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

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EXEUTIVE SUMMARY

Climate change has emerged as a real concern for the horticulture sector with visible changes in productivity, quality of crop yields, and acreage already being reported around the globe. Crop production systems in South Asia and sub-Saharan Africa are observed to be at undisputable climatic exposure, where temperature increase is already closer to or beyond the threshold, which is having a limiting impact on overall vegetative growth. A far greater impact of extreme dry and wet spells compared to changes in long-term mean precipitation is also being reported on fruit crop productivity.

Particularly, in the fragile Himalayan eco-system, where over 72 million people survive and thrive on hill-agriculture based livelihood, the increasing pressure from burgeoning population combined with global climate change is rendering the occupation challenging and un-fruitful. The Himalayan ecosystem offers an enabling environment characterised with favourable micro-climatic conditions for cultivation of a wide range of horticulture crop such as apples, plums, peaches, bananas, mangoes, pineapples, citrus fruits, walnuts and more. Fruits and vegetables cover around 16 per cent of the total crop land in Indian Himalayan Region, with the western Himalayas accounting for around 20 per cent of farmlands, and the central and eastern Himalayas with only 5 per cent. In Himachal Pradesh, which is known as the fruit bowl of India, around 71 per cent of the 6.86 million people are dependent on the agriculture / horticulture sector for employment and income sources. There is heightened exposure to climate change induced vulnerability on sector's and individual crop's sustainability.

To this effect, a study was conducted with a view to ascertain the impact of climate change on horticulture sector in District Kangra. Seasonal trends on climatic variables i.e. minimum, maximum, and diurnal temperatures, and rainfall patterns (quantity and rainy days) were conjugated with a standardised anomaly index, and a multivariate regression analysis was conducted to unearth the climate and crop yield relationship as per the phenological stages of *pre-flowering, flowering, and fruit setting and development.*

As per the analysis the ***average maximum temperature*** registered an inclining trend at a rate of 0.045°C per year between 1970-2018 (as exhibited by the Sen's slope) during the ***pre- flowering season*** i.e., between November – February. During the ***flowering season*** i.e., March to April the average maximum temperature increased by 0.04°C per year and minimum temperature showed decline in temperature by -0.02°C per year. Also, the average maximum temperature ***and diurnal temperature*** during ***fruit setting stage*** i.e., between May – August also registered an inclining trend progressing at a rate of 0.013°C and 0.04°C per year between 1970-2018. Rainfall during fruit setting stage show increase by 5.31mm.The remaining climatic variables did not exhibit any significant variation during the *pre-flowering, and fruit setting* and *development stages.*

As per the analysis the *average maximum temperature* registered an inclining trend at a rate of 0.045°C per year between 1970-2018 (as exhibited by the Sen's slope) during the *pre- flowering season* i.e., between November – February. During the *flowering season* i.e. March to April the average maximum temperature increased by 0.04°C per year and minimum temperature showed decline in temperature by -0.02°C per year. Also, the average maximum temperature *and diurnal temperature* during *fruit setting stage* i.e., between May – August also registered an inclining trend progressing at a rate of 0.013°C and 0.04°C per year between 1970-2018. Rainfall during fruit setting stage show increase by 5.31mm.

Highly significant correlation between climate variability and productivity was observed during the pre-flowering stages, with a predominant impact on the productivity of Orange, Mango, Galgal (*Citrus Pseudolimon*) and Louqat. Orange productivity exhibited strong correlation with maximum and minimum temperatures during the pre-flowering period with coefficient values of 0.58 and 0.36 respectively. Amongst all the studied crops, Mango, Orange and Galgal productivity showed significant correlation to climatic variations during Pre flowering and flowering stages i.e. (15%, 20%, 10%) orange (39%, 1%, 6%) and Galgal (34%, 52%,3%). With respect to individual crops, this means that the observed variations in productivity for mango crop from 1990-2016 is explained by the variations in climatic parameters only to the extent of 15% during pre-flowering stage, 20% during the flowering stage, and 10% during the fruit setting and development stage. While the other crops such as Lemon (8%, 4%, 8%), Litchi (9%, 5%, 6%), and Guava (1%, 11%, 12%) Pear productivity showed sensitivity to climatic variations during all three stages with non significant correlation.

CHAPTER 1 - INTRODUCTION

CLIMATE AND HORTICULTURE

Horticulture is a vibrant sister sector of Agriculture, distinguished by scale of production and commercialisation, and assumes a pivotal role to foster food, economic, and nutritional security, globally. India is the second largest contributor to world's horticulture produce, where it accounted for a record 307.16 MT of production in 2017-18 (IBEF, 2018). Nonetheless, this high contributing sector has a wider exposure to climate change when compared to its close associate Agriculture sector, but with a relatively smaller carbon footprint. In India, 8.71 per cent of carbon emissions came from the Agriculture, Food, and Land-use in 2013 (WRI, 2018); however, the carbon sequestration quotient from a mixture of perennial horticulture crops such as tree fruits, tree nuts, vine fruits, and seasonal vegetables, herbs offering carbon storage above the ground, net offs the sector's carbon footprint.

Climate Change, *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* has observed manifestation in the horticulture sector through two parameters – erratic precipitation (rains and snowfall), and uncertain spells of temperature rise that has unpredictable impact on fruit crop productivity. Loss in vigour, fruit bearing ability, reduction in fruit size, and increase in pest attack eventually result in low production and poor quality of temperate fruit crops such as apple, peach, plum and more. Various exploratory studies have analysed the potential impact of climate variability on horticulture productivity, especially in the context of developing countries.

Crop production systems in South Asia and sub-Saharan Africa are observed to be at the receiving end of undisputable climatic exposure. Located in lower altitudes, these developing countries are already experiencing temperatures closer to or beyond the threshold thereby any increase in mean temperatures is bound to negatively impact horticulture crop productivity (Malhotra, 2017). Samedi and Cochran (1976) highlight the role of rising temperature in limiting vegetative growth, and affecting fruit setting especially of citrus fruits which is visible through burning or scorching of blossoms in higher plains, a phenomenon generally seen in desert areas. Meanwhile, higher temperatures are also expected to alter precipitation rates leading to changes in both frequency and intensity of droughts and floods. In South Asia, a median 11 per cent change in precipitation is expected by the end of 21st century, with decrease in dry seasons and an increase throughout the year (IPCC, 2007). In

India, mean temperatures are likely to rise by 3-4 °C by the end of 21st century, as per IPCC Fourth Assessment Report on Climate Change (2007). These exacting changes in temperature and precipitation patterns, irrespective of the study area, are expected to give rise to following omnipresent issues for the horticulture industry:

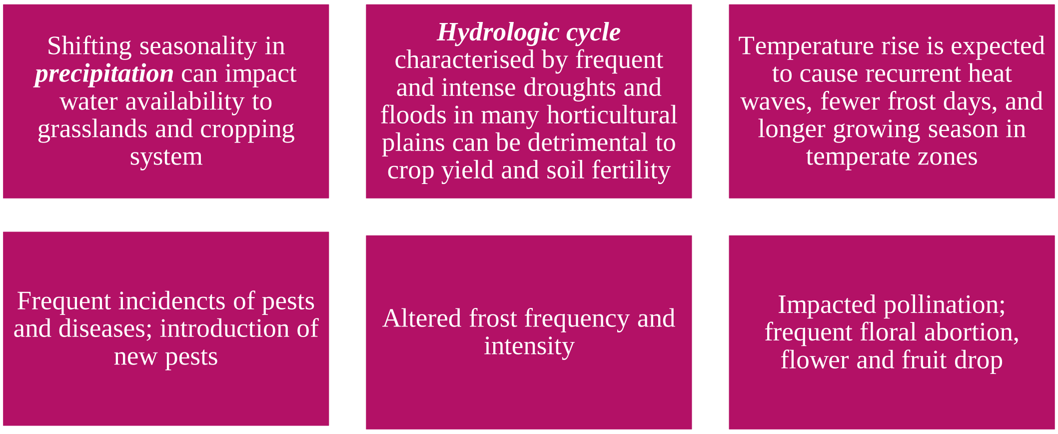


Figure 1: Horticulture and Climate Change Impact

Climatic variations manifest differently with respect to fruit crop varieties and phenological stages of *pre-flowering, flowering, and fruit setting and development*. Phenological stages have been identified as the preferred and appropriate indicator to quantify plants response to climate change variations (Chmielewski & Rötzer, 2001). Table 1 below discusses the impact of variations in temperature and precipitation condition with their impacts during the three phenological stages:

Table 1Climate Change Impact and Phenological Stages

Phenological Stage	**Climate Change Impact**
Pre-flowering	• Flower bud initiation is extremely sensitive to temperature variations from extreme high to low-growing season temperatures • High temperatures leads to under-development of plant reproductive organs
Flowering	• Soil moisture variations driven by changing temperatures also decide the flowering time and seed germination • Temperature rise leads to early bud sprouting (2-3 weeks in Apple and Almond) and increases susceptibility to frost damage (Choudhary et al., 2015) • Moderate winds during flowering stage enables better fruit setting; however harsh winds accompanied with heavy rains at low temperatures hinders appropriate flowering • Hailstorms anytime during the flowering stage are catastrophic for fruit crops
Fruit Setting	• Orchards deep seated in valley have better fruit setting as compared to plantations in windward sides • Spring frost can either destroy flower sexual organ or completely damage blossom with impacts on fruit-set

	• Frequent incidents of pests and diseases under high temperature conditions
Fruit Development	• Hailstorms anytime during fruit development stage are catastrophic for fruit crops • Excessive rains and fog near maturity leads to poor fruit quality with improper colour development and fungal spots • Extreme and sudden hailstorms leads to spotting and fruit drop, especially for temperate fruits. • High temperature decreases anthocyanin accumulation in fruit trees resulting fruit discolouration • High temperatures are known to alter fruit taste and flavour, sugar content, firmness, and antioxidant activity

THE HIMALAYAS AND CLIMATE CHANGE VULNERABILITY

The Himalayan ecosystem 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 (IHR) is home to over 72 million people living in over 10 states covering 95 districts expanded in an area of 5 lacs square km, representing around 16 per cent of country's geographical area. It offers an enabling environment with favourable micro-climatic conditions for cultivation of a wide range of horticulture crops such as apples, plums, peaches, bananas, mangoes, pineapples, citrus fruits, walnuts and more. Fruits and vegetables cover around 16 per cent of the total crop land in IHR, with the western Himalayas accounting for around 20 per cent of farmlands, and the central and eastern Himalayas with only 5 per cent (Partap & Partap, 2010). However, due to its high biological and socio-cultural diversity, the Himalayan ecosystem is susceptible to natural hazards that are prone to aggravated occurrence of floods, droughts, and landslides, caused by drastic changes in climatic conditions that stand to impact the life and livelihood of those dependent on the region for economic and social needs.

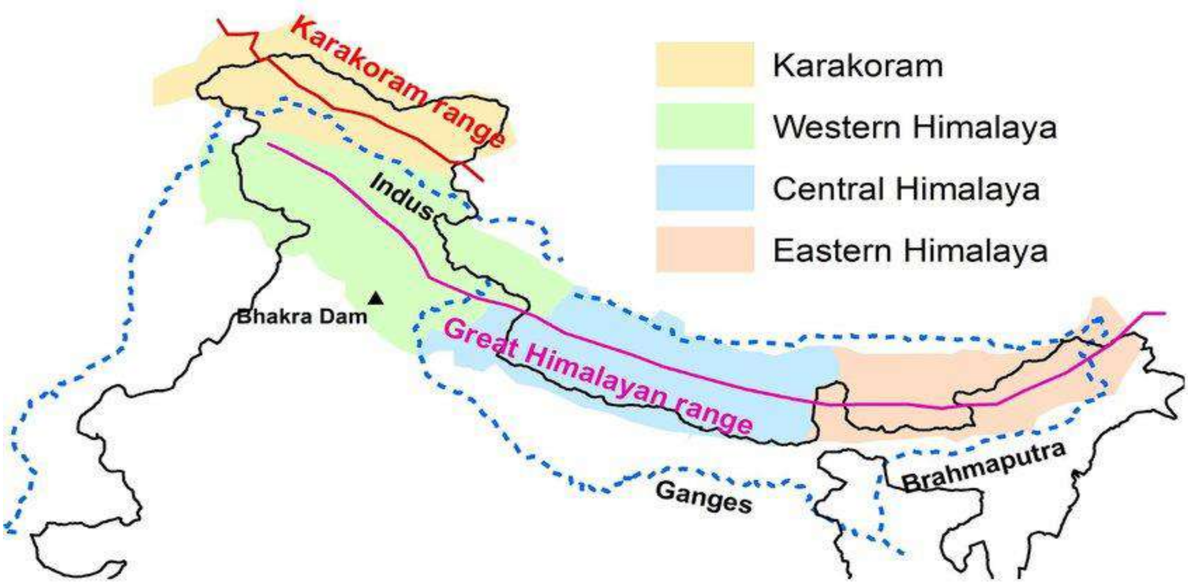


Figure 2: Geographical Representation of the Indian Himalayas
Source: Divecha Centre of Climate Change, Indian Institute of Science, Bengaluru (2018)

In the western Himalayas, in particular, striking vegetative changes are observed where in various plant species are migrating to higher altitudes owing to warming trends (Padma, 2014), while other remain in danger of extinction. Additionally, the Hindu-Kush-Himalayan region is witnessing early trends of greening while 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 0.7ºC 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/horticulture activities 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. Himachal Pradesh is known as the fruit bowl of India with Horticulture sector contributing around 38 per cent to state's GDP from primary sector (agriculture and allied services account accounted for 10 per cent of state GDP in 2015-16); while offering a range of farm and off-farm employment opportunities. (MoSPI, 2016).

