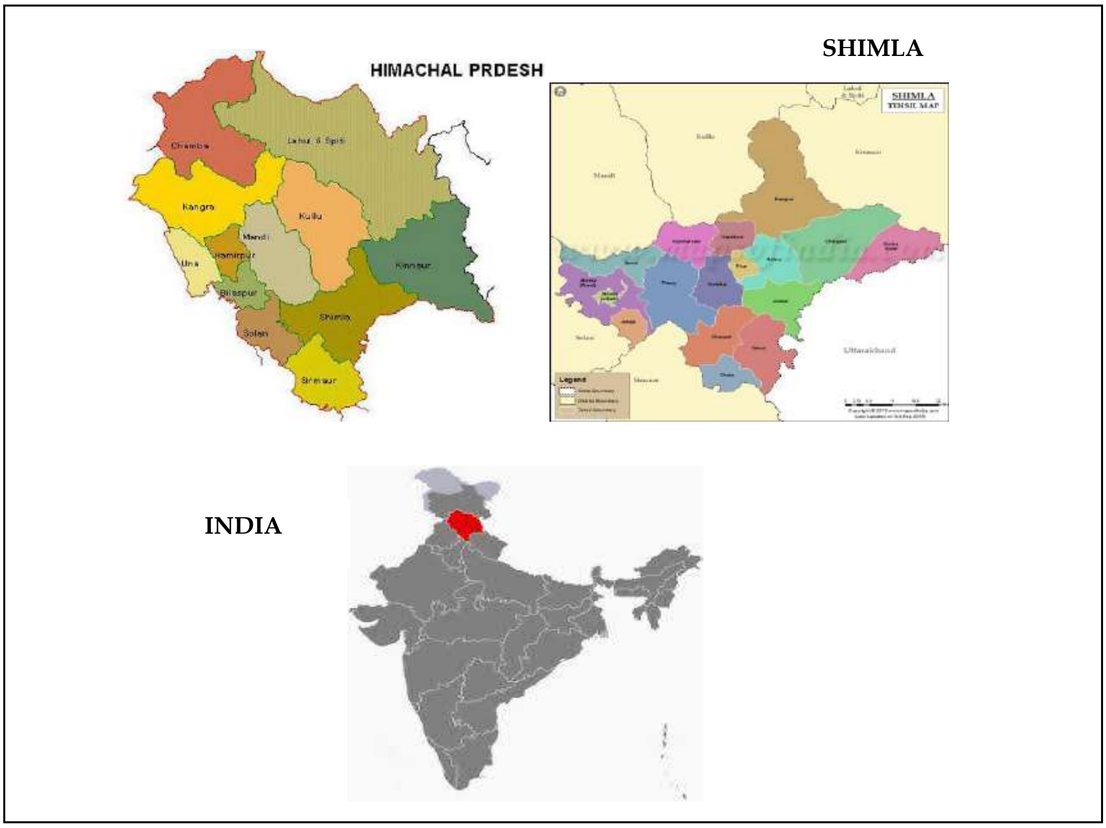


Figure 4: Map of District Shimla, Himachal Pradesh

Climate: District Shimla experiences all four broad seasons.. Winters starts from mid November up till mid March, where severe cold conditions prevail in the months of December, January and February. The upper reaches of the district are characterized by snow and sleet whereas the lower areas are frequented with rain showers. The higher peaks receive heavy snowfall as early as the beginning of October that stays till March.

From mid March to mid May continues the spring season, which is characterized with cooler nights. From mid-May till mid-July, the weather is predominately hot, especially at places in the lower reaches situated at river banks and streams. Post mid-July commences the rainfalls that extend up to mid-September. District Shimla experiences relatively shorter Autumns from mid-September to mid-November. Usually, the rainy season gets extends making way for an early onset of winter seasons. Altitude variations drive variations in temperature. Minimum temperature in the higher reaches, dips below 0°C during the winter months, whereas the maximum temperature in the lower areas, crosses even 40° C during the summers.

Agriculture: Agriculture remains the primary occupation for the populace in District Shimla. Conducive agro-climatic conditions and favourable soil profile, enables cultivation of a varied typescereals, off season vegetables, temperate and stone fruits, and other cash crops in the district. Lower elevations are suitable for the production of cereal crops, stone and citrus fruits, owing to hotter climatic conditions; whereas, the places in higher elevations are most suitable for cultivation of seed potatoes, off season vegetables, and temperate fruits. District Shimla is broadlydivided into three regions agriculture production - (i) Valleys and basin areas; (ii) Mid hills; and (iii) High hills. The low lying areas of Rampur, Seoni, Kumarsain, Jubbal and Kotkhai, Chopal, Mashobra, Theog and Rohru tehsils, are suitable for the cultivation of cereal crops.; whereas in mid hill areas of these areas/blocks, vegetables, fruits and cereals are cultivated. The higher elevations of these blocks are suitable, for growing apples, cherry, seed potatoes, almonds, and walnuts, paddy, wheat, maize, millets and pulses. Number of vegetables i.e. potatoes, peas, cauliflower are also grown in the district.

Table 3: District Shimla: Agriculture Profile

Agriculture Profile – District Shimla					
Agricultural Land Use	**Total Geographical Area ('000 ha)** : 508.322	**Net Sown Area ('000 ha):** 67.7	**Cropping Intensity:** 141.5%		
Agro-Ecological Zone	Western Himalayas, Zone II (mid hills sub-humid), Zone III (wet-temperate high hills)				
Agro Climatic Zone (NARP)*	1. High Hill Temperate Wet Zone (HP-3)				
Irrigation	**Net Irrigated Area ('000 ha)** : 3.7	**Gross Irrigated Area ('000ha):** 4.3	**Rainfed Area ('000 ha):** 92.06		
	Sources of Irrigation:		***Number***	***Area ('000 ha)***	***Irrigated Area (%)***
		Tanks	242	0.64	14.9
		Lift Irrigation Scheme	27	0.3	7.8
		Kuhls	158	3.3	77.2
Major Crops	*Grain Crops:* Wheat, Maize, Rice, Barley, Pulses (Rajmah, Moong, Mash.), Oil seeds (Mustard, other oilseeds) *Fruit Crops:* Apple, Pear, Walnut, Citrus, Other fruit *Veg.:* (Cauliflower, French- bean, Capsicum)				
Crop Sowing Window	***Kharif – rainfed:*** Maize – 2nd week of May- 2nd week of June Pulses – 2nd week of June - 1st week of July Vegetables- 1 st week of March - 4th week of June ***Kharif – irrigated:*** Paddy -2nd week of June -2nd week of July Pulses – 2nd week of June - 4th week of June Vegetables- 1 st week of March - 4th week of June ***Rabi – rainfed:*** Wheat – 4th week of October - 2nd week of November Vegetables- Ist week of October - November ***Rabi – irrigated:*** Wheat – 4th week of October to 2nd week of November Barley – 1st week to 4th week of November				

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

METHODS

Within the context of collocation of climate variability and agriculture productivity in District Shimla, 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 Shimla was collected from India Meteorological Department (IMD), Shimla 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, Shimla covering the time period 1966 to 2009. Wheat and Barley are *Rabi* crops while the remaining crops are categorized as *Kharif* crops. This dataset was used to conduct all three assessment techniques viz. Mann Kendall Test, Standardized Anomaly Index, and Multivariate Linear Regression Analysis.

