IMPACT OF CLIMATE CHANGE ON HORTICULTURE SECTOR IN DISTRICT SHIMLA, HIMACHAL PRADESH

STATE CENTRE ON CLIMATE CHANGE

Under the aegis of

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

In collaboration with

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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 Shimla. 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*.

Higher variability in temperature and rainfall parameters observed during ***pre flowering period*** *as compared to* ***flowering and fruit setting period*** from 1990 to 2016. During ***pre flowering period*** maximum temperature and diurnal temperature increased by 0.01°C per year from 1990 to 2016. Maximum temperature increased by 0.02°C per year from 1990 to 2016 during ***flowering period.*** Meanwhile, the maximum temperature increased by 0.04°C per year from 1990-2016 during ***fruit setting period.***

The statistical assessment of variations in climatic parameters of temperature and rainfall with changes in horticulture productivity registered maximum impact during the ***pre-flowering*** phenological stage i.e. for Apple crop with diurnal temperature and rainfall, while for flowering stage and fruit setting stage fewer statistically significant correlation was witnessed between fruit crops productivity and climatic parameters.

Amongst all the studied crops, Apple productivity showed maximum sensitivity to climatic variations during all three stages (24%, 26.3%, 25.5%) with significant correlation observed for Apricot (19.8%, 38.9%, 16%), Peach (11.9%, 32.9%, 18.3%), Plum (18.7%, 17.9%, 11%), and Pear (17.6%, 7.6%, 19.7%). With respect to individual crops, this means that the observed variations in productivity for Apple crop from 1990-2016 is explained by the variations in climatic parameters only to the extent of 24 % during pre-flowering stage, 26.3% during the flowering stage, and 25.5% during the fruit setting and development stage. Similar interpretations are valid for Apricot, Peach, Plum and Pear.

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:

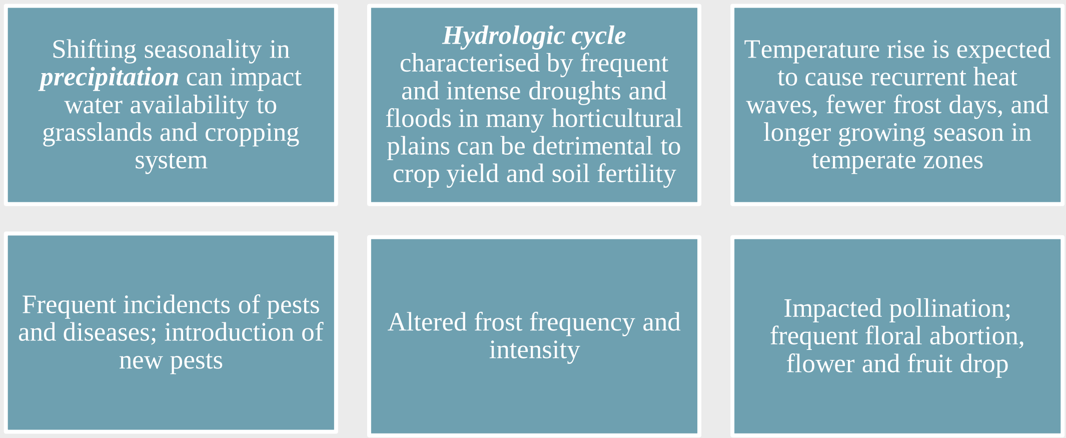


Figure 1: Horticulture and Climate Change Impact

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 1: Climate 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.

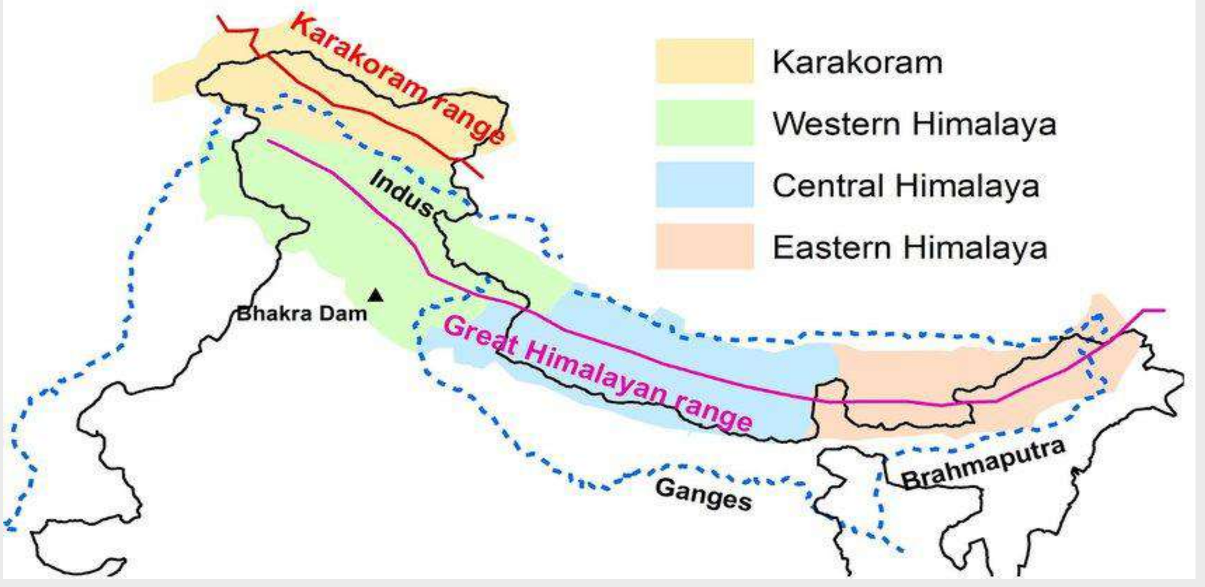


Figure 2: Geographical Representation of the Indian Himalayas
Source: Divecha Centre of Climate Change, Indian Institute of Science, Bengaluru (2018)

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, 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 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, 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)**