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, Kangra*)*, and *the Greater Himalayas or the Alpines* (covering District Kinnaur, Lahaul & Spiti, Chamba).

Climate change does not have even and uniform impact on any region and with these topographical and varied climate classifications in Himachal Pradesh, the vulnerability and risk quotient becomes significant and tends to vary from one region to another. 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 average in the last century, and concluded that rate of increase in maximum temperature changes is directly linked to the changes in altitudes. Bhan and Manmohan (2011) predicted a shortening of seasons by 10-12 days 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 respectively. 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 and horticulture sector. 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 has been divided into four agro-ecological zones based on characteristics of 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 3.

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	14 ºC - 22ºC	9.1 ºC – 20.6ºC	9 ºC - 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, Kangra, Sirmaur, Kullu, Kinnaur, Hamirpur, Bilaspur	Kangra, Chamba, Kangra, Mandi, Kullu, Solan, Sirmaur, Kinnaur, Lahaul & Spiti	Kangra, Lahaul & Spiti, Kinnaur, and Parts of Chamba, Mandi, Kullu, Sirmaur, Kangra

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

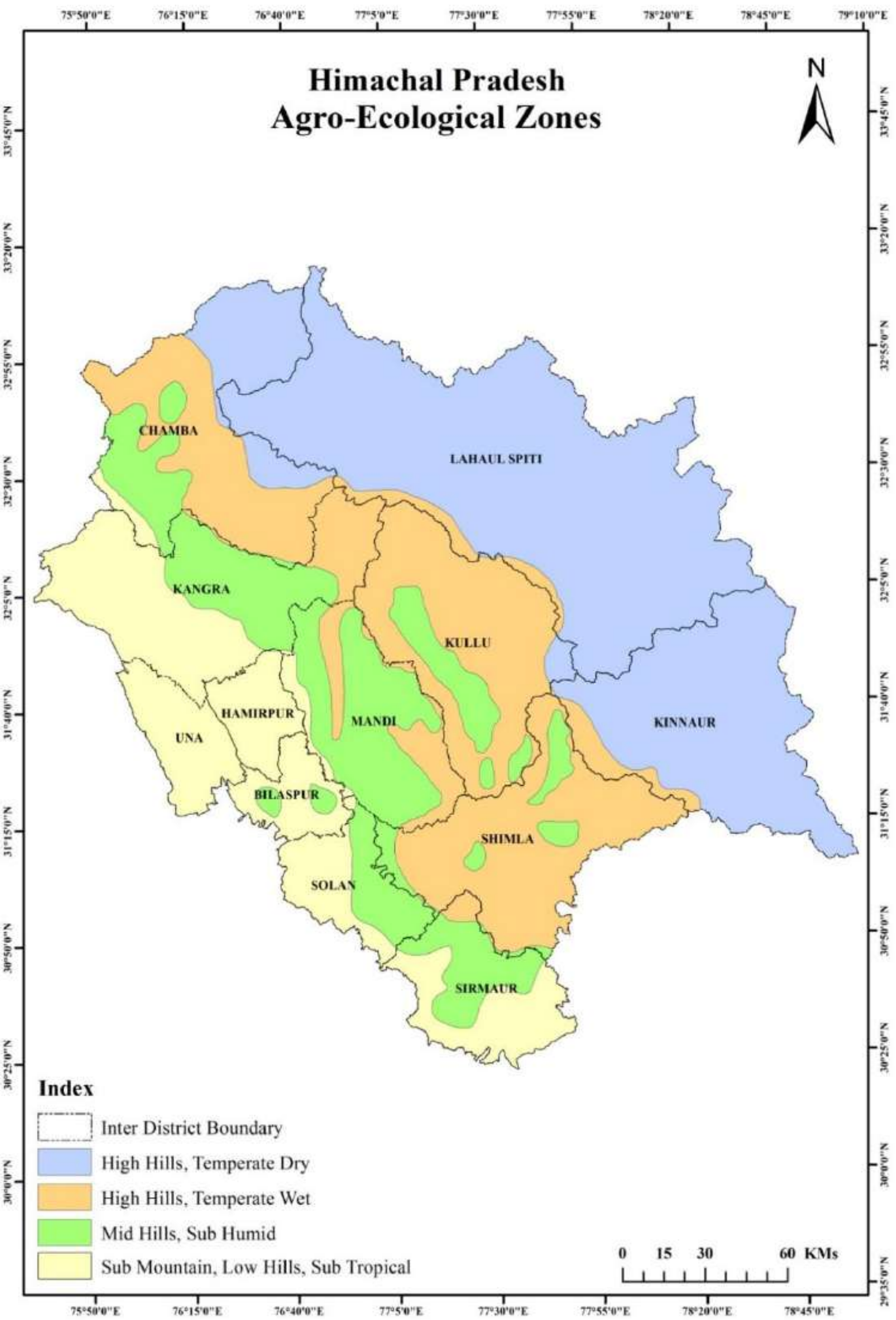


Table 3 Himachal Pradesh Agro-Ecological Zones

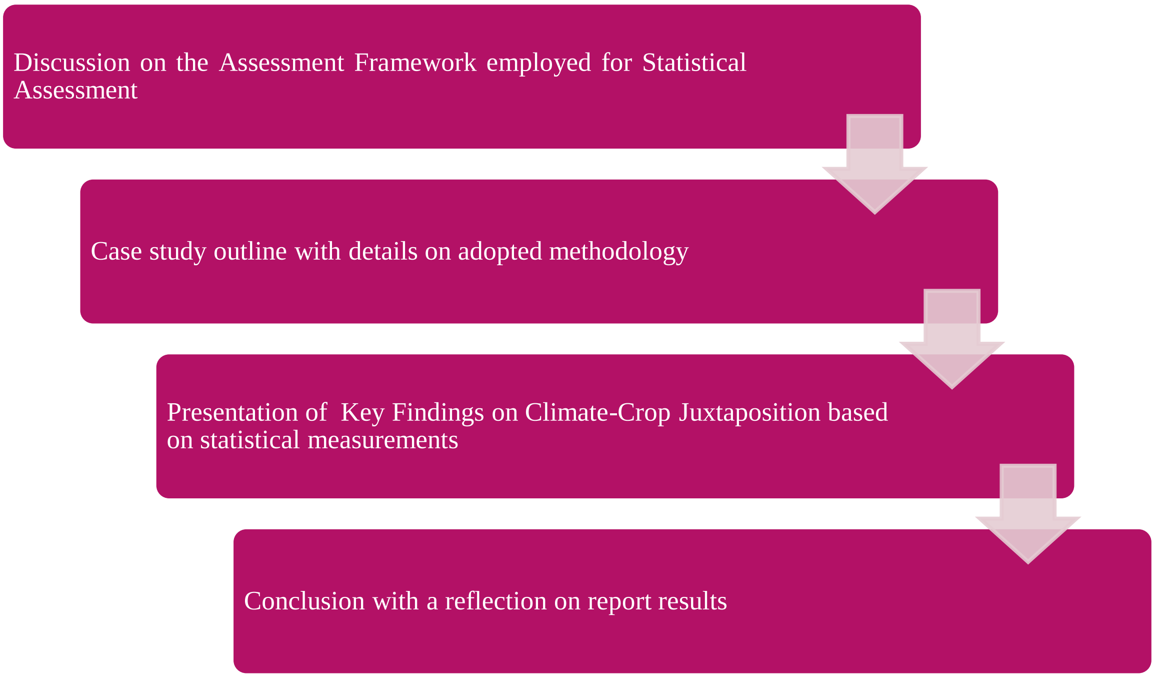
Source: Adapted by HPSCCC from Agro-Ecological Zonation of Himachal Pradesh – Agricultural System Information Development at micro-level, Centre of Geo-informatics, CSK Himachal Pradesh Agriculture University, Palampur (Bhagat et al., 2006)

As noticeable from above, a majority of horticulture exposure is spread across Zone III and IV in the State which has significant share of land under apple and other temperate fruits cultivation. Nevertheless, each zone and each district is characterised with different soil, climatic, and precipitations pattern. Human managed ecosystems such as food production and livelihood sustenance are found to be highly vulnerable to climate change in Asia. Jindal et al (2001) while assessing the five-year fruit production and meteorological data highlighted the instrumental role of abnormal climatic factors during the flowering and fruit development stages causing reduction in apple productivity. The said study also underscored the presence of other factors such as monoculture of Delicious varieties, compromised standards of orchard management, amongst others being detrimental to fruit crop productivity. Meanwhile, Crepinsek and Bogataj (2004) discussed the impact of rising temperatures (per degree) on faster occurrence of leaf and fruit ripening by 2 days in apple and plum crops. Interestingly, there have been a few perception based assessments that have concluded the perceived role of climate change in altering the blossoming, bearing, and productivity of apple crop. Vedwan and Rhoades (2001) reported a remarked shift of apple belt in Kullu valley along with a significant gap in flowering periods of male and female trees. Nevertheless, the growing share of literature is essentially focused on an assessment of historic and current weather parameter such as precipitations and temperature vis-à-vis horticulture productivity with limited and under-theorised discourse on farmers' perceptions on their exposure, sensitivity, and adaptive capacity to climate change in tandem with observed changes in climatic parameters.

To bridge this gap, a status study was conducted with a view to ascertain the impact of climate change on horticultural sector in District Kangra. Seasonal trends on climatic variables of minimum, maximum, and diurnal temperatures, and rainfall patterns were conjugated with a standardised anomaly index and a multivariate regression analysis was conducted to establish the climate and crop yield relationship during the phenological stages of *pre-flowering, flowering, and fruit setting and development*.

ORGANISATION OF STATUS REPORT

The status report designed to provide a snapshot view of statistical and perceived impact of climate change on horticulture in the state with an astute focus on District Kangra, 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 horticulture productivity, the following statistical measures were employed.

TREND ANALYSIS

Seasonal trends on climatic variables such as minimum, maximum, and diurnal temperatures, and rainfall (quantity and days) 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, and then the Sen's Slope is calculated as the median from all linear slopes that gives the magnitude of the observed seasonal trend. Another statistics linked to the Mann Kendall test is the *p-value.* Smaller the p-value (smaller than 0.05), greater is the weight of evidence against the null hypothesis of no trend.

For this study, the statistical Mann Kendall test is carried on software XLSTAT 2017. The null hypothesis is tested at 95% confidence level for minimum, maximum, and diurnal temperate, and rainfall (quantity and days) for the time period 1990-2016. Further, annual trends were conducted for productivity of apple, pear, plum, peach, apricot, cherry, pomegranate, walnut, and almond crops

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 horticulture (for three phonological stages) were computed for the study area. Similarly, the standardized precipitation indices were also calculated for the pre-flowering (November-February), flowering (March-April), and fruit-setting and development stages (May- August).

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 phenological stages of the fruit crops. Coefficients α, β, γ, and δ are the coefficients of minimum, maximum, diurnal temperature and rainfall, respectively. ΔT_{min}, ΔT_{max}, T_{dt}, ΔR, and Δ*Rd* are the observed changes in minimum, maximum, diurnal temperature, rainfall and rainy days respectively for the cropping seasons during the study period.