CHAPTER 4 – CLIMATE TREND AND AGRICULTURE: DISTRICT SHIMLA

CURRENT CLIMATE TRENDS –DISTRICT SHIMLA

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 45 years, while for Rabi crop season, only the diurnal temperature underwent statistically significant changes. Table 4 exhibits the results of Mann Kendall test at 95% confidence level for minimum, maximum, and diurnal temperate, and rainfall for the time period 1971-2015.

Table 4: Mann Kendall Test Results – Climatic Trends for Kharif and Rabi Season (1971-2015)

	Mean	Sen's slope	p-value
Kharif			
Max T	25.86	**0.05**	<0.0001
Min T	10.79	0.06	<0.0001
Diurnal T	15.07	**-0.007**	0.643
Rainfall	1076.5	0.48	0.850
Rabi			
Max T	19.92	0.08	<0.0001
Min T	1.26	0.07	<0.0001
Diurnal T	18.66	**0.02**	0.18
Rainfall	301.26	3.32	0.03

During Kharif crop season, the maximum temperature rose at the rate of 0.05°C per year (as exhibited by the Sen's slope).Meanwhile the diurnal temperature exhibited a decreasing trend of 0.007 °C per year. Rainfall, on the other hand, did not show any significant variation from 1971-2015.

As per the output from SAI, after 1992, maximum temperature remained above the long term average except for the years 1998 and 2008 indicating an overall warming trend. A continued warming trend was observed in case of minimum temperature except for few years. Rainfall, on the other hand, did not show any significant variation from 1971 to 2015 during the Kharif crop season.

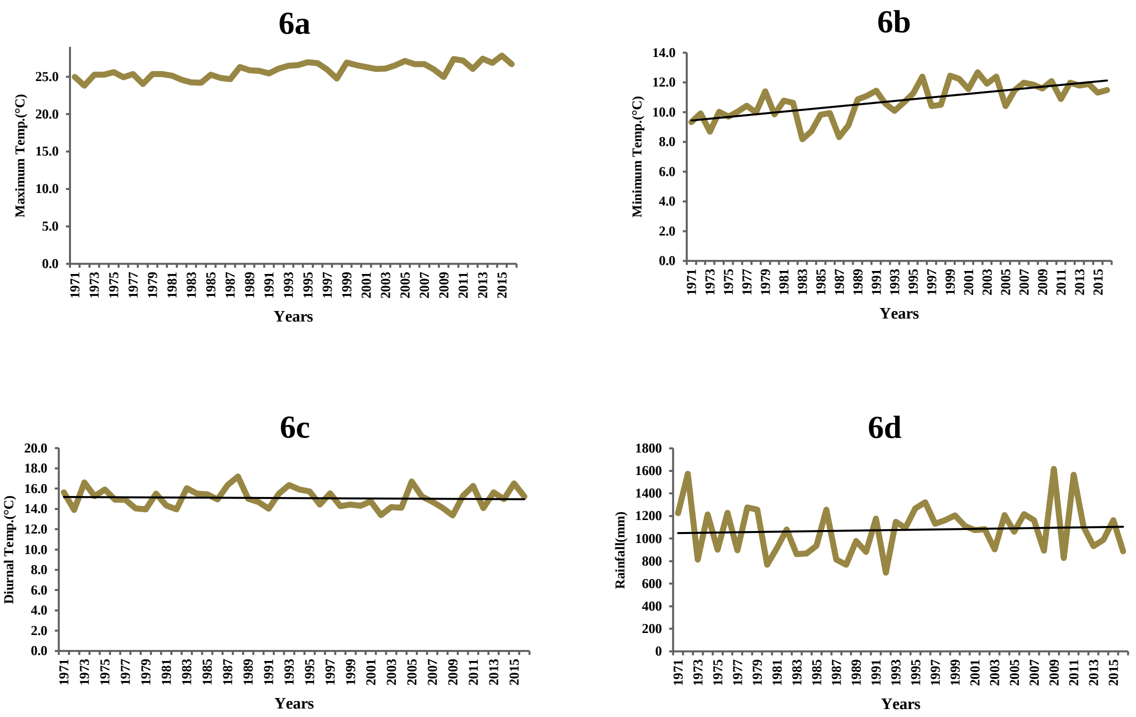


Figure 6: Variations in Climatic Parameters- Minimum T, Maximum T, Diurnal T and Rainfall during *Kharif Crop* season (1971-2015), District Shimla, H.P.