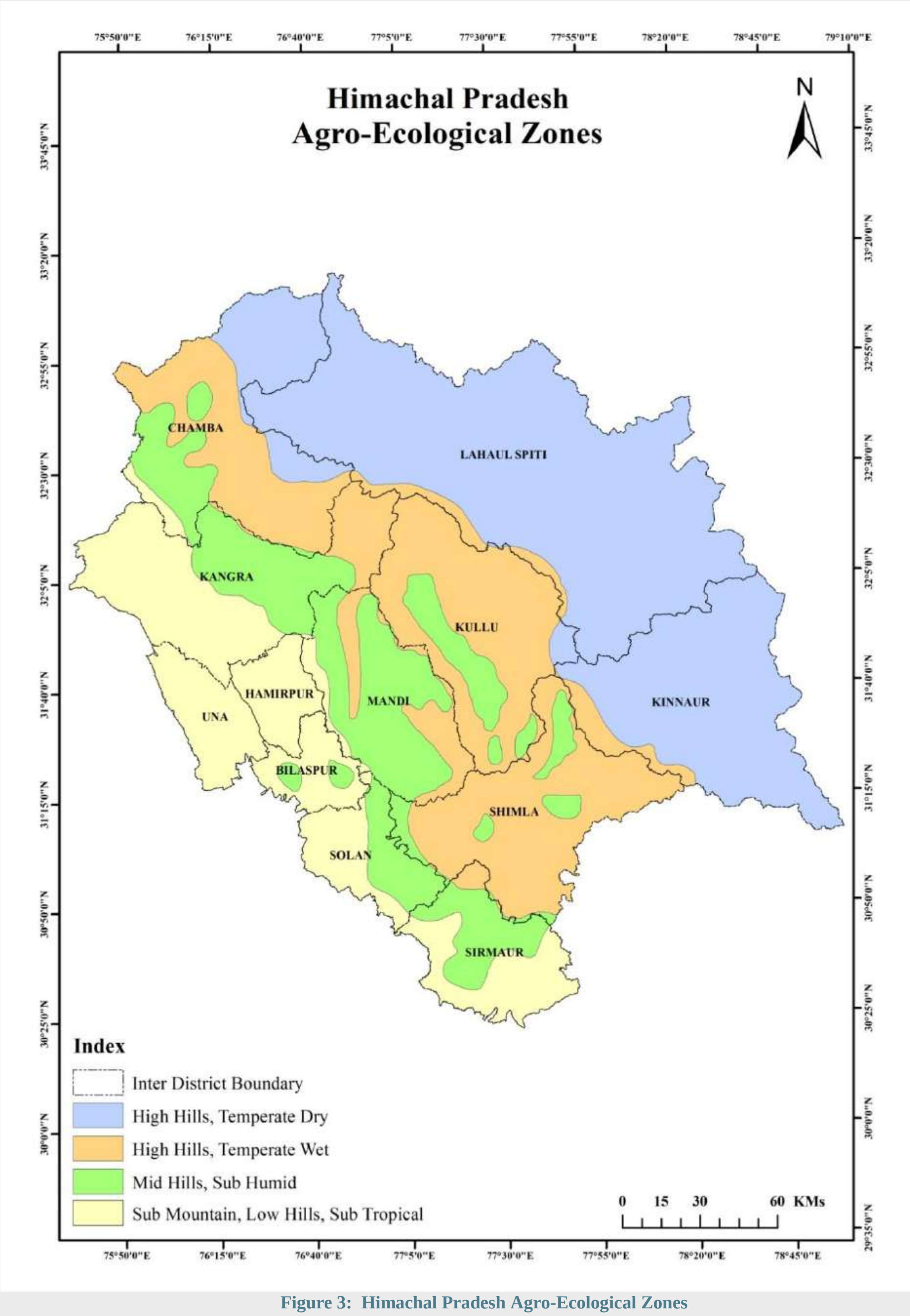


Figure 3: Himachal Pradesh Agro-Ecological Zones

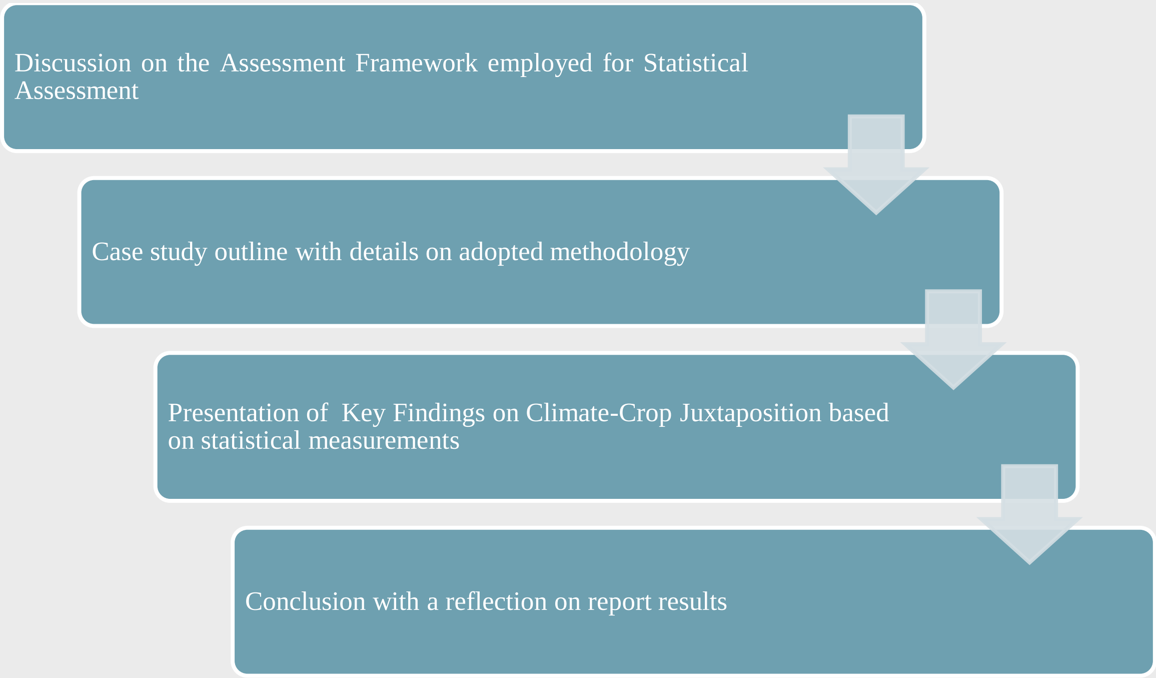
Source: Adapted by HPSCCC from Agro-Ecological Zonation of Himachal Pradesh – Agricultural System Information Development at micro-level, Centre of Geo-informatics, CSK Himachal Pradesh Agriculture University, Palampur (Bhagat et al., 2006)