CHAPTER 3 - PILOT CASE AND METHODS

DISTRICT KANGRA – A BACKGROUND

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

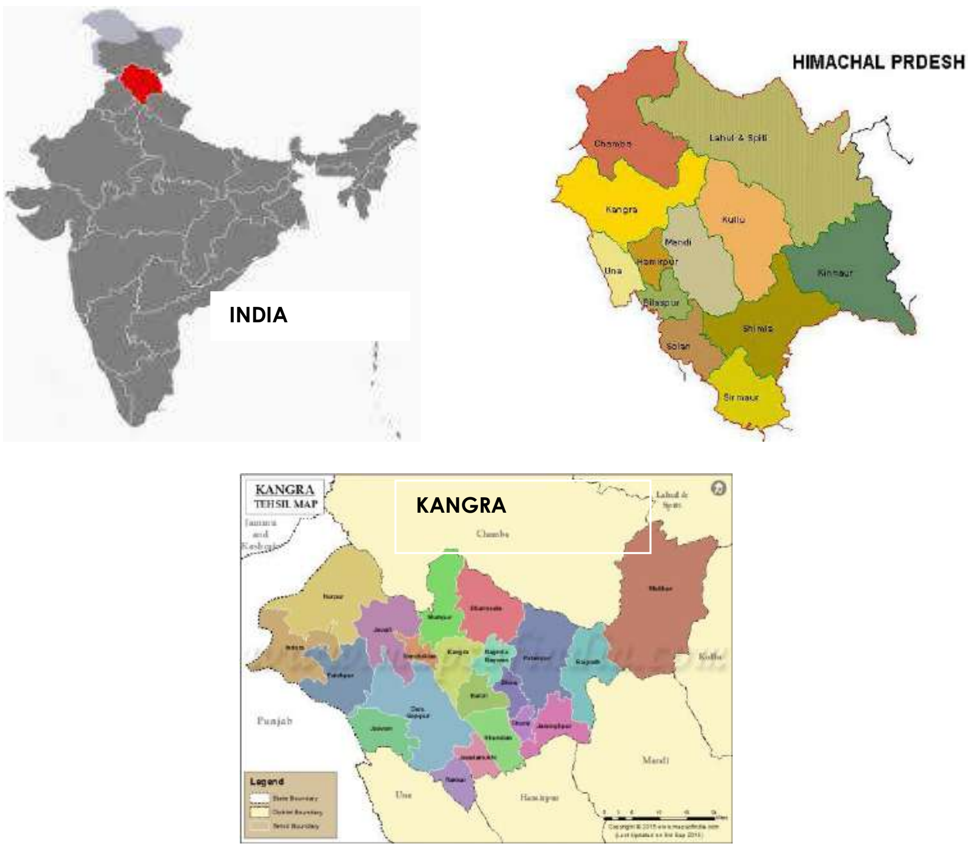


Figure 3: Map of District Kangra, Himachal Pradesh

Table 4 Himachal Pradesh: Horticulture Profile

Horticulture Profile – Himachal Pradesh			
Horticulture Land Use	Total Geographical Area ('000 ha): 229.202	% of Total Cultivable Area: 37.58 %	% Area under Temperate Fruit: 63.5 %
Agro-Ecological Zone – District Kullu	Western Himalayas, Zone II (sub-temperate and sub-humid hills), Zone III (wet-temperate high hills)		
Agro Climatic Zone (NARP)*	1. Low Hills/Valley Areas (35.50%) 2. Mid Hill Mild Temperate Areas (44.23%) 3. High Hill Temperate Areas (16.50%) 4. High Hill Wet Temperate Areas (4.41%)		
Economic Profile	Gross Value of fruit Produce: INR 3117.35 Cr.	Per Capita Income from Fruits: INR 4547	Employment: 900 lacs Man-days
Infrastructure	Progeny-cum-Demonstration orchards & Nurseries: 97 (5 in Kullu)	Private Registered Nurseries: 568 (130 in Kullu)	Packing and Grading Houses: 11
Major Fruit Crops	Fruit Crops: Apple, Plum, Peach, Apricot, Pear, Cherry, Pomegranate, Strawberry, Kiwi, Olive, Orange, Malta, Lime, Galgal, Other citrus fruits, Mango, Litchi, Guava, Papaya, Jackfruit, Loquat. Nuts: Almond, Walnut, Picanut, Hazelnut		
Apple Cultivation	Altitude: 1,500-2,700m with 1,000-1,500 hours of cold weather with 7 °C or below winter temperature. Growing Season: Ideal Temperature of 21to 24 °C , 100-125 cm annual rainfall (evenly distributed) Soil: Loamy, rich in organic matter, pH 5.5-6.5 Varieties in Himachal Pradesh: Clonal Rootstock: M9, M26, M7, MM106, MM11 Scab Resistant: Prima, Priscilla, Sir Prize, Jonafree, Florina, Macfree, Nova Easy Grow, Nova Mac, Liberty, Freedom, Firdous Hybrids: Lal Ambri, Sunehari, Chaubatti Princess, Chaubatti Anupam, Ambred, Ambrich, Ambroyal Low Chilling: Michal, Schlomit, Anna, Tamma, Vered, Neomi, Tropical Beauty, Parlin's Beauty Pollinizing: Red Gold, Golden Delicious, Mc Intosh, Lord Lambourne, Winter Banana, Granny Smith, Golden Spur, Tydeman's Early		

Source: ENVIS Centre, Himachal Pradesh (2016), *HPAGRISNET* (2017)

KANGRA AND THE CLIMATE

Climate: District Kangra 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. From Mid February to March the season is called the spring season. Some areas of the district are frequented with rain showers. 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.

S. No.	SEASON	PERIOD	TYPE	OTHER FEATURES	MEAN TEMPERATURE
1.	Cold Weather or Winter Season	Mid November to Mid March	Cold and Dry	From Mid February to March the season is called the spring season	11 °C
2.	Hot Weather or	April to June	Hot and Dry	From the mid of April to the	29 °C

	Summer Season			end of June.	
3.	SW Monsoon OR Rainy Season	July Mid September	Humid and Hot	From July first week to mid September.	31 °C
4.	The seasons of retreading monsoon or Cool season	Mid September to Mid November	Moderately Hot and Humid	From Mid September to October the season is called Autumn season, which is very pleasant	19 °C

July commences the rainfalls that extend up to mid-September. Usually, the rainy season gets extends making way for an early onset of winter seasons. The last season is seasons of retreading monsoon or Cool season it occurs from mid September to mid November.

AGRICULTURE

Agriculture remains the main occupation for the population of the district Kangra. Conducive agro-climatic conditions and favourable soil profile, enables cultivation of a varied types cereals, off season vegetables, various fruits and other cash crops in the district. Lower elevations are suitable for the production of cereal crops, citrus fruits, owing to hotter climatic conditions. Shivalik Hill Zone (Sub Tropical, Sub Mountain and Low Hills): Comprising of upland of part of Chamba, Kangra, Hamirpur, Solan, Sirmour and Bilaspur district. Climate Sub Tropical consists of foothills and valley area having elevation from 240 to 1000 meters above sea level. It occupies about 35% of the geographical area and about 33% of the cultivated area of the State. The major crops grown in this Zone are Wheat, Maize, Paddy, Black Gram, Sugarcane, Mustard, Potato, Vegetables, Pulses and Barley. The major crops are Wheat, Maize, Paddy, Black Gram, Barley and Beans, Pulses and Forages etc. This zone has very good potential for the cultivation of cash crops like off season Vegetables, Ginger and production of quality seeds of temperate vegetables like cauliflower and root crops.

LAND USE PATTERN

Looking at the land utilization pattern of the district (Table 2.5) it has been observed that land utilization in the district has remained by and large the same with very little changes over the years. Table 2.5 reveals that maximum geographical area (55 per cent) reported was under forest & pastures. Therefore, the scope for extension of cultivation is limited. The striking feature is the increase in area under non-agricultural uses (13 per cent). The table further reveals that about 20 per cent of the geographical area is cultivated in the district (2003-04). There has been an increase in the fallow land area and area put to non-agricultural uses. There is a change or diversion of agricultural land area to non-agricultural uses because of rising land prices and the contribution of infrastructural facilities like roads, etc.

Particulars	Forest land	Barren land	Non-agri. uses	Culture able waste	Pasture	Misc trees/ groves	Current fallow	Other fallow	Net sown area
Kangra									
1990-91	40.08	6.37	13.59	8.81	8.13	0.80	1.38	0.07	20.78
1995-96	39.43	0.00	14.33	7.02	17.06	0.37	1.62	0.75	19.41
2000-01	40.28	2.52	13.36	4.72	15.77	1.26	1.63	0.05	20.42
2002-03	40.16	3.12	13.42	4.74	15.14	1.34	1.83	0.07	20.18
H P									
1990-91	30.85	5.46	5.74	3.72	33.72	1.43	1.33	0.46	17.31
1995-96	31.10	4.07	5.66	3.64	35.44	1.35	1.55	0.76	16.43
2000-01	24.05	17.75	6.90	2.74	33.63	1.25	1.19	0.30	12.20
2002-03	24.20	17.75	7.03	2.69	33.41	1.28	1.33	0.33	11.99

Source: Statistical outline, Govt. of H.P., Directorate of Economics and Statistics, Shimla

HORTICULTURE PROFILE

The state of Himachal Pradesh is known as the apple bowl of the country. The state has climate for growing a wide range of fruit crops. The fruits have higher productivity and provide higher income per unit area. Therefore, these fruit crops are playing a vital role in improving the economy of the hills. The district is known for growing of crops like citrus, mango, litchi and other stone fruits besides having age old seedling mangoes. The area under these crops is steadily increasing and the district has a potential to grow these crops. Table 2.19 depicts the relative share of the district in area and production during 2001. It can be seen from the table that Kangra district has 20.38 per cent share in the total fruit area of Himachal Pradesh. The contribution of this district in the total fruit production is hardly 3.79 per cent. Observing the trends in fruit production of Kangra district, it can be seen from the table that the area under fruit has grown at the rate of 5.41 per cent per annum as compared to 4.15 per cent per annum for Himachal Pradesh. The production trend, however, has not shown a satisfactory picture. The growth trend observed in the district is 1.09 per cent per annum Table (2.20). Field survey of the district reveals that there are many wild fruit trees which can be improved to superior varieties and can be made more profitable for which the efforts of department of horticulture and universities need to be strengthened either by top working operations or strengthening the research and development efforts of state agricultural universities. Further, special efforts need to be undertaken for promoting development of horticultural industry of the district by promoting figs, mushroom and beekeeping. Once the fruit production gears up, the efforts for better marketing and processing would be required for its further expansion.

METHODS

Within the context of collocation of climate variability and agriculture productivity in District Kangra, Himachal Pradesh, a study was designed *to determine the statistical impact of variations in climatic parameters (temperature and rainfall) vis-à-vis horticulture crop productivity*.

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 horticulture sector pertaining to phonological stages of *pre-flowering, flowering* and *fruit-setting and development*.

CLIMATE DATASETS

The mean minimum, maximum, diurnal temperatures, and rainfall data for Kangra District was collected from India Meteorological Department (IMD), Kangra covering a time period of 1990-2016. Datasets were further categorised for different phenological stages i.e. *pre flowering, flowering, and fruit setting and development stages* from November to February, March to April and May to August respectively.

HORTICULTURAL DATASETS

Apple, Pear, Peach, Mango, Orange, Lemon, litchi and Guava horticulture crops acreage and production data was collected from the Directorate of Horticulture, Himachal Pradesh, covering the time period 1980 to 2016.

METHODOLOGY CONSTRAINTS

Nevertheless, the study should be viewed with its intrinsic shortcomings. The data on acreage and production of horticulture crops had several gaps and outlier values that were correct using estimates of historic data trend and mean values. Similar data gaps were observed in temperature and rainfall figures that were addressed using the above mentioned approximations.

CHAPTER 4 – CLIMATE TREND AND HORTICULTURE: DISTRICT KANGRA

CURRENT CLIMATE TRENDS –DISTRICT KANGRA

To capture the nerve of climatic changes in the district**,** temperature (min, max, diurnal), and rainfall (quantity and days) are considered as explanatory indicators. Based on the statistical analysis, Mann Kendall trend test, a highly significant change in climatic variables was observed in ***flowering, fruit setting season*** and ***pre-flowering season*** .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 1970-2018.