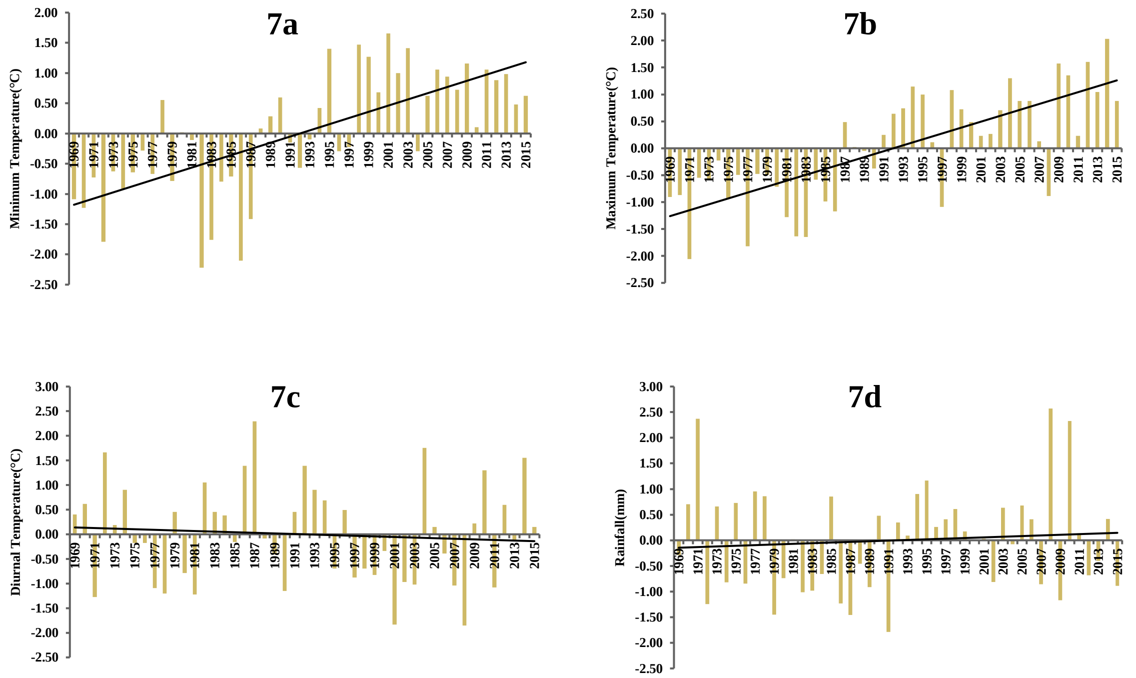


Figure 7: SAI for Climatic Parameters- Minimum T, Maximum T, Diurnal T and Rainfall, during *Kharif Crop* season (1971-2015), District Shimla , HP

During Rabi crop season, Diurnal temperature registered statistically significant increase of 0.02 °C per year in District Shimla. Meanwhile, the maximum and minimum temperature and rainfall did not show significant changes from 1971-2015.

As per the outputs from SAI, minimum and maximum temperature showed a warming trend from 1993 onwards, except for dip in the year 1997 for both maximum and minimum temperatures. Whereas no significant pattern was observed for diurnal temperature and rainfall.

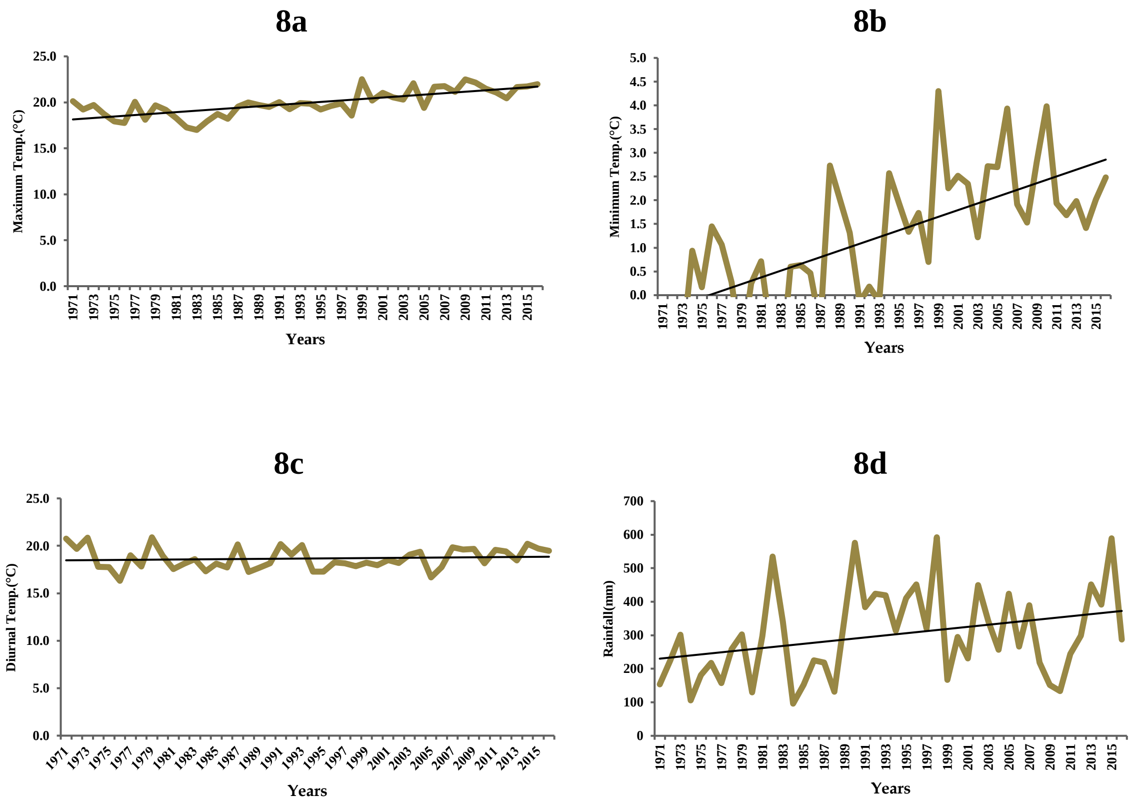


Figure 8: Variations in Climatic Parameters- Minimum T, Maximum T, Diurnal T and Rainfall during *Rabi Crop* season (1971-2015), District Shimla, HP