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 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 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 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 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 XLSTAT2017. 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:

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

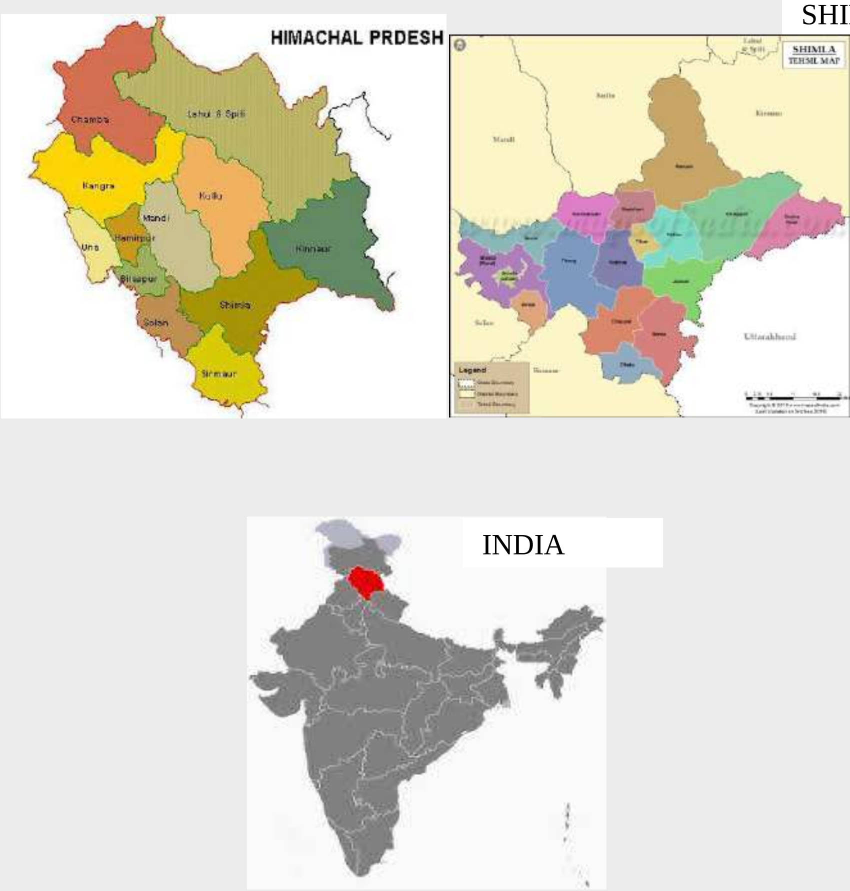
Where, ΔP is the observed change in the productivity due to minimum, maximum, diurnal temperature, and rainfall in the respective phenological stages of the fruit crops. Coefficients α, β, γ, and δ are the coefficients of minimum, maximum, diurnal temperature and rainfall, respectively. ΔT_{min}, ΔT_{max}, T_{dt}, ΔR, and ΔRd 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 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.

SHIMLA DISTRICT



INDIA

Figure 4: Map of District Shimla, Himachal Pradesh

Table 3: 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)

SHIMLA AND THE CLIMATE

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.

METHODS

Within the context of collocation of climate variability and agriculture productivity in District Shimla, 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 Kullu District was collected from India Meteorological Department (IMD), Shimla 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, Plum, Peach, Apricot, Cherry, Pomegranate, Walnut and Almonds 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 SHIMLA

CURRENT CLIMATE TRENDS –DISTRICT SHIMLA

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 ***pre-flowering season*** from November to February in comparison to ***flowering and fruit setting 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 1990-2016.

Table 4: Mann Kendall Test Results – Climatic Trends for pre-flowering, flowering and fruit setting seasons (1990-2016)

	Mean	Sen's slope	p-value
Pre Flowering (November- February)			
Av. Max Temperature	14.11	0.09	**0.001**
Av. Min. Temperature	5.3	0.03	0.07
Diurnal Temperature	8.84	0.05	**0.001**
Total Rainfall	199.31	-3.46	0.16
Flowering (March – April)			
Av. Max. Temperature	19.51	0.11	**0.002**
Av. Min. Temperature	12.9	0.06	0.2
Diurnal Temperature	6.64	0.04	0.06
Total Rainfall	143.04	0.12	0.96
Fruit- Setting (May- August)			
Av. Max. Temperature	23.98	0.029	**0.04**
Av. Min. Temperature	16.2	0.02	0.29
Diurnal Temperature	7.77	0.02	0.06
Total Rainfall	932.97	2.56	0.89

As per the analysis the ***average maximum temperature and diurnal temperature*** registered an inclining trend at a rate of 0.001°C per year between 1990-2016 (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 0.002°C per year. Also, the average maximum temperature during ***fruit setting stage*** i.e. between May – August also registered an inclining trend progressing at a rate of 0.04 °C per year between 1990-2016. The remaining climatic variables did not exhibit any significant variation during the *pre-flowering, and fruit setting* and *development stages.*