Table 5 Mann Kendall Test Results – Climatic Trends for pre-flowering, flowering and fruit setting seasons (1970-2018)

	Mean	Sen's slope	p-value
Pre Flowering (November- February)			
Av. Max Temperature	17.753	**0.045**	**0.002**
Av. Min. Temperature	7.69	0.01	0.29
Diurnal Temperature	10.05	0.02	0.12
Total Rainfall	73.60	-0.28	0.25
Flowering (March – April)			
Av. Max. Temperature	23.97	**0.04**	**0.01**
Av. Min. Temperature	13.09	**-0.02**	**0.89**
Diurnal Temperature	10.88	**0.07**	**0.001**
Total Rainfall	93.44	0.35	0.5
Fruit- Setting (May- August)			
Av. Max. Temperature	28.92	**0.013**	**0.06**
Av. Min. Temperature	19.98	-0.02	0.12
Diurnal Temperature	8.94	**0.04**	**0.02**
Total Rainfall	452.38	5.319	**0.00**

As per the analysis the ***average maximum temperature*** registered an inclining trend at a rate of 0.002°C per year between 1970-2018 (as exhibited by the Sen's slope) during the ***pre- flowering season*** i.e. between November – February. The remaining climatic variables did not exhibit any significant variation during the *pre-flowering* season. During the ***flowering season*** i.e. March to April the average maximum temperature increased by 0.01°C per year and diurnal temperature showed increase in temperature by 0.001°C per year. Also, the average maximum temperature ***and diurnal temperature*** during ***fruit setting stage*** i.e. between May – August also registered an inclining trend progressing at a rate of 0.06°C and 0.02°C per year between 1970-2018. Rainfall during fruit setting stage show increasing trend.

Figure 5 illustrates the trend variation in climatic parameter during the three phenological stages

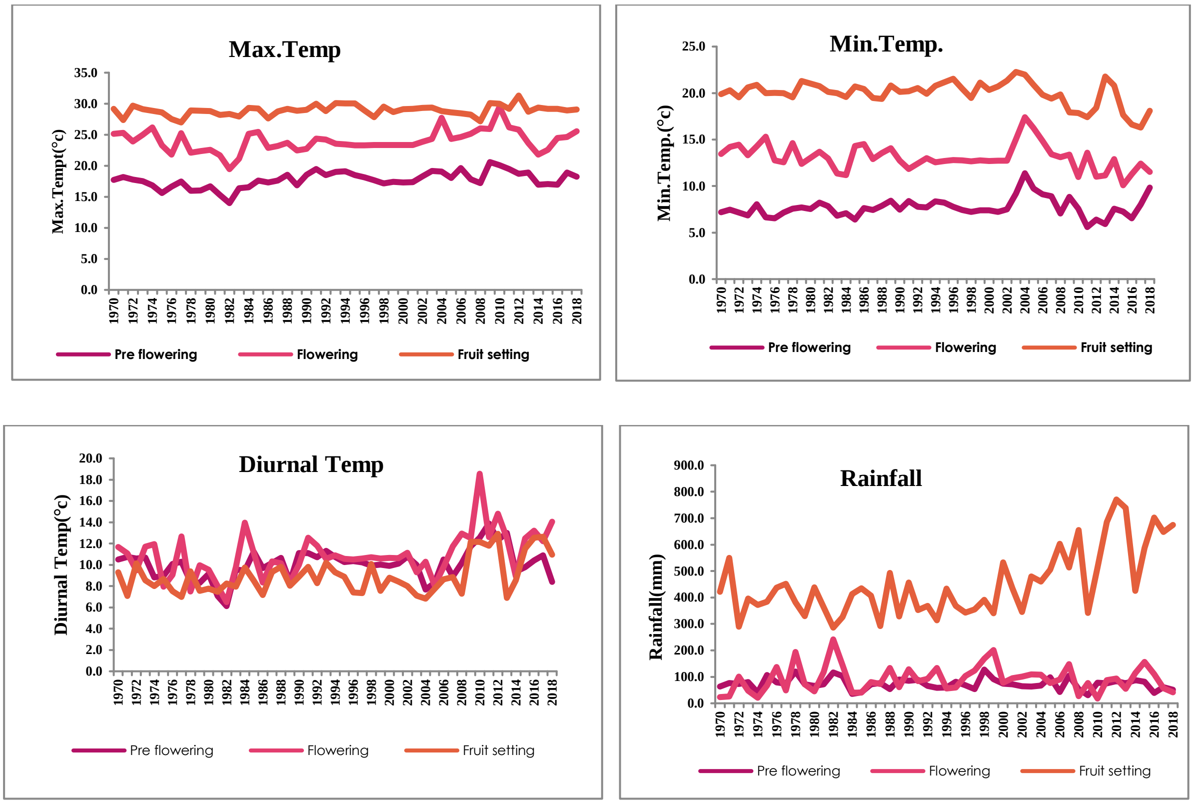


Figure 4. Variations in Climatic Parameters- Minimum T, Maximum T, Diurnal T and Rainfall during *pre-flowering, flowering, and fruit setting stages* (1970-2018), District Kangra, HP

A cooling trend in mean maximum temperature during ***pre-flowering, flowering and fruit setting*** was observed from 1972 to 1987 (figure 6) followed by continuous warming trend with temperatures rising above the long term averages from 1988 till 2018 except some year 1998, 1999, 2000, 2008, 2014, 2015 and 2016. Trend analysis of anomalies from 1990 to 2016 depicted a significant deviation in maximum and diurnal temperature from their respective long term average values. Mean minimum temperature during flowering and fruiting stage showed decrease trends from 1970-2018(figure 7). Diurnal temperature during pre-flowering, flowering and fruit setting showed increase trends (figure 8). Trend analysis of anomalies from 1990 to 2018 depicted a significant deviation in maximum, minimum and diurnal temperature from their respective long term average values (Table 4). For instance, during the ***flowering and pre-flowering season*** the mean maximum temperature was higher than the long term averages, post 2000. For ***fruit setting and development stages***, in the initial years warming trend but after 2006 there was continuous cooling years were recorded (figure 7). Rainfall show continuous increasing trend from the year 2001 to 2018 during fruit setting stage.

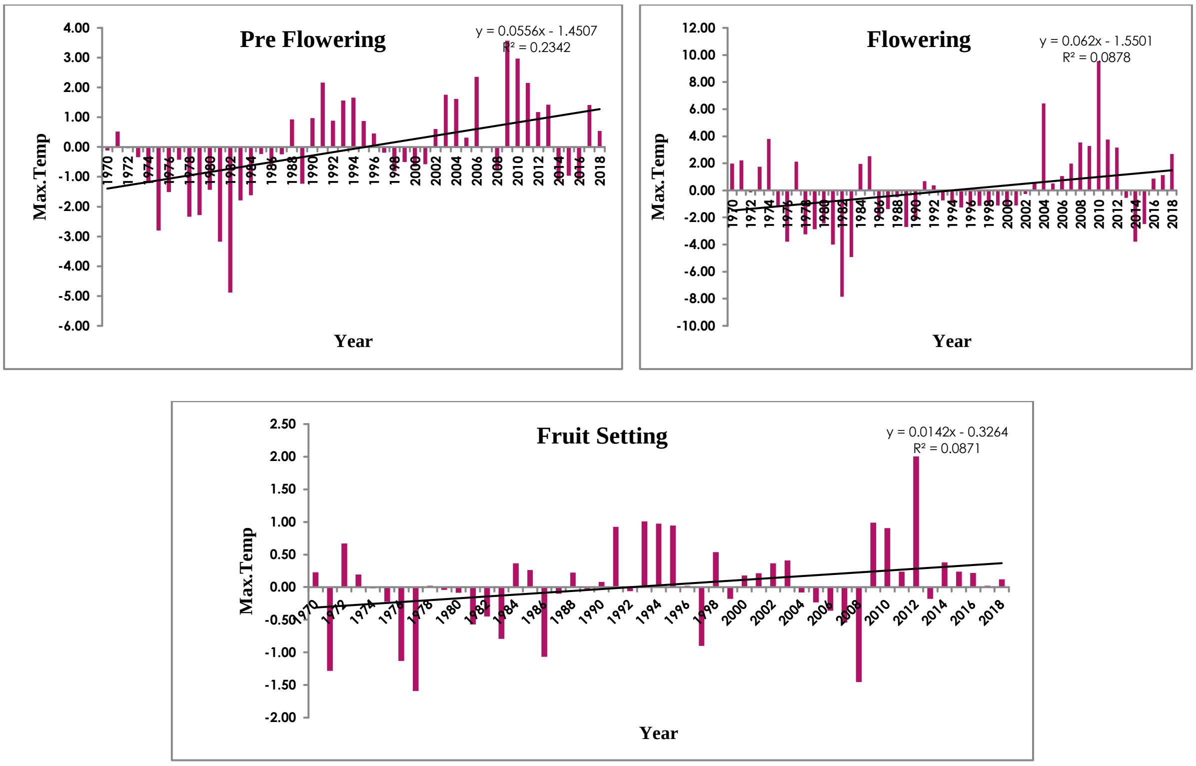
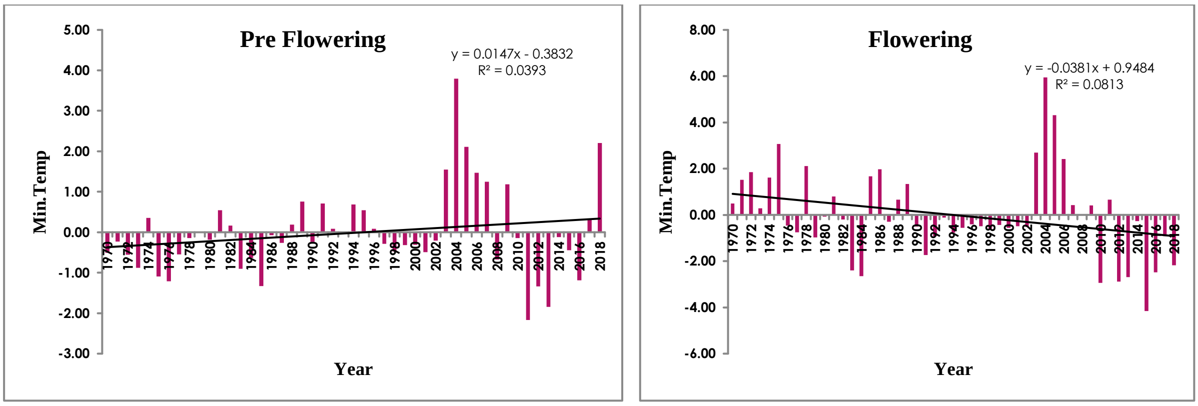


Figure 5 SAI for Mean Maximum Temperature during pre-*flowering, flowering, and fruit setting stages* (1970-2018), District Kangra, HP



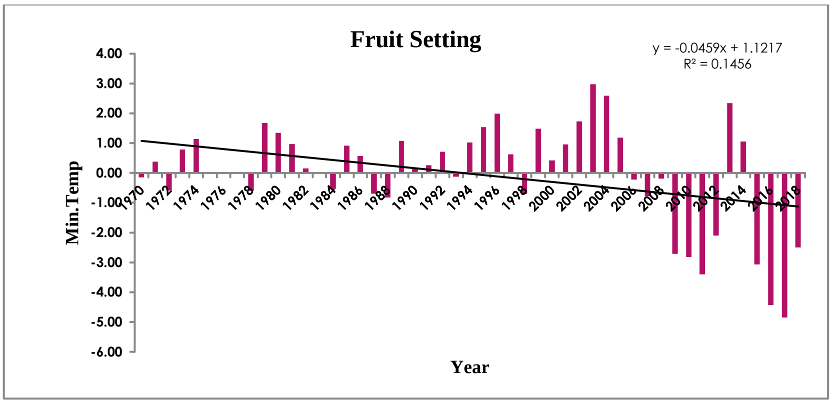
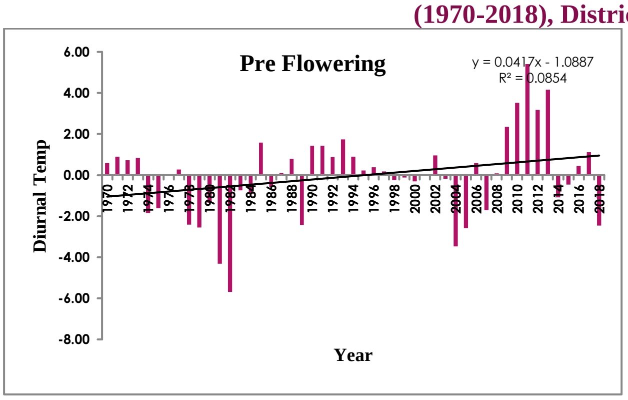
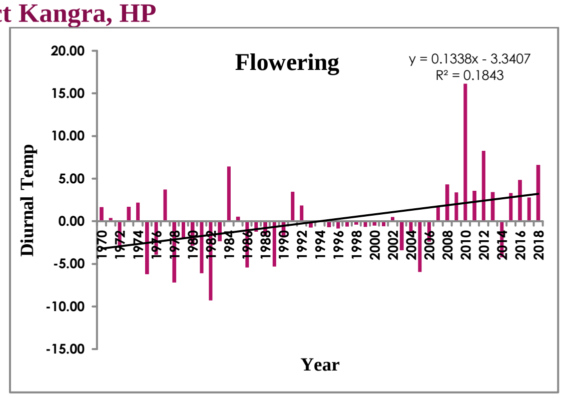