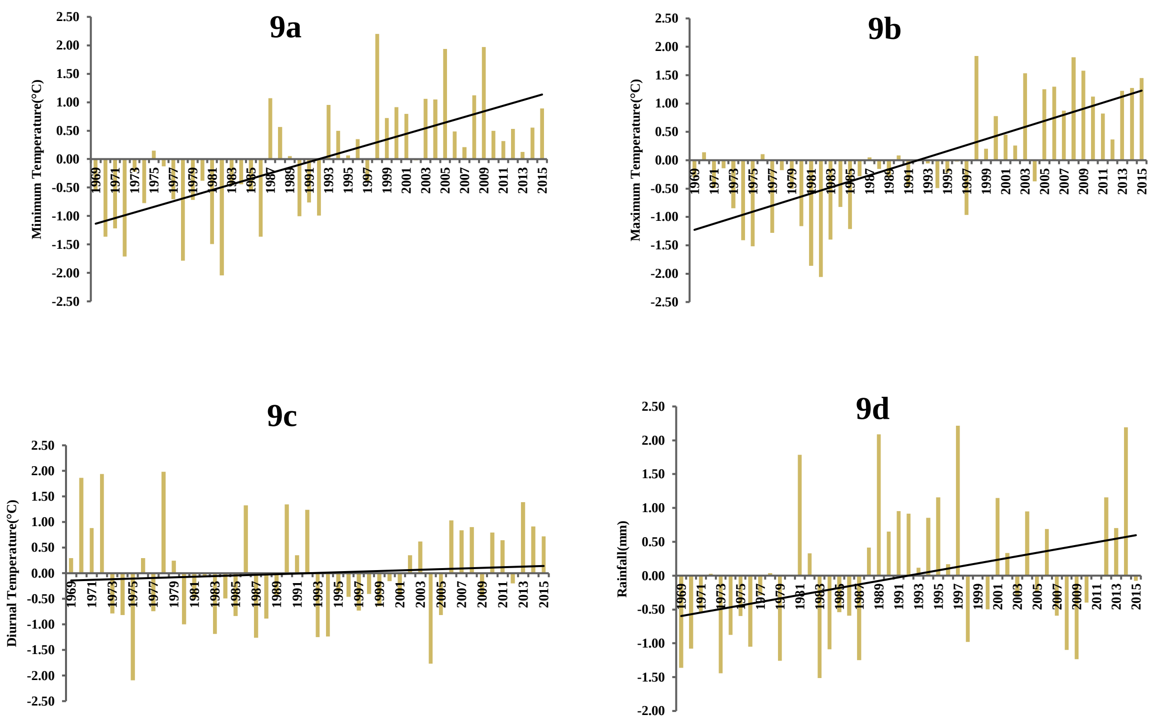


Figure 5: SAI for Climatic Parameters- Minimum T, Maximum T, Diurnal T and Rainfall during *Rabi Crop* season (1971-2015), District Shimla, HP

The discussed variations in temperature and rainfall patterns are not confined to District Shimla 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. 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 SHIMLA

LAND USE CHANGES IN DISTRICT SHIMLA:

The total area of District Shimla is 5,131 sq. km., of which the net sown area increased by 106.73% from 31,898 ha to 65944 ha between 1965 and 2010. The cropping intensity declined from 139.39% to 131.12% .Similarly a sharp decline was observed in culturable waste land by 55.72% from 29,538 ha to 13,078 ha. This decline in cropping intensity is expected to be linked to the reduction in culturable waste land in the district. Therefore, changes in the total cropped area were studied to understand the categorized shift in cropping patterns between food grains, vegetables, and orchard farming.

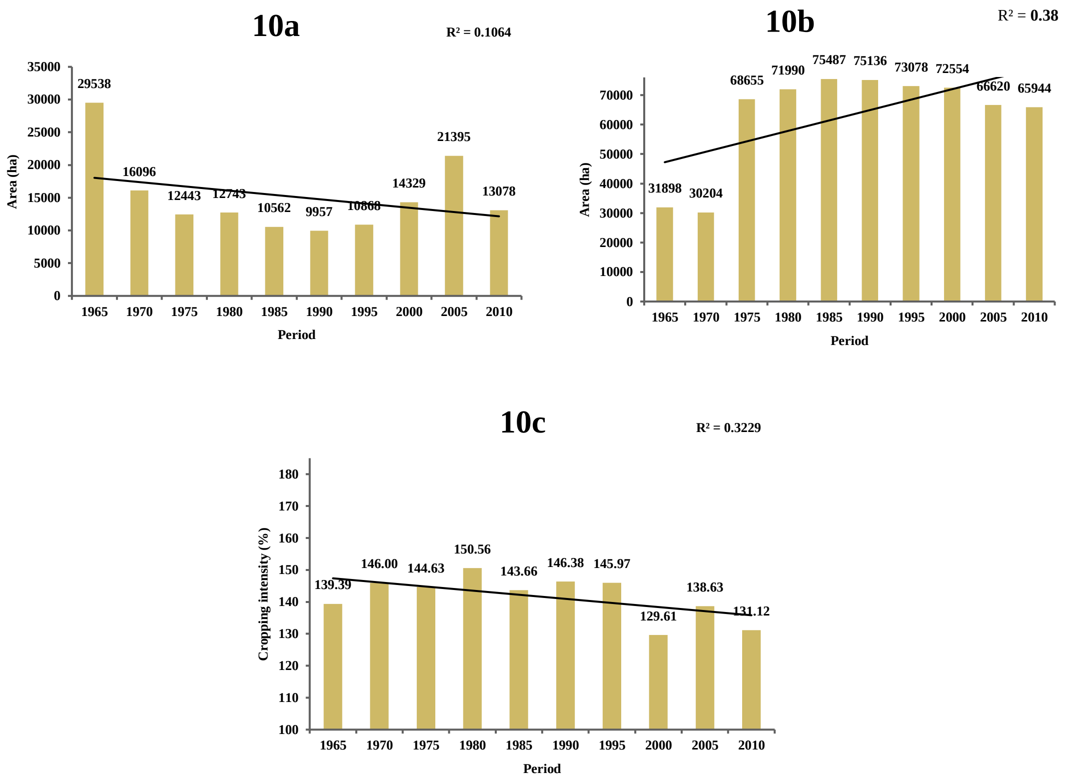


Figure 10: Change in area under Culturable wasteland, Net sown area and Cropping intensity (1965 to 2010) District Shimla, H.P.

Based on the data from the Annual Crop and Season report by Directorate of Land Records, cropped area under food grains increased by 133.53% from 38,455 ha to 89,806 ha upto 1975 thereafter decreased by 68.05% from 86,886 ha to 28,691 ha from 1975 to 2015. Meanwhile, area under vegetables and orchards exhibited a sharp increase of 1400 per cent from 844 ha to 12,667 ha, and 29513 per cent from 154 ha to 45,605 ha respectively, from 1965 to 2010 (figure 11)