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

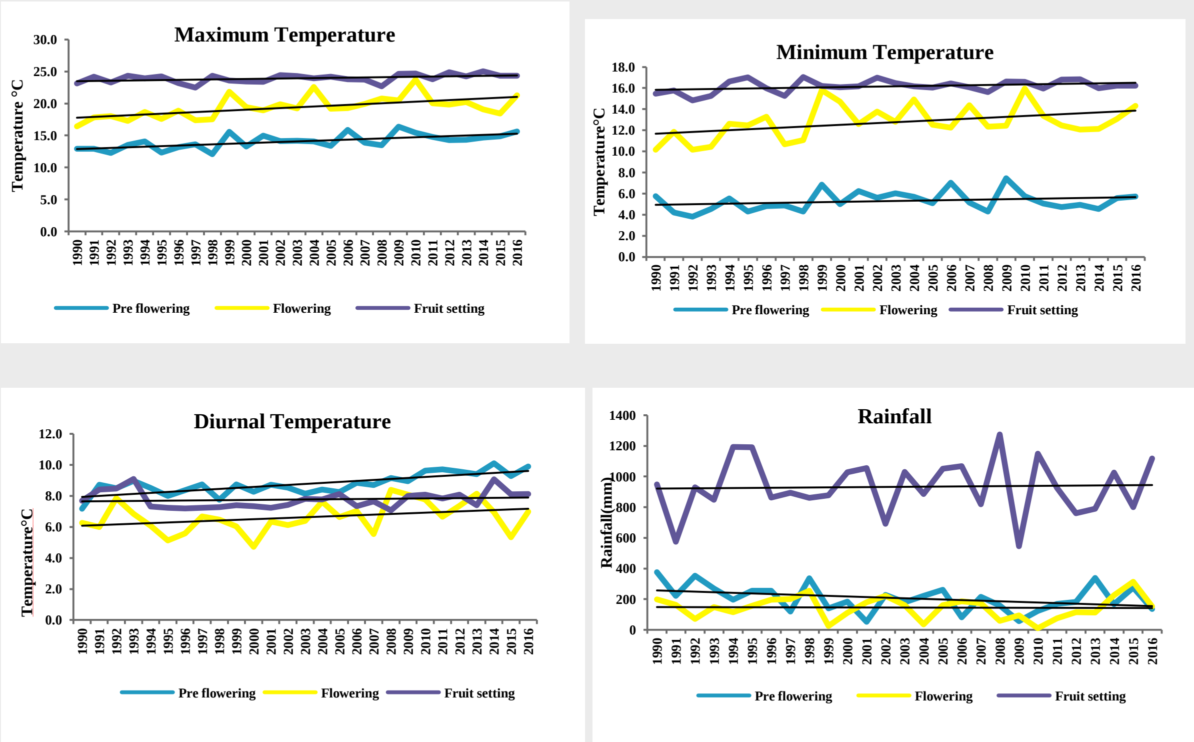


Figure 5: Variations in Climatic Parameters- Minimum T, Maximum T, Diurnal T and Rainfall during *pre-flowering, flowering, and fruit setting stages* (1990-2016), District Shimla, HP

A cooling period in mean maximum temperature during ***pre-flowering and flowering stages*** was observed up to 1999 (figure 6) followed by a continuous warming trend with temperatures rising above the long term averages from 2001 till 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 (Table 4). For instance, during the ***flowering and pre-flowering season*** the mean maximum temperature was higher than 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***, 9 out of 14 warming years were recorded after 2000 (figure 7).

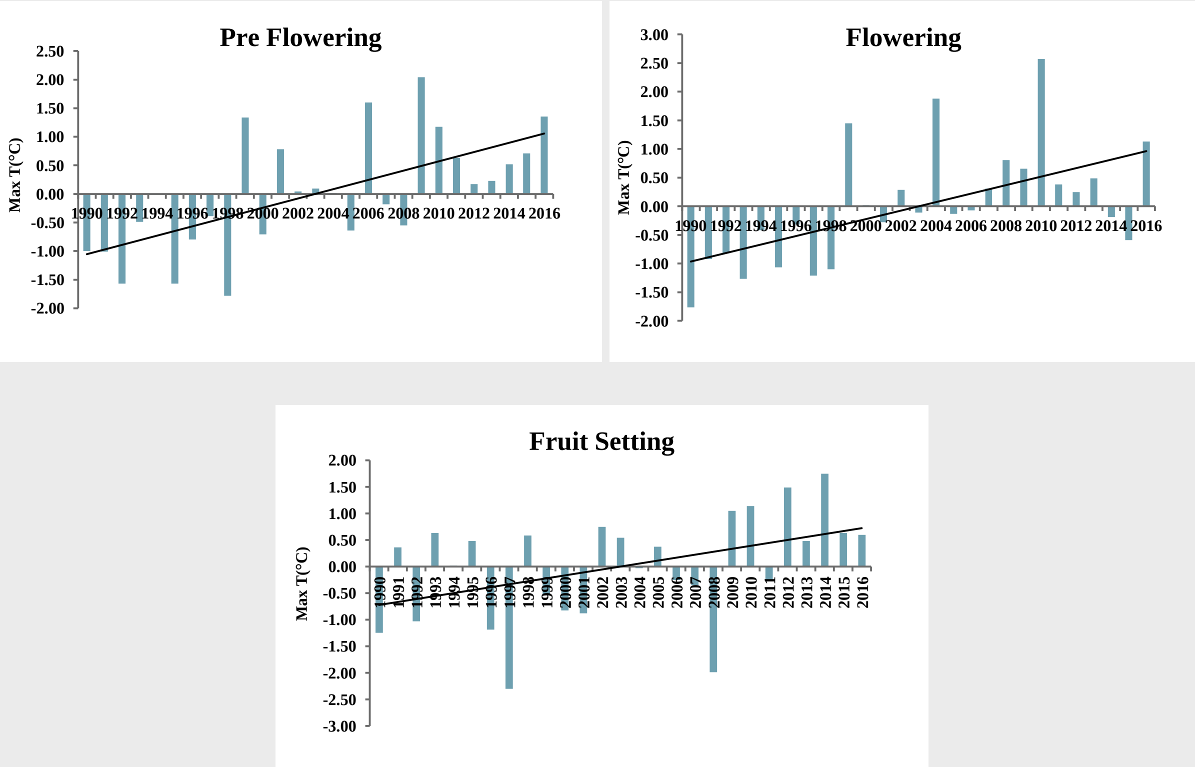


Figure 6: SAI for Mean Maximum Temperature during pre-*flowering, flowering, and fruit setting stages* (1990-2016), District Shimla, HP