Figure 6 SAI for Mean Minimum Temperature during pre-*flowering, flowering, and fruit setting stages* (1970-2018), District Kangra, HP





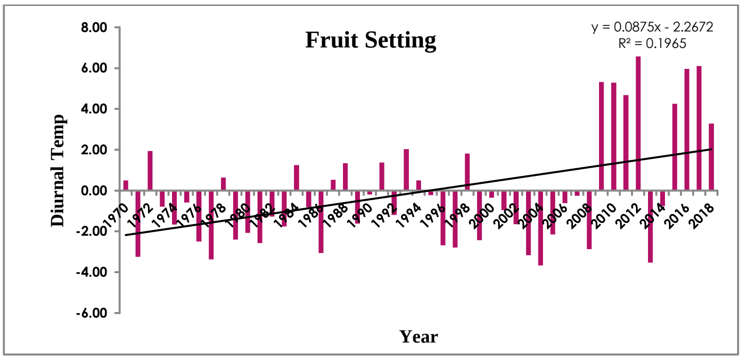
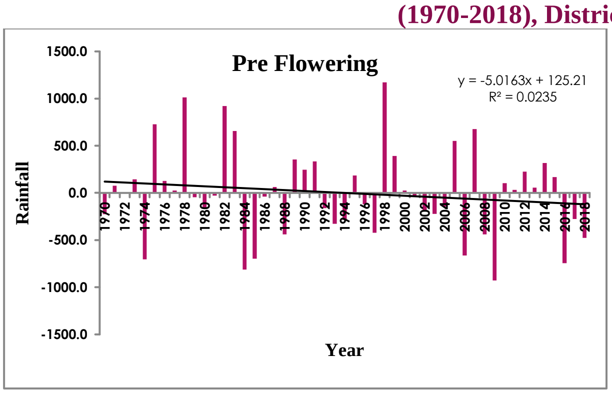
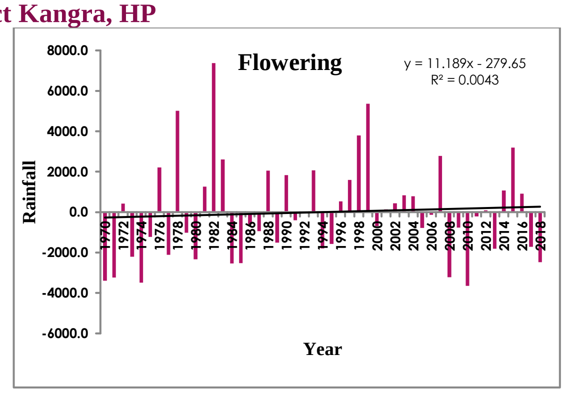


Figure 7 SAI for Mean Diurnal Temperature during *pre-flowering, flowering, and fruit setting stages* (1970-2018), District Kangra, HP





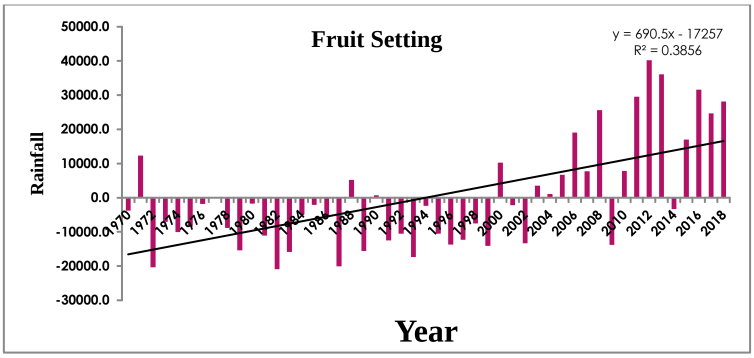


Figure 8 SAI for Mean Annual Rainfall during *pre-flowering, flowering, and fruit setting stages* (1970-2018), District Kangra, HP

The discussed variations in temperature and rainfall patterns are not confined to District Kangra but are corroborated by observations from other studies in the Himalayan region. The variation in mean maximum, minimum temperature and annual rainfall is not same for the district but same studies were recorded by different researchers. The results are correlated with different 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. Shekhar *et al.* (2010), in their assessment of climatic variations in the mountain ranges of the western Himalaya *viz.*, Pir Panjal, Shamshawari, Greater Himalaya, and Karakoram, recorded increase in seasonal mean, maximum, and minimum temperatures by 2.0 °C, 2.8 °C, and 1 °C, respectively. 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). Erratic precipitation patterns have been reported during different phenological stages by other studies as well. In district Kullu, Vishvakarma et al. (2003) reported 7 cm decrease in rainfall, 12 cm decrease in snowfall, and an increase of 0.25-1°C increase in mean maximum and minimum temperatures.

FRUIT CROP PRODUCTIVITY – DISTRICT KANGRA

ACREAGE, PRODUCTION, PRODUCTIVITY ASSESSMENT OF MAJOR HORTICULTURE CROPS

In District Kangra, the acreage under orchards has increased sharply from 154 ha in 1965 to 45,605 ha in 2010, registering a growth of 29,513 per cent. To get a better overview in this growth trajectory, temporal trend of changes in acreage, production, and productivity for, pear, orange, lemon, mango, litchi, guava, papaya, Galgal, Loquat and Apple in Kangra district were studied.

Acreage under **Pear** (*Pyrus sp.*) cultivation decreased from 1254 ha in 1990 to 377 ha 377-1254/1254*100 in 2015 (a decrease of 69.1 per cent) and the production surged from 517 MT to 1355 MT (1990-2015) (an increase of 61.8 per cent), as illustrated in Figure 10. The productivity of pear increased from (1980-2015). Nonetheless, pear productivity was recorded minimum (0.19 t ha-1) in 2001 and maximum (5.06t ha-1) in 2004.

Acreage under **Orange** (*Citrus sinensis*) cultivation decreased from 9360 ha in 1990 to 5736 ha in 2015 (an decrease of 63.1 per cent) and the production surged from 6541 MT to 9375 MT (1990-2015), as illustrated in Figure 11. The productivity of orange increased from (1980-2015). Productivity of orange with minimum productivity of 0.20 t ha-1 in 1994 and maximum of 3015 t ha-1 in 2006.

Acreage under **Lemon** (*Citrus limon*) cultivation decreased from 4287 ha in 1990 to 3173 ha in 2015 and the production showed increase from 708 MT to 4018 MT (1990-2015), as illustrated in Figure 12. The productivity of lemon with minimum productivity of 0.11 t ha-1 in 1999 and maximum of 1.65 t ha-1 in 2006.

Acreage under **Mango (***Mangifera indica)* cultivation increased sharply from 11,032 ha in 1990 to 21,286 ha in 2015 (48.1 per cent) and the production increased from 4,886 MT to 24900 MT (1990-2015), as illustrated in Figure 13. The productivity of mango increased from (1980-2015). Productivity of mango with minimum productivity of 0.11 t ha-1 in 1992 and maximum of 2.45 t ha-1 in 2006.

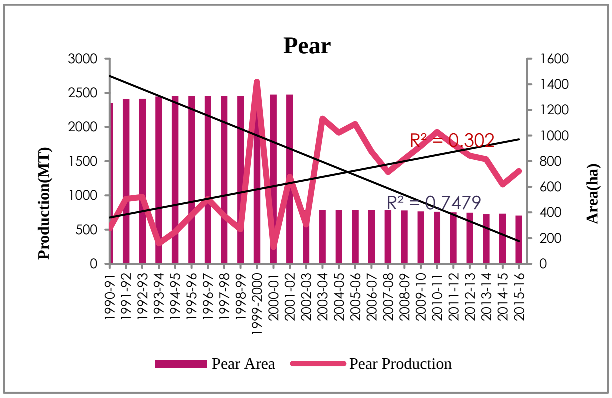
Acreage under **Litchi (***Litchi chinensis***)** cultivation increased sharply from 756 ha in 1990 to 3142 ha in 2015 and the production increased from 111 MT to 4132 MT (1990-2015), as illustrated in Figure 14. The productivity of Lichi increased from (1980-2015). The productivity of litchi is was recorded maximum in 1.31 t ha-1 in 2006.

Acreage under **Guava** *Psidium guajaba* cultivation increased from 333 ha in 1990 to 615 ha in 2015 and the production increased from 354 MT to 615 MT (1990-2015), as illustrated in Figure 15. The productivity of guava increased from (1980-2015). The productivity of guava with minimum productivity of 0.39 t ha-1 was recorded in 2003 and maximum of 3.46 t ha-1 in 2005.

Acreage under **Papaya** (*Carica papaya)* cultivation is comparatively less other then fruits crops it showed increase from 32 ha in 1990 to 103 ha in 2015 and the production increased from 434 MT to 556 MT (1990-2015), as illustrated in Figure 16. The productivity of papaya with minimum productivity of 0.31 t ha-1 in 2003 and maximum of 23.14 t ha-1 in 1997.

Acreage under **Louqat** (*Eriobotrya japonica)* cultivation decreased from 73 ha in 1990 to 45 ha in 2015 and the production sharply decreased from 468 MT to 19 MT (1990-2015), as illustrated in Figure 17. Productivity of **Louqat** with minimum productivity of 0.42 t ha-1 in 2015 and maximum of 7.70 t ha-1 in 1993.

Acreage under **Galgal** (C*itrus psedolimon)* cultivation decreased from 711 ha in 1990 to 550ha in 2015 and the production increased from 1175 MT to 1789 MT (1990-2015), as illustrated in Figure 18. The Productivity of **Galgal** with minimum productivity of 0.76 t ha-1 in 1994 and maximum of 6.40 t ha-1 in 2004.



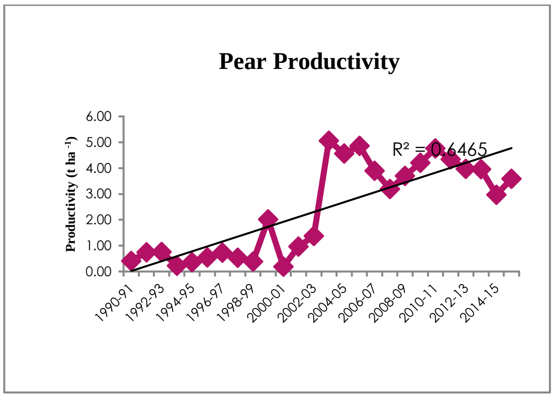


Figure 9. Variations in Annual Acreage, Production, and Productivity – Pear (1990-2016), District Kangra, HP

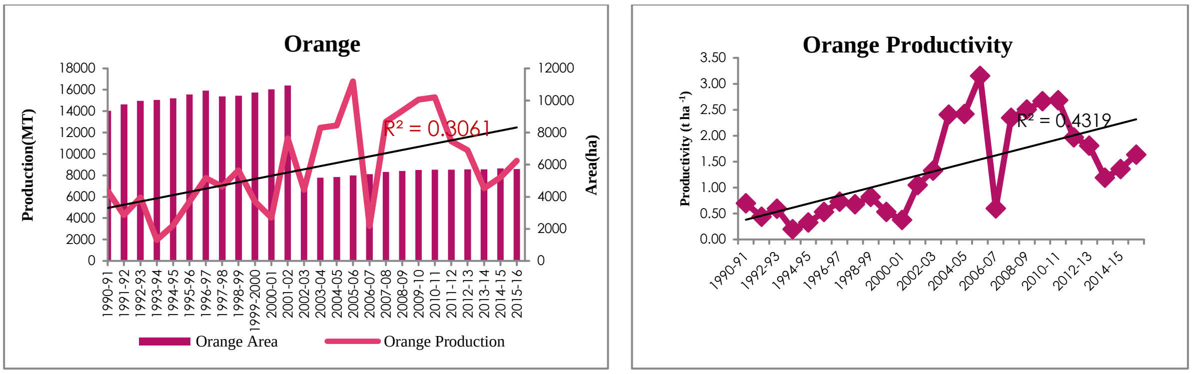


Figure 10Variations in Annual Acreage, Production, and Productivity – Orange (1990-2016), District Kangra, HP