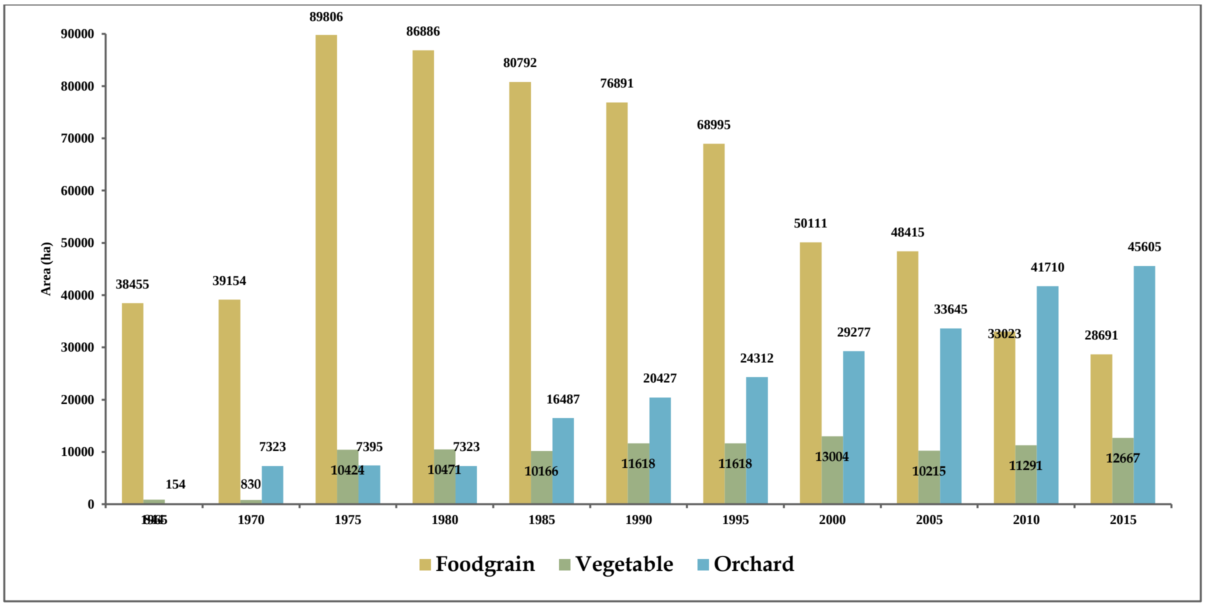


Figure 11: Change in area under food grains, vegetable and orchards from 1965 to 2015 District Shimla

A proportional shift from food grains towards vegetable and orchard farming could have suggested an absolute improvement through crop diversification and inherent economic attractiveness of cash crops. However, while orchard acreage reported a steady incline, vegetable showed fluctuated acceptance amongst the farmers in the district. Therefore, an understanding on the role of other influencing factors associated with variations in climatic conditions on individual crop productivity was deemed imperative.

ACREAGE AND PRODUCTION ASSESSMENT OF MAJOR AGRICULTURAL CROPS

Major food crops of the district are Paddy, Maize, Wheat, Barley and Potato. Acreage under these crops has also witnessed a change over the time. Temporal trends of change in area, production and productivity of different food crops in District Shimla are illustrated in figure 12 to 17. Rice crop acreage witnessed a drastic decrease of 56.35 per cent from 2,912 to 1,271 ha during 1966 to 2010, while production decreased from 2,271 MT to 1,587 MT in 2010. Area and production of Maize exhibited a decreasing trend, from 13,766 ha in 1966 to 10,281 ha in 2010; whereas the production decreased by 19.31 % from 27,662 MT in 1966 to 22,318 MT in 2010. Similarly, Wheat experienced a decreasing trend in acreage from 11,943 ha in 1966 to 9,338 ha in 2010; whereas production of wheat increased by 36.42 % from 8,207 MT to 11,196 MT in 2010 . However, Barley and Potato showed a consistent increase in acreage as well as production during the study period. Barley crop acreage witnessed a drastic increase by 226.81 per cent where as production increased by 477.3%. Similarly in case of Potato the area under potato crop increased by 580.4 % and production showed an increase of 3086.7 % in the study period.

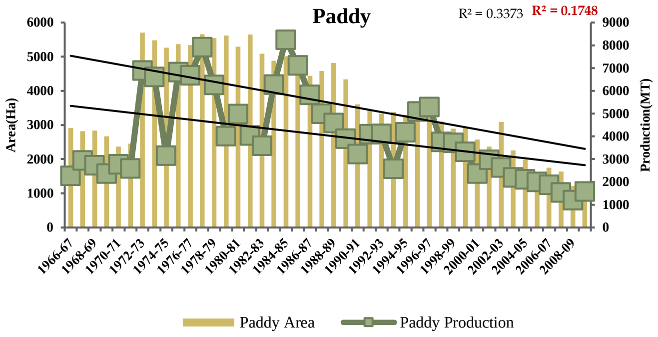


Figure 6: Variations in Area and Annual Production of Rice (1966-2009), District Shimla, HP

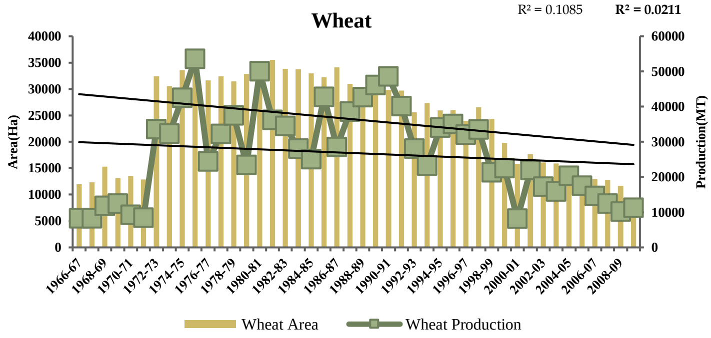


Figure 7: Variations in Area and Annual Production of Wheat (1966-2009), District Shimla, HP

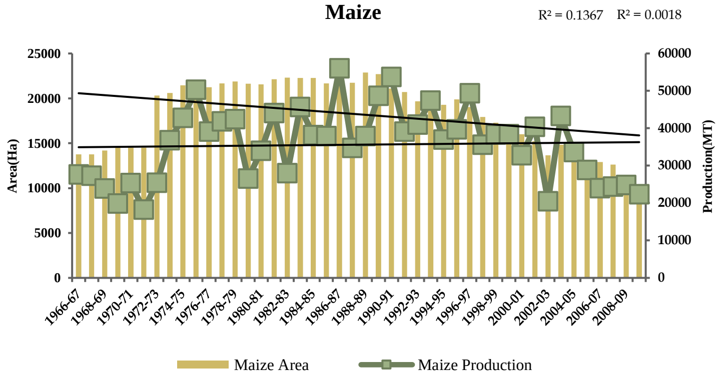


Figure 8: Variations in Area and Annual Production of Maize (1966-2009), District Shimla, HP