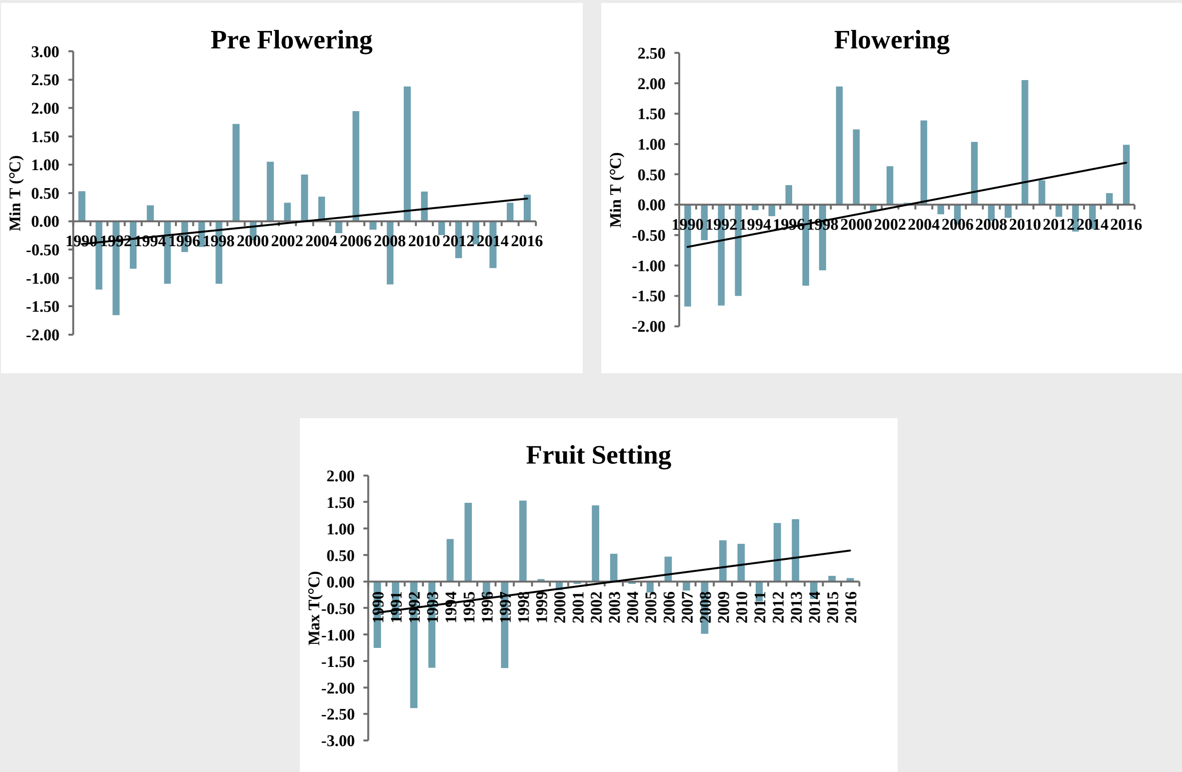


Figure 5: SAI for Mean Minimum Temperature during pre-*flowering, flowering, and fruit setting stages* (1990-2016), District Shimla, HP

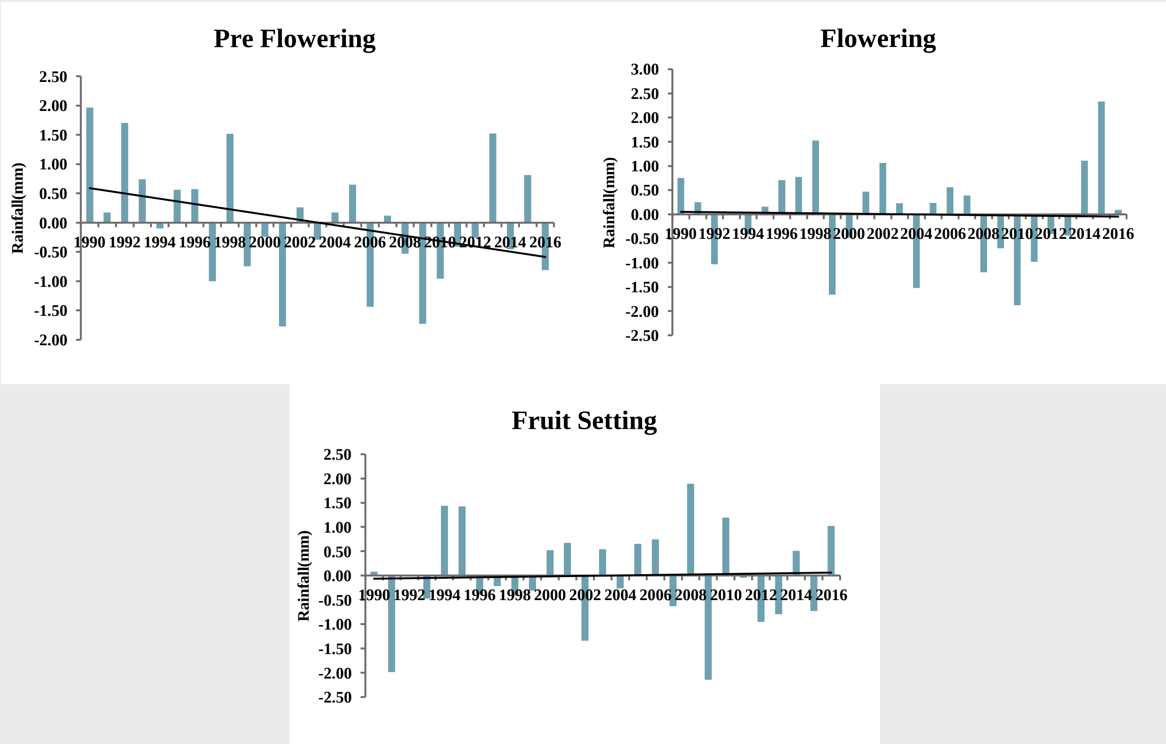


Figure 8: SAI for Mean Annual Rainfall during *pre-flowering, flowering, and fruit setting stages* (1990-2016), District Shimla, HP