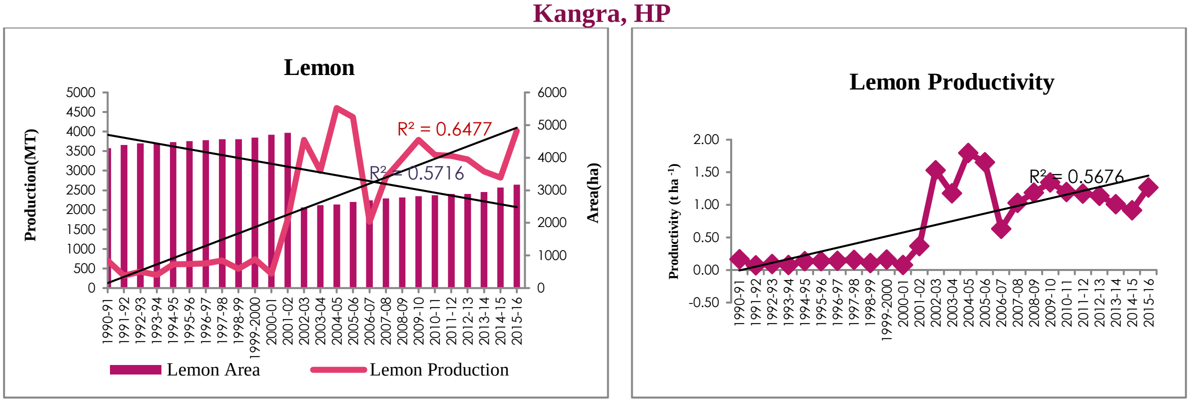


Figure 11 Variations in Annual Acreage, Production, and Productivity – Lemon (1990-2016), District Kangra, HP

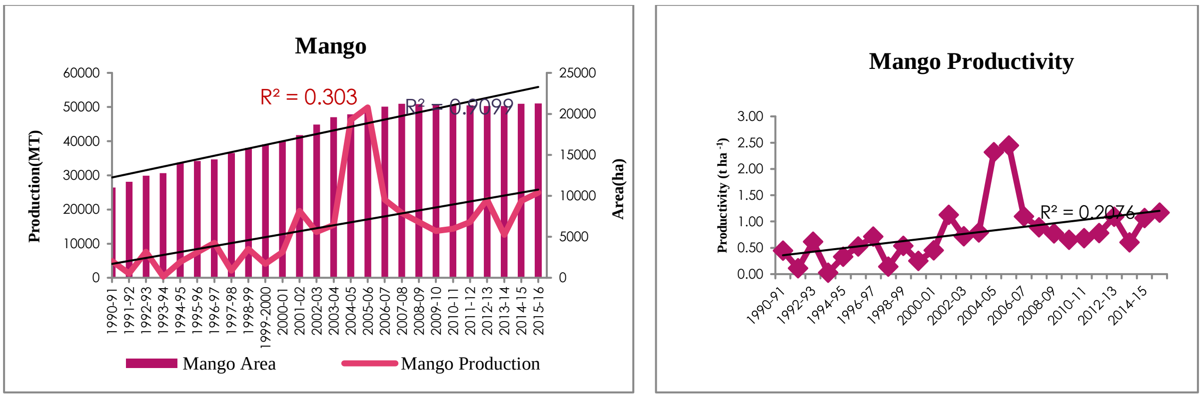


Figure 12. Variations in Annual Acreage, Production, and Productivity – Mango (1990-2016), District Kangra, HP

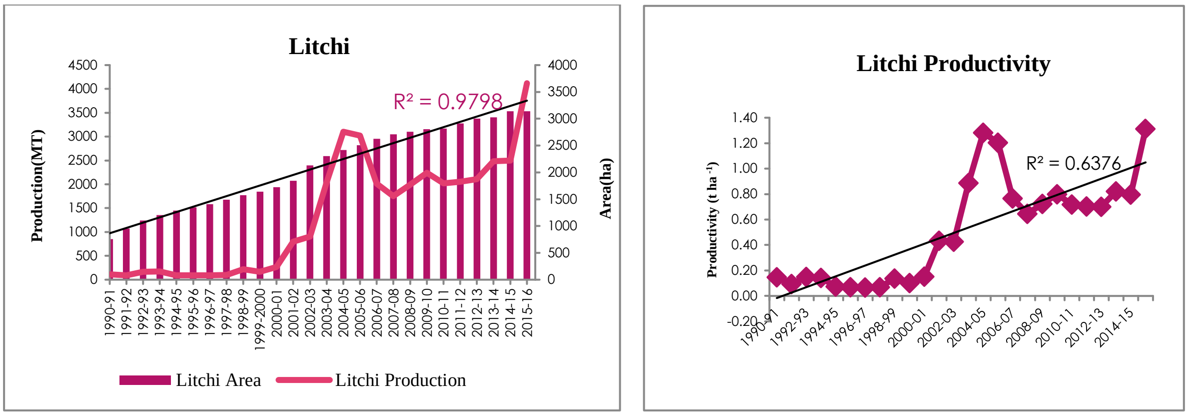


Figure 13 Variations in Annual Acreage, Production, and Productivity – Litchi (1990-2016), District Kangra, HP

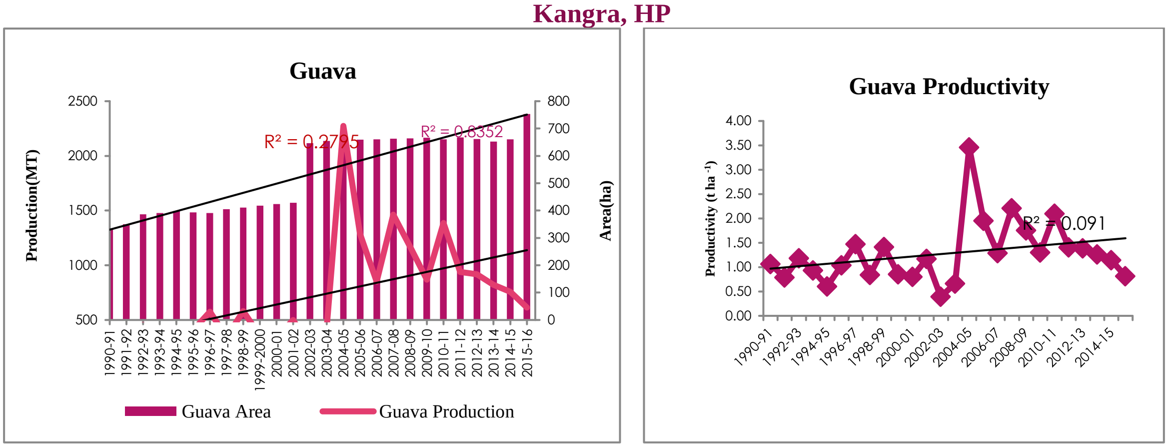


Figure 14 Variations in Annual Acreage, Production, and Productivity – Guava (1990-2016), District Kangra, HP

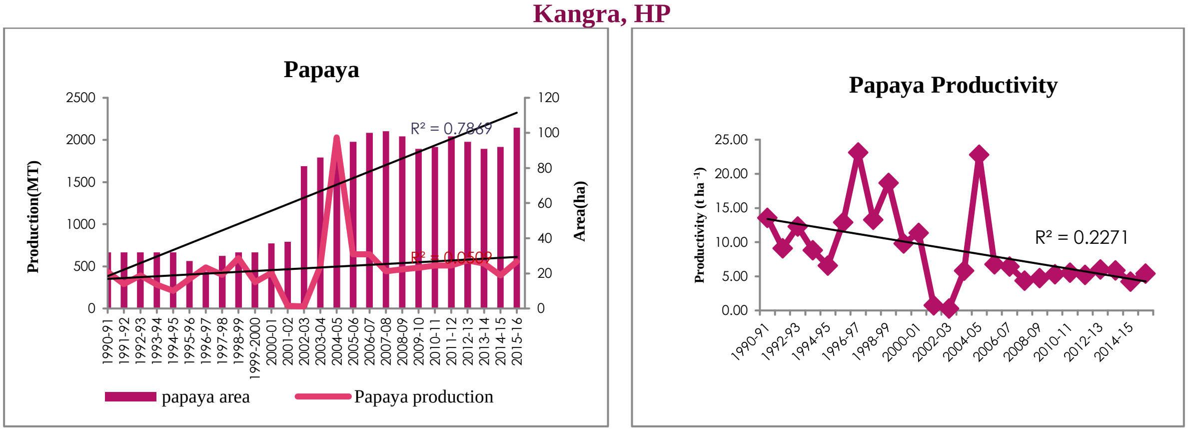


Figure 15 Variations in Annual Acreage, Production, and Productivity – Papaya (1980-2016), District Kangra, HP

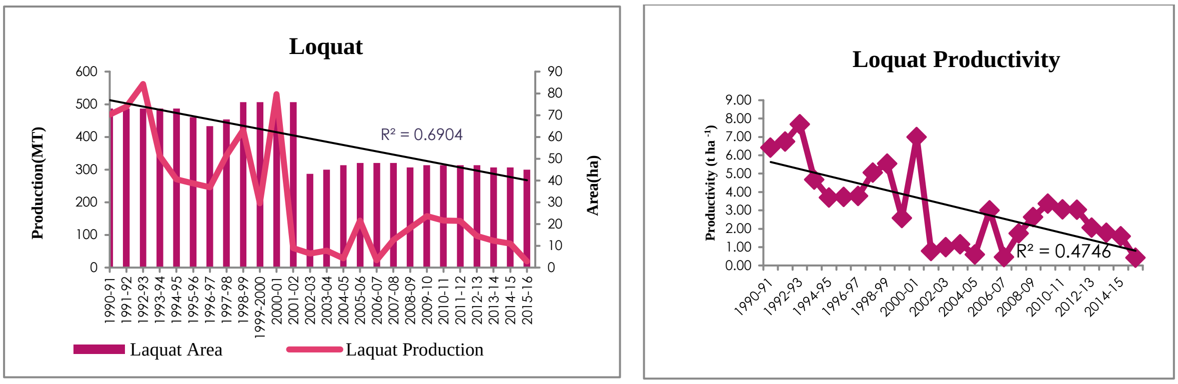


Figure 16 Variations in Annual Acreage, Production, and Productivity – Loquat (1990-2016), District Kangra, HP

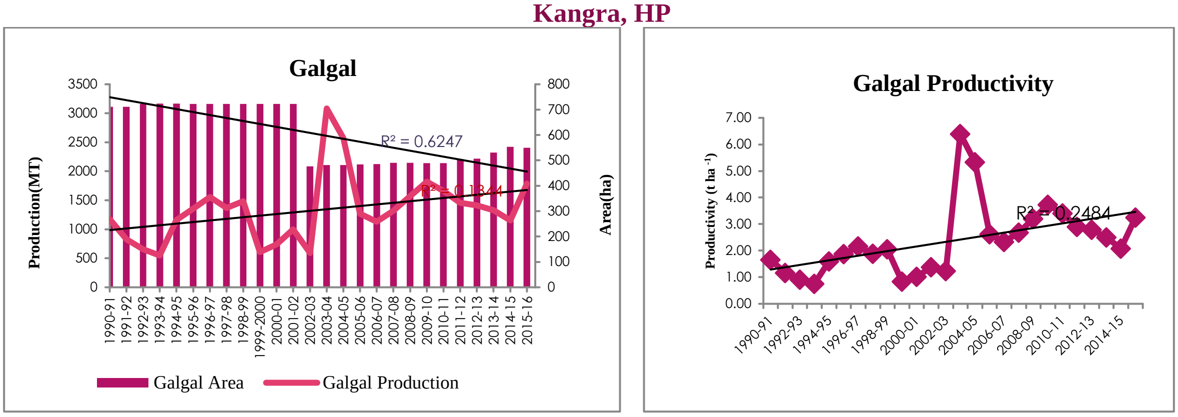


Figure 17 Variations in Annual Acreage, Production, and Productivity – Galagal (C*itrus psedolimon)* (1990-2016), District Kangra, HP

For other temperate fruits, the composite acreage decreased from 2794 ha in 1980 to 1168 ha in 2016), the total production surged from 480 in 1980 to 2881 in 2016), and productivity increased from 17.18 to 246 t ha^{-1} in past 35 years (Figure 11). Composite area under dry fruits i.e. Almond and Walnut, slightly increased from 1126 ha to 1168 ha till 2016., productivity showed also an increasing trend , moving from 18 t ha^{-1} in 1980 to 24 t ha^{-1} in 2016 (Figure 12). For citrus fruit area, production and productivity increased from 1980 to 2016(Figure 13). Subtropical fruit in Kangra showed maximum increase in area from 5023 ha to27141ha and productivity increased from 44 t ha^{-1} to 119 t ha^{-1} (Figure 14).