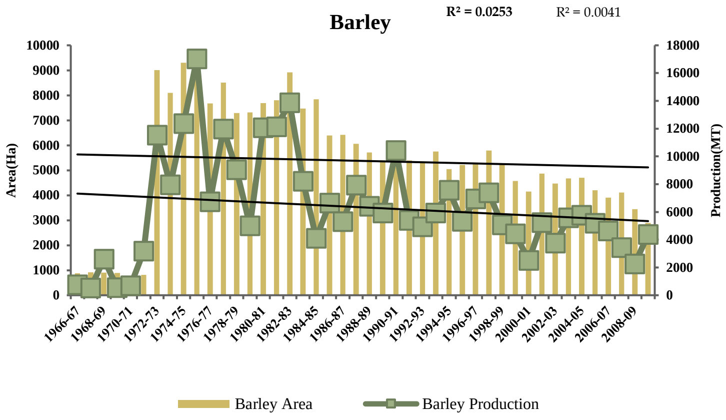


Figure 15: Variations in Area and Annual Production of Barley (1966-2009), District Shimla, HP

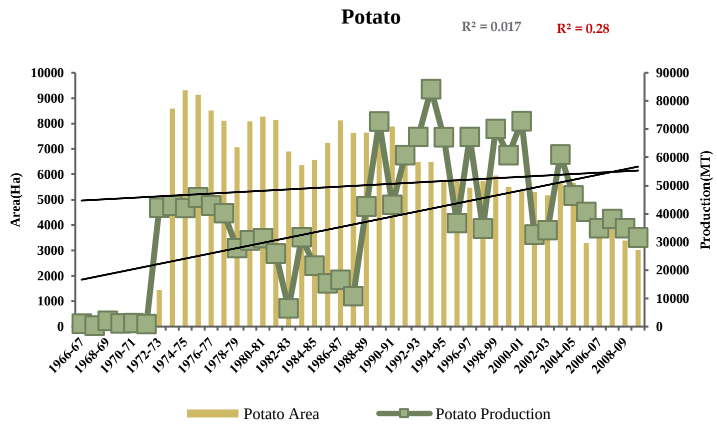
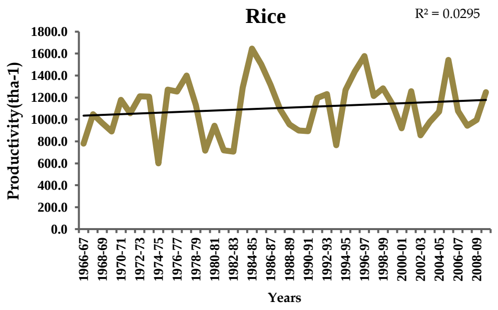
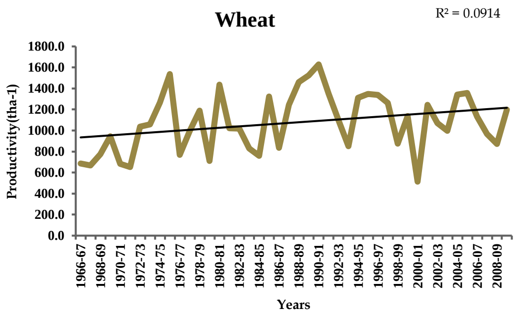


Figure 9: Variations in Area and Annual Production of Potato (1966-2009), District Shimla, HP

Analysis of productivity trends for Rice, Maize, Potato, Millets, and Wheat crops showed significantly changing yields during 1966-2009 time periods, except for Barley (illustrated in figure 17).





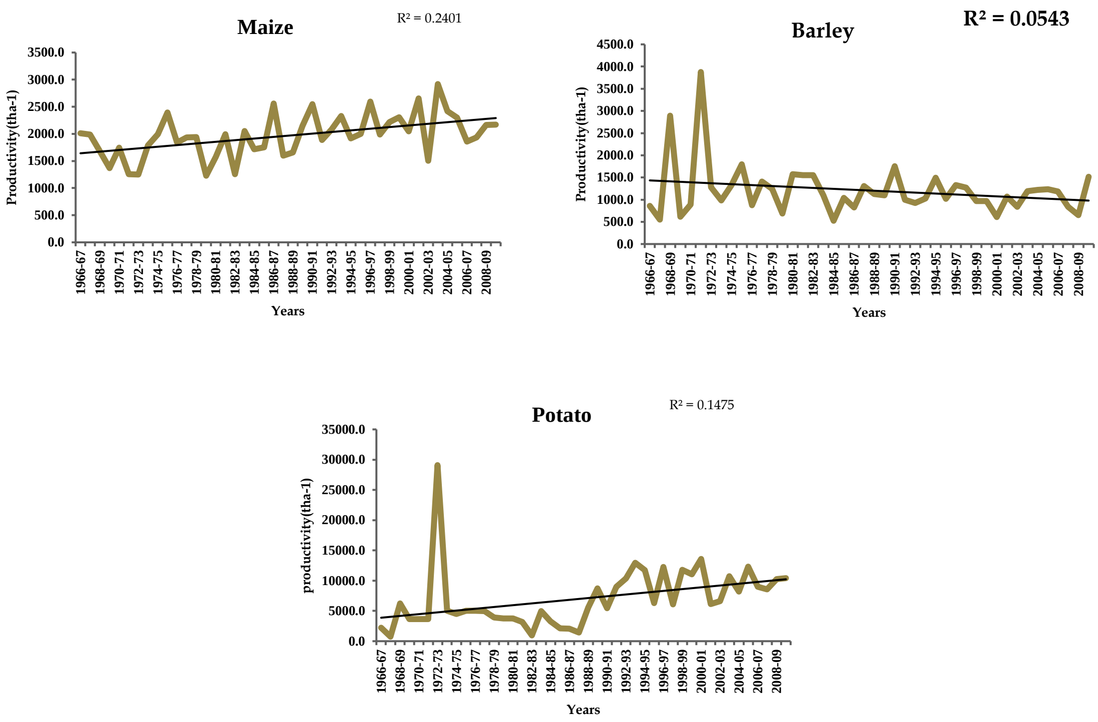


Figure 10: Variations in Productivity - Rice,Wheat, Maize, Barley ,Potato, (1966-2009), District Shimla, HP

As per the outputs from Mann Kendal Tests, an overall increased productivity trend is recorded for Maize and Potato (see table 5), wherein Potato crop had the lowest p-value (0.001) exhibiting significant changes in productivity compared to the other crops. Maize showed an increased crop yield of 0.002t $ha^{-1}year^{-1}$ respectively. Only Barley crop registered a decline in productivity by 9.7 t ha^{-1} $year^{-1}$.