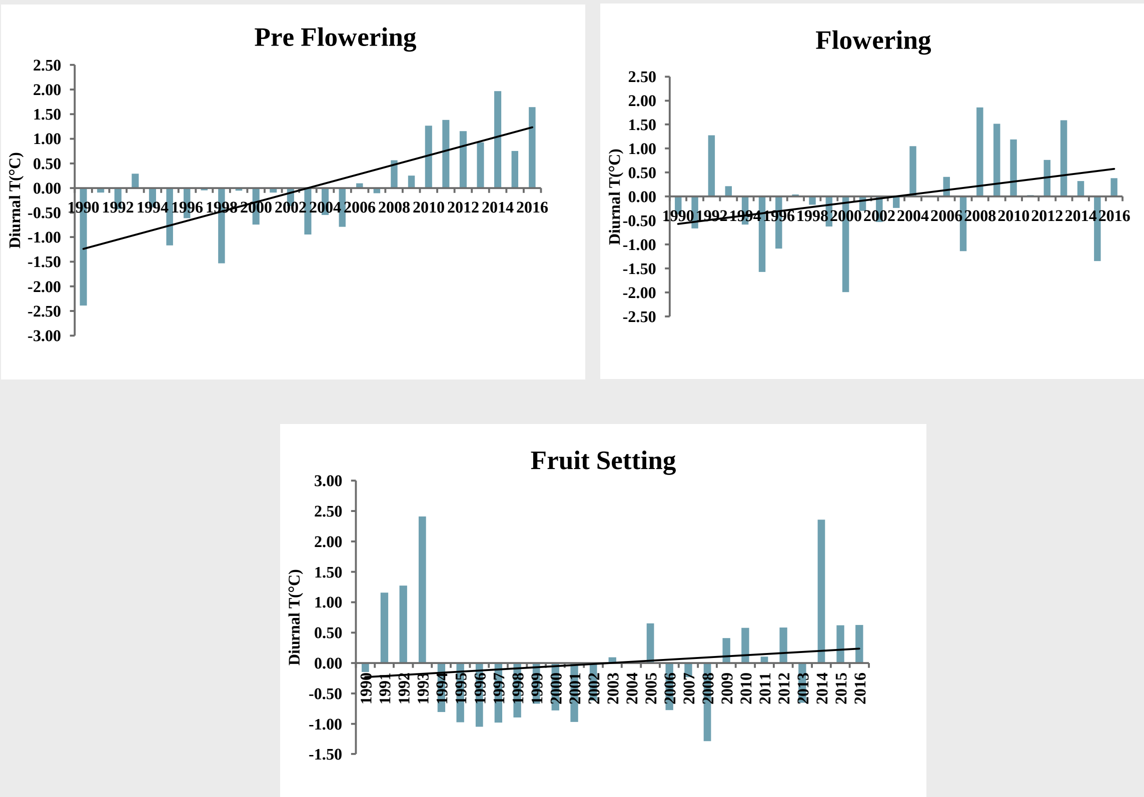


Figure 9: SAI for Mean Diurnal Temperature during *pre-flowering, flowering, and fruit setting stages* (1990-2016), District Shimla, HP

Rainfall pattern during the phenological stages of flowering, and fruit setting and development stages did not show any variation over the long term averages, except during the pre-flowering stage where rainfall registered a decreasing trend post 2002, with small spikes in 2002,2003, 2004, 2005,2007, 2013,2015.

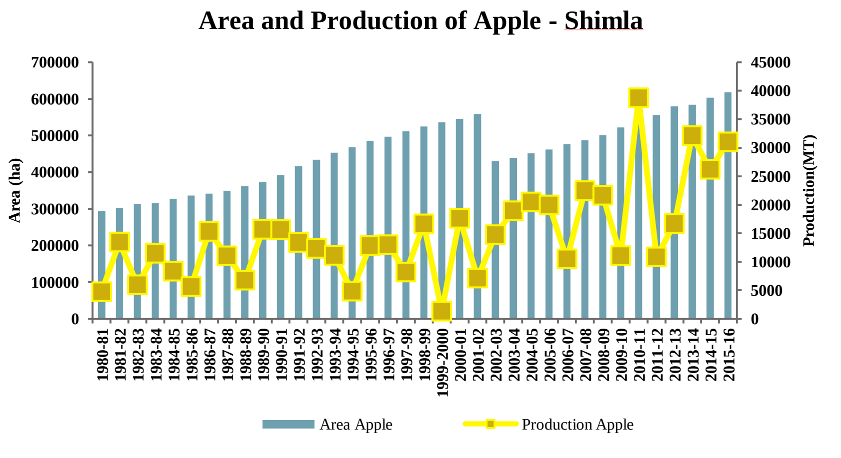
The discussed variations in temperature and rainfall patterns are not confined to District Kullu but are corroborated by observations from other studies in the Himalayan region. Poudel and Shaw (2016) observed an increase of 0.07°C in minimum temperature and 0.02°C in maximum temperature from 1980 to 2010 in Nepal bound Himalayan region, while comparing minimum annual temperatures with maximum temperatures. 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.

ACREAGE, PRODUCTION, PRODUCTIVITY ASSESSMENT OF MAJOR HORTICULTURE CROPS

In District Shimla, 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 Apple, and other fruit crops viz. Plum, Peach, Apricot and Pear in Shimla district were studied.

Acreage under apple cultivation increased from 18,887 ha in 1980 to 39,728 ha in 2015 (an increase of 110.34 per cent) and the production surged from 73,521 MT to 48, 2388 MT (1980-2015), as illustrated in Figure 10. Whereas the productivity of Apple increased from 3.89 per cent to 12.14 per cent (1980-2015). Nonetheless, productivity of Apple did not register any statistically significant variations, with minimum productivity of 2.50 t ha-1 in 1994 and maximum of 17.41 t ha-1 in 2010 there after declining to 12.14 t ha-1 by 2016.

For other temperate fruits, the composite acreage increased by 58.25 per cent (2,494 ha in 1980 to 3,947 ha in 2015), the total production surged by 909.49 per cent (811 MT in 1980 to 8,187 MT in 2015), and productivity increased from 0.33 to 2.07 t ha^{-1} in past 35 years (Figure 11). Composite area under dry fruits i.e. Almond, Walnut, and Picanut increased by 153.76 per cent from 718 ha to 2041 ha till 2001, thereafter declined to 1822 ha by the end of 2015. While, productivity showed an increasing trend , moving from 0.22 t ha^{-1} in 1980 to 0.33 t ha^{-1} in 2015 (Figure 12).