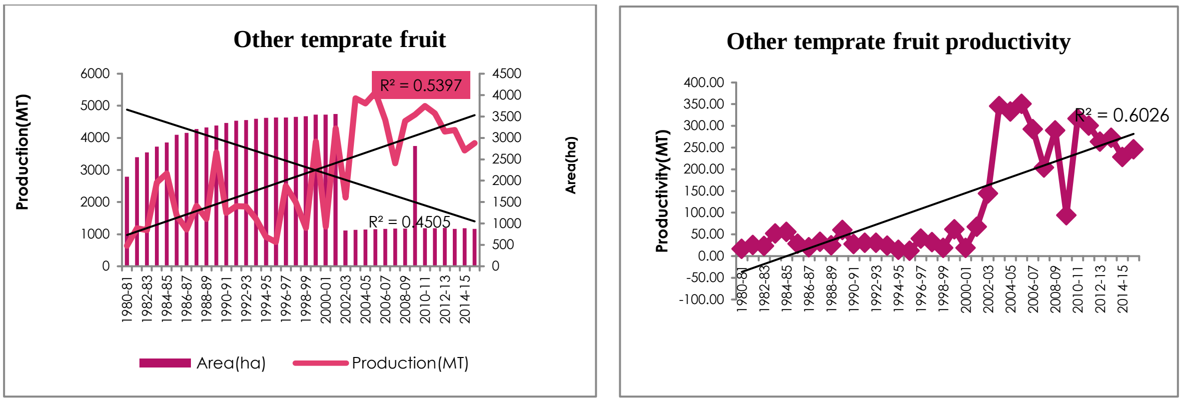


Figure 18 Variations in Annual Acreage, Production, and Productivity – Other Temperate Fruits: Plum, Peach, Apricot, Pear (1980-2016), District Kangra, HP

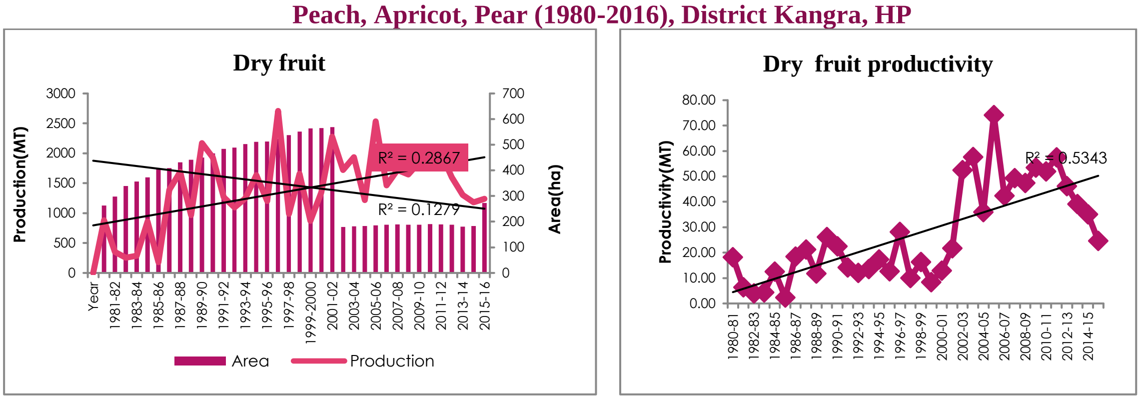


Figure 19 Variations in Annual Acreage, Production, and Productivity – Dry Fruits: Almond, Walnut, Picanut (1980-2016), District Kangra, HP

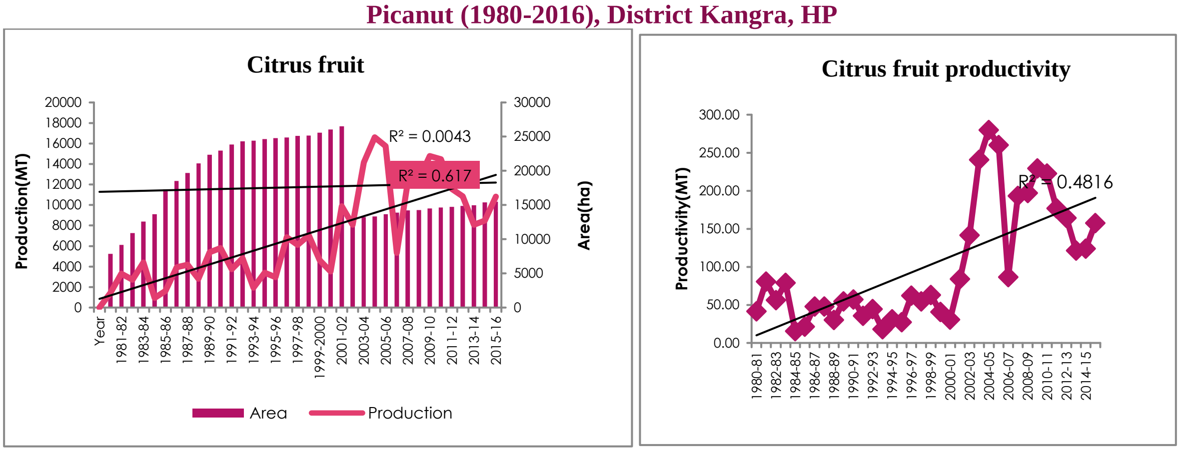


Figure 20 Variations in Annual Acreage, Production, and Productivity – Citrus Fruits: (1980-2016), District Kangra, HP

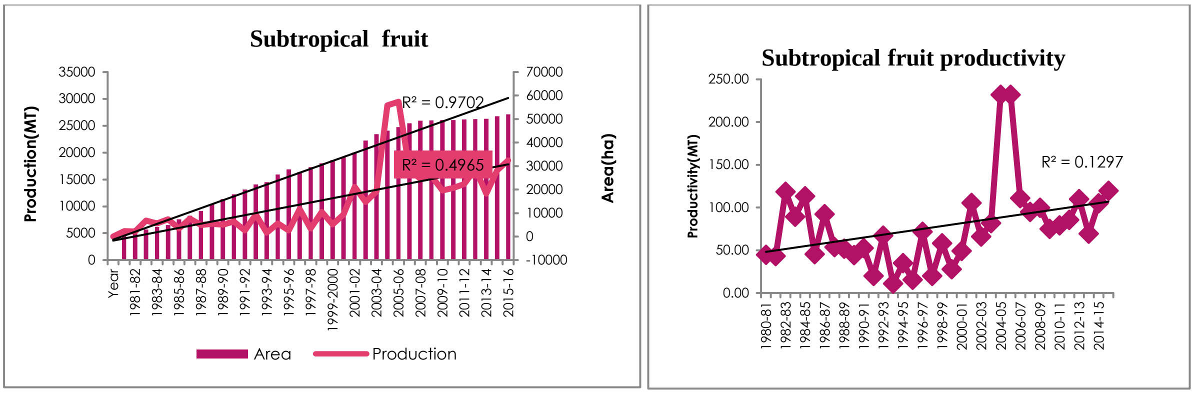


Figure 21. Variations in Annual Acreage, Production, and Productivity –Subtropical Fruits: (1980-2016), District Kangra, HP

Dwelling deeper into the productivity trends for the horticulture crop, an overall increasing productivity trend is recorded for all crops except papaya and loquat (-0.27 t $ha^{-1}yr^{-1}$) and (-0.17 t $ha^{-1}yr^{-1}$) statistically significant p-values at 95 per cent confidence interval. (Table 5)

Table 6 Mann Kendall Test Results – Crop Yields for Fruit Crops (1980-2016)

Fruits Productivity	Mean	Sen's slope	p-value
Pear	2.476	0.182	**0.002**
Galgal	2.403	0.087	**0.001**
Loquat	3.090	-0.174	**0.003**
Papaya	8.630	-0.270	**0.003**
Guava	1.289	0.021	0.199
Litchi	0.531	0.040	**0.000**
Mango	0.794	0.033	**0.002**
Lemon	0.743	0.053	**0.000**
Orange	1.374	0.074	**0.001**

Trend data in tandem with the outcomes of Mann Kendall Test results hint toward a shift in focus from Apple crop to other stone crop and a consistent decline in dry fruit, solely in terms of productivity. Consistent trends have been reported by different research studies upholding the role of climate change in impacting the productivity of apple and other temperate fruits in Himachal Pradesh. While, Singh (2003) discussed the role of changing weather patterns such as reduced annual snowfall and fluctuating temperatures during flowering period in determining the success of apple crop in Himachal Pradesh; Gautam et al. (2004) unearthed the factors of reduction in natural pollinating agents, inadequate winter chilling, frequent spring frosts and hails, droughts as reasons for poor fruit setting in Delicious variety. Therefore, at this stage it becomes imperative to get a better insight into factors leading to this supposed transition with specific role of climate change led variations in individual crop productivity. The next section explores the juxtaposition of horticulture crop productivity with respect to climate change variations, through a multivariate regression analysis.

CLIMATE- FRUIT CROP JUXTAPOSITION

To determine the relationship between climatic variables during phenological periods and productivity of fruit crops, a correlation analysis was performed. Highly significant correlation between climate variability and productivity was observed during the ***pre-flowering stages***, with a predominant impact on the productivity of Orange, Mango, Galgal (C*itrus psedolimon)* and Louqat (table 8). Orange productivity exhibited strong correlation with maximum and minimum temperatures during the pre-flowering period with coefficient values of 0.58 and 0.36 respectively. It also shows correlation with maximum and minimum temperatures during the flowering period. That means with an increase in ***mean maximum and minimum temperatures***, during the ***pre-flowering and flowering stages***, orange productivity increase. In case of Mango productivity increase in minimum temperature cause increase productivity during pre flowering and fruit setting stage by 0.37 and 0.45 respectively. Galgal productivity exhibited strong correlation with minimum temperatures during the pre-flowering and flowering period with coefficient values of 0.55 and 0.59 respectively. Productivity of loquat had a negative correlation with increase in minimum temperature during pre flowering season cause decline in productivity by -0.57 during the study period.

With reference to variations in ***mean maximum temperature***, guava crop showed significant negative correlation of -0.31 during the ***fruit setting season***. That is with slight increase in maximum temperature, guava crops shows decreased in productivity. For ***rainfall variations*** during the ***pre-flowering, flowering and fruit setting season***, there is no statistically significant correlation was observed. During ***the flowering*** period. For the ***fruit setting and development stages***, with reference to variations in ***mean maximum temperature***, Guava crop showed significant negative correlation of -0.31 during the ***fruit setting season***. That is with slight increase in maximum temperature, guava crops shows decreased in productivity.

To summarise the above discussion on the regression outcomes of detrended [1] climatic variables of minimum, maximum, diurnal temperature, rainfall, and rainy days with the productivity of selected crops of fruits crop. Of the three phenological stages, maximum impact of climatic parameters was observed during the ***pre-flowering stage*** i.e. the contribution of climatic variables in impacting the productivity of orange, mango loquat and Galgal. R-squared statistics is used to ascertain the percentage of variation in productivity (positive or negative) that is explained by variations in minimum, maximum, diurnal temperature and rainfall.

For the phenological stages of ***flowering stage***, variations in climatic parameters of temperature and rainfall accounted for 17 per cent of the variability in pear productivity, 45 per cent (increase) in orange and 52 per cent for Galgal. During ***the fruit setting and development*** stages 24 per cent variations (decrease) in Louqat productivity. Factors of quality planting material and better orchard management practices are touted to be the explanatory reasons for remainder variations in fruit crop yield (Jindal & Chauhan, 2001).

In nutshell, amongst all the studied crops, Mango, Orange and Galgal productivity showed significant correlation to climatic variations during Pre flowering and flowering stages i.e. (15%, 20%, 10%) orange (39%, 1%, 6%) and Galgal (34%, 52%,3%). With respect to individual crops, this means that the observed variations in productivity for mango crop from 1990-2016 is explained by the variations in climatic parameters only to the extent of 15% during pre-flowering stage, 20% during the flowering stage, and 10% during the fruit setting and development stage. While the other crops such as Lemon (8%, 4%, 8%), Litchi (9%, 5%, 6%), and Guava (1%, 11%, 12%) Pear productivity showed sensitivity to climatic variations during all three stages with non significant correlation.