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

Crops	Sen's slope	p-value	Confidence interval
Wheat	2.3	0.59	0.51,3.88
Barley	-9.7	0.06	-12.7,-6.82
Rice	0.9	0.80	-0.73,2.51
Maize	17.4	**0.002**	15.5,18.7
Potato	178.4	**0.001**	163.3,210.5

From the table above it can be seen that only Maize and Potato 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 Shimla (Table 6). While testing the effects of variability in maximum temperature, diurnal temperature, and rainfall, a significant and positive trend (0.26, 0.34 and 0.22) was observed for Wheat crop productivity (with a p-value of 0.04, 0.02 and 0.02).

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, Potato, Maize, Barley and Rice only 16.8%, 9.6%, 7.3%, 6.7%, and 4.6% 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 Maize and Potato from 1971-2011 is explained by the variations in climatic parameters only to the extent of 7.3% and 9.6% respectively. 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).

Table 6: Multivariate Linear Regression Analysis – Crop Yields and Climatic Parameters, (1971-2011)

Crop	Variable / Statistics	Minimum temperature	Maximum temperature	Diurnal temperature	Rainfall	R^2	Change (%)
Wheat	Coefficient	-0.13	**0.26**	**0.34**	**0.22**	0.168	**16.8 %**
	p-value	0.21	**0.04**	**0.02**	**0.02**		
Barley	Coefficient	-0.14	0.12	0.23	-0.01	0.067	**6.7%**
	p-value	0.18	0.23	0.07	0.47		

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

Rice	Coefficient	0.01	-0.01	-0.01	-0.06	0.046	**4.6%**
	p-value	0.47	0.46	0.47	0.37		
Maize	Coefficient	-1.86	0.10	0.24	-0.16	0.073	**7.3%**
	p-value	0.12	0.26	0.06	0.16		
Potato	Coefficient	0.02	-0.23	-0.22	-0.02	0.096	**9.6%**
	p-value	0.44	0.07	0.08	0.45		

CONCLUDING POINTERS

Crop Variations:
*Rice, Maize, Potato, and Wheat crops showed significantly changing yields during **1966-2009** time periods, except for Barley.*

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.
Climate Crop Juxtaposition:
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 Shimla.
Strong relationship between climate variability and productivity of Rabi crop such as Wheat whereas negligible association observed for Kharif crops (Rice & Maize) in District Shimla. The effects of variability in maximum temperature, diurnal temperature, and rainfall, a significant and positive trend (0.26, 0.34 and 0.22) was observed for Wheat crop productivity (with a p-value of 0.04, 0.02 and 0.02).

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 Shimla. The 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. Whereas rainfall did not register any statistically significant result. Moreover, the Standardized Anomaly Index of minimum temperature depicted a warming trend from 1992 onwards except for dips in 1996, 1997 and 2004. Similarly the diurnal temperature increased by 0.02 °C per year during Rabi crop season. Maximum, minimum temperature and rainfall did not register any statistically significant result. Moreover the Standardized Anomaly Index of Minimum and maximum temperature showed a warming trend from 1993 onwards. A 1°C rise in maximum temperature in Rabi season reduces the yield of wheat crop significantly by around 10%, while a similar rise in minimum temperature leads to a significant in the yield by 6% (Ritambhara Singh et al, 2017).

For all assessed crop varieties viz. Wheat, Potato, Maize, Barley and Rice only 16.8%, 9.6%, 7.3%, 6.7%, and 4.6% 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 increase in productivity for Maize and Potato from 1965-2011 is explained by the variations in climatic parameters only to the extent of 7.3% and 9.6% respectively. Similar interpretation stands for the decline in productivity for Wheat, Barley and Rice. Impact of higher precipitation on Wheat production also depends strictly on geographical area. In general, higher precipitation in arid and semi-arid regions affects Wheat production positively. However, in regions with already high rainfall, more precipitation can reduce Wheat production by nutrient leaching and water logging (Ludwig and Asseng, 2006).

BIBLIOGRAPHY

AGRICOOP, 2012. *Agriculture Contingency Plan for District: SHIMLA* [Online] Available at: http://agricoop.nic.in/sites/default/files/HP5-Kullu-31.12.2012.pdf [Accessed 25 September 2018].

Alwang, J., Siegel, P.B. & L., J.S., 2001. *Vulnerability: A View from Different Disciplines.* Discussion Paper Series No. 0115. Washington DC: World Bank Social Protection Unit.

Ashutosh, K. et al., 2018. *Policy Brief: State of Himalayan glaciers and future projections*. [Online] Available at: https://www.researchgate.net/publication/323991338_Policy_Brief_State_of_Himalayan_glaciers_and_future_projections [Accessed 24 September 2018].

Bhagat, R.M., Singh, S. & Kumar, V., 2006. *Agro-Ecological Zonation of Himachal Pradesh - Agricultural System Information Development at Micro-Level*. Study Report. Palampur: Centre for Geo-informatics, CSK Himachal Pradesh Agricultural University.

Bhan, S.C. & Singh, M., 2011. Analysis of total precipitation and snowfall patterns over Shimla. *Journal of Agrometeorology*, 13(2), pp.141-44.

Bhutiyani, M.R., Kale, V.S. & Pawar, N.J., 2007. Long Term Trends in Maximum, Minimum and Mean Annual Air Temperature across the North-western Himalayas During the Twentieth Century. *Climatic Change*, 85(1-2), pp.159-77.

Brooks, N., 2003. Vulnerability, risk and adaptation: A conceptual framework. *Tyndall Centre for Climate Change Research*, Working Paper No. 38.

Brooks, N., Adger, N. & Kelly, P., 2005. The determinants of vulnerability and adaptive capacity at the national level and the implications for adaptation. *Global Environmental Change*, 15(2), pp.151-63.

Bruijnzeel, L.A., 2004. Hydrological functions of tropical forests: not seeing the soil for the trees? *Agriculture, Ecosystems & Environment*, September. pp.185-228.

Census, 2011. *District Census Handbook - Shimla* [Online] Available at: http://censusindia.gov.in/2011census/dchb/0204_PART_A_DCHB_SHIMLA.pdf [Accessed 24 September 2018].

DESTHP, 2012. *State Strategy & Action Plan on Climate Change*. Status Report. Department of Environment, Science & Technology, Government of Himachal Pradesh.