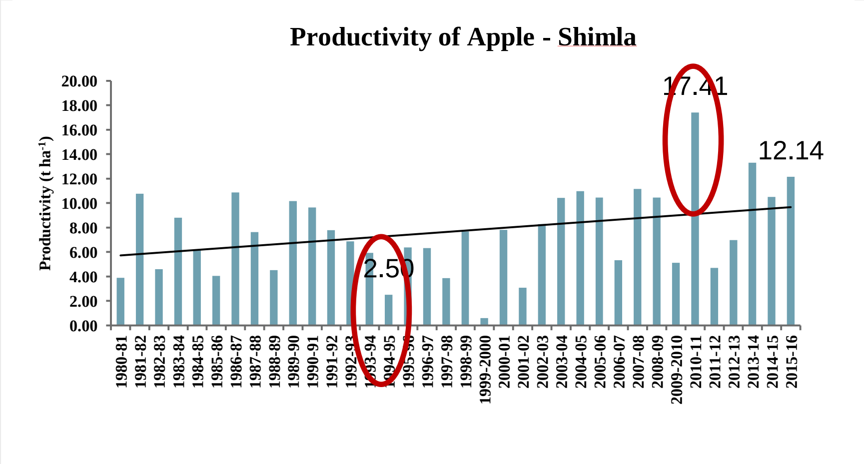
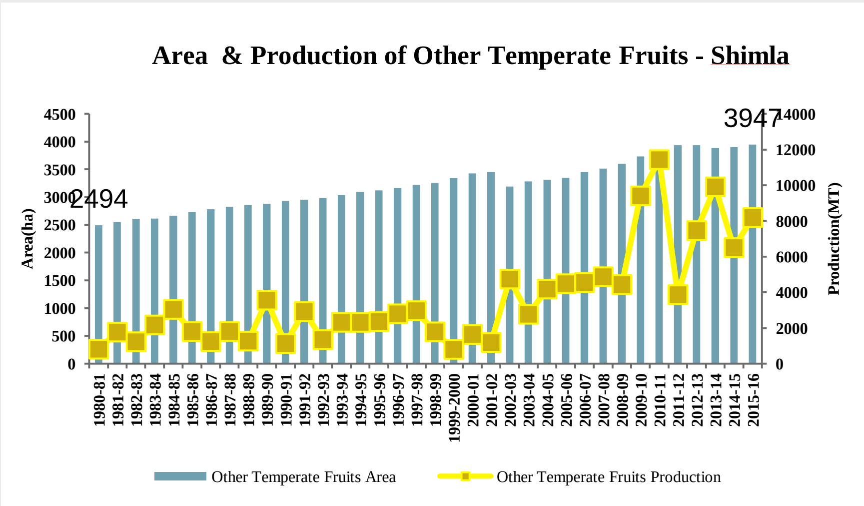


Figure 6: Variations in Annual Acreage, Production, and Productivity – Apple (1980-2016), District Shimla, HP



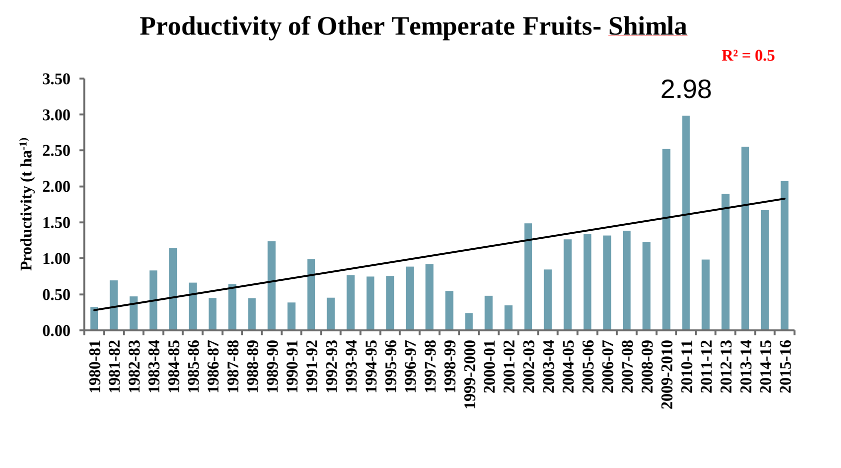
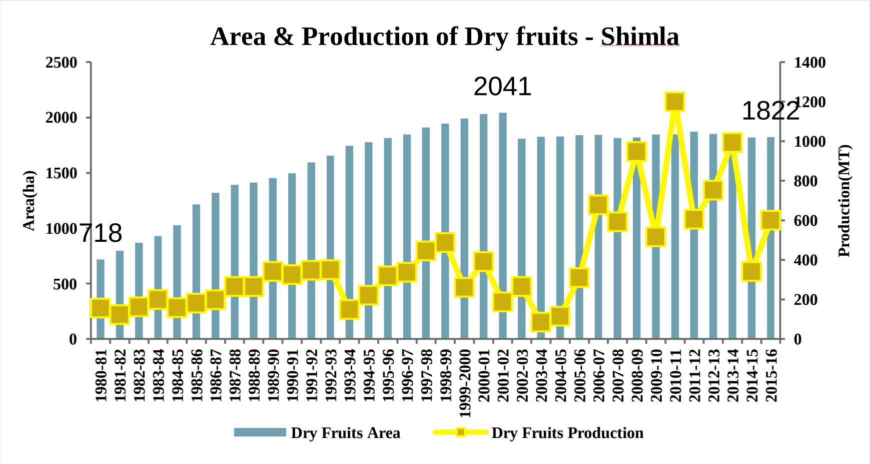


Figure 7: Variations in Annual Acreage, Production, and Productivity – Other Temperate Fruits: Plum, Peach, Apricot, Pear (1980-2016), District Shimla, HP