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

Table 7 Multivariate Linear Regression Analysis – Crop Yields and Climatic Parameters, (1990- 2016)

S No.	Crops	Variable / Statistics	Pre Flowering					Flowering					Fruit Setting				
			Max T	**Min T**	**DT**	**RF**	**R^2**	**Max T**	**Min T**	**DT**	**RF**	**R^2**	**Max T**	**Min T**	**DT**	**RF**	**R^2**
2.	**Pear**	Coefficient	0.266	0.140	0.077	0.134	0.392	0.049	-0.087	0.107	-0.097	0.017	0.177	0.020	0.062	-0.183	0.060
		p-value	0.094	0.248	0.354	0.258		0.407	0.335	0.302	0.318		0.194	0.462	0.382	0.185	
3.	**Orange**	Coefficient	**0.588**	**0.368**	0.119	-0.226	0.392	**0.577**	**0.444**	0.119	-0.278	0.451	-0.083	-0.093	0.037	0.115	0.024
		p-value	**0.001**	**0.032**	0.281	0.134		**0.001**	**0.011**	0.281	0.085		0.344	0.327	0.430	0.288	
4.	**Lemon**	Coefficient	-0.163	-0.032	-0.095	-0.180	0.089	0.054	0.205	-0.116	0.039	0.044	-0.204	-0.017	-0.076	0.218	0.083
		p-value	0.213	0.438	0.322	0.189		0.397	0.158	0.287	0.425		0.158	0.466	0.356	0.142	
5.	**Mango**	Coefficient	0.147	**0.373**	-0.222	-0.140	0.154	0.040	**0.445**	-0.312	0.007	0.201	-0.312	0.101	-0.219	0.079	0.104
		p-value	0.237	**0.030**	0.138	0.248		0.424	**0.011**	0.060	0.486		0.060	0.312	0.141	0.350	
6.	**Litchi**	Coefficient	-0.102	0.038	-0.112	-0.223	0.092	0.069	0.235	-0.126	0.024	0.057	-0.200	-0.021	-0.072	0.164	0.062
		p-value	0.309	0.426	0.293	0.136		0.369	0.124	0.269	0.454		0.163	0.460	0.364	0.212	
7.	**Guava**	Coefficient	0.102	0.071	0.014	0.034	0.017	0.094	0.295	-0.153	-0.159	0.117	**-0.316**	-0.069	-0.085	0.063	0.123
		p-value	0.311	0.365	0.472	0.434		0.324	0.072	0.228	0.218		**0.058**	0.369	0.339	0.380	
8.	**Papaya**	Coefficient	**-0.344**	-0.039	-0.227	0.292	0.156	-0.223	0.086	-0.245	0.245	0.088	-0.271	-0.028	-0.097	-0.023	0.092
		p-value	**0.043**	0.424	0.132	0.074		0.137	0.339	0.114	0.113		0.090	0.446	0.318	0.456	
9.	**Loquat**	Coefficient	0.141	**-0.570**	**0.618**	0.071	0.449	0.018	-0.543	0.434	-0.013	0.315	**0.399**	**-0.372**	0.474	0.177	0.249
		p-value	0.246	**0.001**	**0.000**	0.365		0.464	0.002	0.013	0.476		**0.022**	**0.031**	0.007	0.194	
10.	**Galgal**	Coefficient	0.231	**0.555**	-0.322	0.107	0.343	**0.509**	**0.592**	-0.049	-0.074	0.524	-0.179	0.089	-0.151	-0.008	0.035
		p-value	0.128	**0.002**	0.054	0.301		**0.004**	**0.001**	0.406	0.359		0.190	0.332	0.231	0.485	

CONCLUDING POINTERS

Crop Variations:

- *Dwelling deeper into the productivity trends for the horticulture crop, a significant overall increasing productivity trend is recorded for all crops except Guava.*
- *Highest increase was observed in case of Pear (0.18 t $ha^{-1}yr^{-1}$) followed by Galgal (0.08 t $ha^{-1}yr^{-1}$) and Lemon (0.05 t $ha^{-1}yr^{-1}$);*

Climatic Variations:

Average maximum temperature *registered an inclining trend at a rate of 0.045°C per year from 1970 to 2018 (as exhibited by the Sen's slope) during the* **pre- flowering season**

Flowering period *- the average maximum temperature increased by 0.04°C per year and minimum temperature showed decline in temperature by -0.02°C per year*

Fruit-setting period *– the average maximum temperature and diurnal temperature also registered an inclining trend progressing at a rate of 0.013°C and 0.04°C per year between 1970-2018.*

Climate Crop Juxtaposition:

Strong relationship between climate variability and productivity of fruit crops during pre-flowering period and flowering in comparison to fruit setting stages i.e. for mango and orange (with minimum temperature) during pre flowering stage and flowering., orange and loquat (with maximum temperature) during flowering stage, variations in productivity exhibited statistically significant correlation with changes in considered climatic parameters of temperature. While the other fruit crops do not significantly variability and productivity of fruit crops during pre-flowering period, flowering and fruit setting stage.

CHAPTER 5 – CONCLUSION & RECOMMENDATIONS

The status report was designed to elucidate statistical impact of climate change on productivity of horticulture crops in Himachal Pradesh with a study focused on District Kangra. As per the analysis the average maximum temperature registered an inclining trend at a rate of 0.045°C per year between 1970-2018 (as exhibited by the Sen's slope) during the pre- flowering season i.e., between November – February. During the flowering season i.e. March to April the average maximum temperature increased by 0.04°C per year and minimum temperature showed decline in temperature by -0.02°C per year. Also, the average maximum temperature and diurnal temperature during fruit setting stage i.e., between May – August also registered an inclining trend progressing at a rate of 0.013°C and 0.04°C per year between 1970-2018. Rainfall during fruit setting stage show increase by 5. 31mm.The remaining climatic variables did not exhibit any significant variation during the pre-flowering, and fruit setting and development stages.

Highly significant correlation between climate variability and productivity was observed during the pre-flowering stages, with a predominant impact on the productivity of Orange, Mango, Galgal (*Citrus psedolimon*) and Louqat. Orange productivity exhibited strong correlation with maximum and minimum temperatures during the pre-flowering period with coefficient values of 0.58 and 0.36 respectively. It also shows correlation with maximum and minimum temperatures during the flowering period. In case of Mango productivity increase in minimum temperature cause increase productivity during pre flowering and fruit setting stage by 0.37 and 0.45 respectively. Galgal productivity exhibited strong correlation with minimum temperatures during the pre-flowering and flowering period with coefficient values of 0.55 and 0.59 respectively. Productivity of loquat had a negative correlation with increase in minimum temperature during pre flowering season cause decline in productivity by -0.57 during the study period.

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In nutshell, amongst all the studied crops, Mango, Orange and Galgal productivity showed significant correlation to climatic variations during Pre flowering and flowering stages i.e. (15%, 20%, 10%) orange (39%, 1%, 6%) and Galgal (34%, 52%,3%). With respect to individual crops, this means that the observed variations in productivity for mango crop from 1990-2016 is explained by the variations in climatic parameters only to the extent of 15% during pre-flowering stage, 20% during the flowering stage, and 10% during the fruit setting and development stage. While the other crops such as Lemon (8%, 4%, 8%), Litchi (9%, 5%, 6%), and Guava (1%, 11%, 12%) Pear productivity showed sensitivity to climatic variations during all three stages with non significant correlation.

BIBLIOGRAPHY

AGRICOOP, 2012. *Agriculture Contingency Plan for District: KULLU*. [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.

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.

Caprio, J.M. & Quamme, H.A., 2005. Influence of Weather on Apricot, Peach, and Sweet Cherry Production in the Okanagan Valley of British Columbia. *Canadian Journal of Plant Sciences*, 86, pp.259-67.

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

Chmielewski, F.M. & Rötzer, T., 2001. Response of tree phenology to climate change across Europe. *Agricultural and Forest Meteorology*, 108, pp.101-12.

Choudhary, M.L., Patel, V.B., Siddiqui, M.W. & Mahsi, S.S., 2015. *Climate Dynamics in Horticultural Science, Volume One: Principles and Applications*. 1st ed. Apple Academic Press.

Climate Change R, n.d. [Online].

Coakley, S.M., Scherm, H. & Chakraborty, S., 1999. Climate change and plant disease management. *Annual Review of Phytopathology*, 37, pp.399-426.

Crepinsek, Z. & Bogataj-Kajfez, L., 2004. Effect of air temperature increase on changes in temperatures and length of growing season. In Hudina, D.M., Colaric, M. & Trobec, M., eds. *International Slovenian Fruit Congress*. Ljubljana, 2004. Experimental Fruit Growing Association of Slovenia.

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].

ENVIS Centre, Himachal Pradesh, 2016. *Horticulture*. [Online] Available at: http://hpenvis.nic.in/Database/Horticulture_4022.aspx [Accessed 22 October 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).

Gautam, D., Sharma, G. & Jindal, K., 2004. Fruit Setting Problems of Apples under changing climatic scenario of north-western Himalayas of India. *ISHS Acta Horticulturae 662: VII International Symposium on Temperate Zone Fruits in the Tropics and Subtropics.*, pp.435-41. DOI: 10.17660/ActaHortic.2004.662.66.

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].

Hinkel, J., 2011. indicators of Vulnerability and Adaptive Capacity: Towards a clarification of the science-policy interface. *Global Environmental Change*, 21(1), pp.198-208.

HPAGRISNET, 2017. *HORTICULTURE DEVELOPMENT IN HIMACHAL PRADESH AT A GLANCE*. [Online] Available at: http://hpagrisnet.gov.in/hpagris/Horticulture/Default.aspx?SiteID=5&PageID=1219 [Accessed 22 October 2018].

IBEF, 2018. *Indian Agriculture Industry Analysis*. [Online] IBEF Available at: https://www.ibef.org/industry/agriculture-presentation [Accessed 22 October 2018].

IHCAP, 2015. *Vulnerability, Hazards and Risk: An Integrated Pilot Study in Kullu District, Himachal Pradesh*. Status Report. Indian Himalayas Climate Change Adaptation Programme.

IPCC, 2007. *Climate Change 2007: Impacts, Adaptation and Vulnerability*. UK: Cambridge University Press IPCC.

IPCC, 2007. *IPCC Fourth Assessment Report: Climate Change 2007*. [Online] Available at: https://www.ipcc.ch/publications_and_data/ar4/wg1/en/ch11s11-4-3.html [Accessed 22 October 2018].

IPCC, 2014. *Climate Change 2014: Impacts, Adaptation, and Vulnerability*. UK: Cambridge University Press IPCC.

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 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.

Kumar, P.R. et al., 2009. Impact of Climate Change on Seed Production of Cabbage in North Western Himalayas. *World Journal of Agricultural Sciences*, 5(1), pp.18-26.

Lang, G.A., 2001. Intensive Sweet Cherry Orchard Systems – Rootstocks, Vigor, Precocity, Productivity and Management. *The Compact Fruit Tree* , 34(1), pp.23-26.

Malhotra, S., 2017. Horticultural crops and climate change: A review. *Indian Journal of Agricultural Sciences*, 87(1), pp.12-22.

Mboup, M. et al., 2012. Genetic structure and local adaptation of European wheat yellow rust populations:

The role of temperature-specific adaptation. *Evolutionary Applicatoins*, 5(4), pp.341-52.

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.

MoSPI, 2016. *Success Story & Policy Issues of Farmer's Welfare (Horticulture Sector) in Himachal*. [Online] Available at: http://mospi.nic.in/sites/default/files/cocsso/2_HimachalPradesh.pdf [Accessed 22 October 2018].

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.

Partap, T. & Partap, B., 2010. Mountain Farmers Adaptive Strategies in Response to Impact of Climate Change on their Livelihood Options. In *International Symposium on Benefitting from Earth Observation: Bridging the Data Gap for Adaptation to Climate Change in the HKH Region*. Kathmandu, Nepal, 2010. International Centre for Integrated Mountain Development (ICIMOD). held during October 4-6, 2010.

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.

Samedi, M. & Cochran, L.C., 1976. *Horticulture Science*, pp.10-593.

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.

Shekhar, M.S. et al., 2010. Climate-change studies in the western Himalaya. *Annals of Glaciology*, 51(54), pp.105-12.

Shrestha, U.B., Gautam, S. & Bawa, K.S., 2012. *Widespread Climate Change in the Himalayas and Associated Changes in Local Ecosystems*. [Online] Available at: https://doi.org/10.1371/journal.pone.0036741 [Accessed 22 October 2018].

Singh, J., 2003. Low productivity trends in the apple growing state of India. Himachal Pradesh: contributing factors.. In K.K. Jindal, R. Bawa & T. Partap, eds. *Apple Farming and Livelihoods in Himalayas*. pp.43-58.

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.

Vedwan, N. & Robert, E.R., 2001. Climate Change in the Western Himalayas of India: A Study of Local Perception and Response. *Climate Research*, 19, pp.109-17.

Vishvakarma, S.C.R., Kuniyal, J.C. & Rao, K.S., 2003. Climate change and its impact on apple cropping in Kullu Valley, North-West Himalaya. In *7th International Symposium on Temperate Zone Fruits in the Tropics and Subtropics, 14-18 October 2003*. Nauni-Solan, HP, 2003. Dr. Y.S. Parmar University of Horticulture and Forestry.

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].

WRI, 2018. *By the Numbers: New Emissions Data Quantify India's Climate Challenge*. [Online] Available at: https://www.wri.org/blog/2018/08/numbers-new-emissions-data-quantify-indias-climate-challenge [Accessed 25 October 2018].