Economic Survey, 2018. *Climate, Climate Change, and Agriculture*. [Online] Available at: http://mofapp.nic.in:8080/economicsurvey/pdf/082-101_Chapter_06_ENGLISH_Vol_01_2017-18.pdf [Accessed 24 September 2018].

Forrest, J. et al., 2012. Conservation and Climate Change: Assessing the Vulnerability of Snow Loepard Habitat to Treeline Shift in the Himalaya. *Biological Conservation*, 150(1), pp.129-35.

Gammans, M., Mérel, P. & Ortiz-Bobea, A., 2017. Negative Impacts of Climate Change on Cereal Yields: Statistical Evidence from France. *Environmental Research Letters*, 12(5).

Gornall, J. et al., 2010. Implications of climate change for agricultural productivity in the early twenty-first century. *Philosophical Transactions of the Royal Society B. Biological Sciences*, 365(1554), pp.2973-89.

Goswami, S., 2017. *Climate change impact on agriculture leads to 1.5 per cent loss in India's GDP*. [Online] Available at: https://www.downtoearth.org.in/news/climate-change-causes-about-1-5-per-cent-loss-in-india-s-gdp-57883 [Accessed 24 September 2018].

Ritambhara Singh et al, 2017.Impact *of Rainfall and temperature on the yield of major crops in Gujarat State of India:* A Panel Data Analysis (1980-2011).

Joshi, N.P., Maharajan, K.L. & Piya, L., 2011. Effects of Climate Variables on Yield of Major Food Crops in Nepal: A Time Series Analysis. *Journal of Contemporary Indian Studies: Space and Society, Hiroshima University*, 1, pp.19-26.

Kaur, P. et al., 2011. Quantitative Evaluation of Weather Variability and Rice Yields in Punjab – A Case Study. *Journal of Research, Punjab Agricultural University*, 48(1-2), pp.5-15.

Kelly, P. & Adger, W., 2000. Theory and Pactice in Assessing Vulnerability to Climate Change and Facilitating Adaptation. *Climatic Change*, 47, pp.325-52.

Klein, T., Holzkämper, A. & Calanca, P.e.a., 2014. Adaptation options under climate change for multifunctional agriculture: a simulation study for western Switzerland. *Regonal Environmental Change*, 14(1), pp.167-84.

Koudahe, K. et al., 2017. Trend Analysis in Standardized Precipitation Index and Standardized Anomaly Index in the Context of Climate Change in Southern Togo. *Atmospheric and Climate Science*, 7, pp.401-23. https://doi.org/10.4236/acs.2017.74030.

Kumar, K. & Parikh, J., 2001. Indian agriculture and climate sensitivity. *Global Environmental Change*, 11, pp.147-54.

Ludwig, Fulco and Senthold Asseng, 2006. Climate Change Impacts on Wheat Production in a Mediterranean Environment in Western Australia. *Agricultural Systems* 90:1, 159-179

Mendelsohn, R. & Dinar, A., 1999. Climate change, agriculture, and developing countries: Does adaptation matter? *The World Bank Research Observer*, 14, pp.277-93.

Mendelsohn, R., Dinar, A. & Sanghi, A., 2011. The effect of development on the climate sensitivity of agriculture. *Environment and Development Economics*, 6, pp.85-101.

Mishra, S.K. et al., 2015. Sensitivity Analysis of Four Wheat Cultivars to Varying Photoperiod and Temperature at Different Phenological Stages using WOFOST Model. *Jpurnal of Agrometeorology*, 17(1), pp.74-79.

Padma, T.V., 2014. Himalayan Plants Seek Cooler Climes. *Nature: International Weekly Journal of Science*, 512(7515), p.359. Available at: https://www.nature.com/polopoly_fs/1.15771!/menu/main/topColumns/topLeftColumn/pdf/512359a.pdf.

Panday, P. & Ghimire, B., 2012. Time-series Analysis of NDVI fro AVHRR Data over the Hindu Kush-Himalayan Region for the period 2008-2006. *International Journal of Remote Sensing*, 33(21), pp.6710-21.

PI, 2009. *FAO says Food Production must Rise by 70%*. [Online] Available at: https://www.populationinstitute.org/resources/populationonline/issue/1/8/ [Accessed 24 September 2018].

Pidwirny, M., 2006. *Climate Classification and Climatic Regions of the World*. [Online] Available at: http://www.physicalgeography.net/fundamentals/7v.html [Accessed 25 September 2018].

Pohlert, T., 2018. *Non-Parametric Trend Tests and Change-Point Detection*. Technical Report.

Poudel, S. & Shaw, R., 2016. Relationship between Climate Variability and Crop Yield in a Mountaineous Environment: A Case Study in Lamjung District, Nepal. *Climate*, 4(1), p.13.

Sanchez, P., 2000. Linking climate change research with food security and poverty reduction in the tropics. *Agriculture, Ecosystemes & Enivronment*, 82(1-3), pp.371-83.

Saseendran, S.A. et al., 2000. Effects of Climate Change on Rice Production in the Tropical Humid Climate of Kerala, India. *Climate Change*, 44(4), pp.495-514.

Sharma, H.R., 2011. Crop Diversification in Himachal Pradesh: Patterns, Determinants and Challenges. *Indian Journal of Agricultural Economics*, 66(1), pp.97-114.

Singh, K.K. et al., 2015. Assessment of Climate Change Impact on Productivity of Different Crops in Varanasi, India. *Journal of Agrometeorology*, 17(2), pp.179-84.

Siwar, C., Ahmed, F. & Begum, R.A., 2013. Climate change, agriculture and food security issues: Malaysian perspective. *Journal of Food, Agriculture and Environment*, 11(2), pp.1118-23.

Walker, B. & Steffen, W., 1997. *An Overview of the Implications of Global Change for Natural and Managed Terrestial Ecosystems*. [Online] Available at: https://dlc.dlib.indiana.edu/dlc/bitstream/handle/10535/3389/30.pdf?sequence=1&isAllowed=y [Accessed 24 September 2018].

Walthall, C.L. et al., 2012. Climate Change and Agriculture in United States: Effects and Adaptation. *USDA Technical Bulletin 1935, Washington. DC*, p.186.

WRI, 2014. *Everything You Need to Know About Agricultural Emissions*. [Online] Available at: https://www.wri.org/blog/2014/05/everything-you-need-know-about-agricultural-emissions [Accessed 24 September 2018].