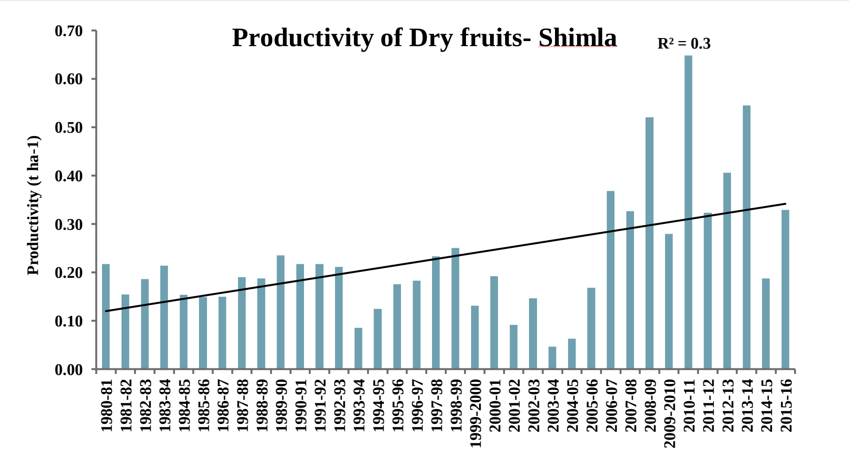


Figure 8: Variations in Annual Acreage, Production, and Productivity – Dry Fruits: Almond, Walnut, Picanut (1980-2016), District Shimla, HP

Dwelling deeper into the productivity trends for the horticulture crop, an overall increasing productivity trend is recorded for Pear, Peach, and Apricot, with statistically significant p-values at 95 per cent confidence interval, while for productivity of apple and plum statistically significant observations weren't registered. Highest increase was observed in case of Pear (0.146 t $ha^{-1}yr^{-1}$) followed by Apricot (0.017 t $ha^{-1}yr^{-1}$) and Peach (0.024 t $ha^{-1}yr^{-1}$). (Table 5)

Table 5: Mann Kendall Test Results – Crop Yields for Fruit Crops (1990-2016)

Fruits Productivity	Mean	Sen's slope	p-value	Confidence interval
Apple	7.836	0.249	0.009	0.219,0.279
Pear	1.640	**0.146**	**0.000**	0.132,0.154
Plum	0.920	0.009	0.508	0.004,0.011
Peach	0.301	**0.024**	**0.001**	0.023,0.025
Apricot	0.221	**0.017**	**0.000**	0.016,0.017

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 temperate 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 Apple, Apricot and Plum crops (table 6). Apple productivity exhibited strong negative correlation with rainfall during the pre-flowering period with coefficient values of -0.44 and positive correlation with diurnal temperature during pre-flowering period with coefficient value of 0.45 respectively. With reference to variations in minimum and maximum temperatures, none of the fruit crops showed significant correlation in productivity, during the pre-flowering stage.

During ***the flowering*** period, apricot productivity showed a negative correlation with variations ***in mean minimum and maximum temperatures*** (-0.38, -0.44). Similarly, plum productivity showed a negative correlation with variations ***in mean minimum temperature.***

For the ***fruit setting and development stages***, productivity of apple crop showed negative correlation with the minimum temperature (-0.46).

To summarise the above discussion on the regression outcomes of detrended [1] climatic variables of minimum, maximum, diurnal temperature and rainfall with the productivity of selected crops of apple, pear, plum peach and apricot. 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 Apple, Pear, Cherry, Pomegranate, and Almond crops. 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. 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. Therefore, during the ***pre-flowering stage***, climatic factors accounted for 24 per cent of the increase in Apple productivity, 19.8 per cent variation in Apricot productivity, 18.7 per cent of productivity decline in Plum, and 17.6 per cent decline in the Pear crop productivity.

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

For the phenological stages of ***flowering stage***, variations in climatic parameters of temperature and rainfall accounted for 38.9 per cent of the variability in Apricot productivity, 32.9 per cent in Peach, and 26.3 per cent in productivity of Apple; and during ***the fruit setting and development*** stages 25.5 per cent variations in Apple productivity, 19.7 per cent in Pear, 18.3 per cent variations in Peach, and 16 per cent of variation in Apricot productivity are explained by the considered climatic parameters.

In nutshell, amongst all the studied crops, Apple productivity showed maximum sensitivity to climatic variations during all three stages (24%, 26.3%, 25.5%) with significant correlation observed for Apricot (19.8%, 38.9%, 16%), Peach (11.9%, 32.9%, 18.3%), Plum (18.7%, 17.9%, 11%), and Pear (17.6%, 7.6%, 19.7%). With respect to individual crops, this means that the observed variations in productivity for Apple crop from 1990-2016 is explained by the variations in climatic parameters only to the extent of 24 % during pre-flowering stage, 26.3% during the flowering stage, and 25.5% during the fruit setting and development stage. Similar interpretations are valid for Apricot, Peach, Plum and Pear.

TABLE 6: MULTIVARIATE LINEAR REGRESSION ANALYSIS – CROP YIELDS AND CLIMATIC PARAMETERS, (1990- 2016)

S No.	Crops	Variable / Statistics	Pre Flowering					Flowering					Fruit Setting				
			Min T	**Max T**	**DT**	**RF**	**R^2**	**Min T**	**Max T**	**DT**	**RF**	**R^2**	**Min T**	**Max T**	**DT**	**RF**	**R^2**
1.	**Apple**	Coefficient p-value	0.06 0.79	0.23 0.25	0.45 **0.02**	-0.44 **0.03**	**0.240**	-0.25 0.22	-0.18 0.38	0.12 0.58	-0.15 0.47	0.263	-0.46 **0.02**	-0.29 0.16	0.12 0.56	0.07 0.75	**0.255**
2.	**Pear**	Coefficient p-value	-0.13 0.52	-0.01 0.96	0.27 0.19	0.04 0.87	**0.176**	0.22 0.29	0.23 0.26	0.03 0.90	-0.25 0.22	0.076	-0.25 0.22	-0.19 0.35	0.03 0.90	-0.41 **0.04**	**0.197**
3.	**Plum**	Coefficient p-value	0.05 0.80	-0.02 0.94	-0.17 0.41	-0.07 0.74	**0.187**	-0.39 **0.05**	-0.37 0.06	0.02 0.93	0.18 0.38	0.179	-0.16 0.42	-0.13 0.54	0.03 0.90	0.29 0.16	**0.110**
4.	**Peach**	Coefficient p-value	0.004 0.99	0.06 0.79	0.12 0.50	-0.24 0.20	**0.119**	-0.31 0.13	-0.38 0.06	-0.12 0.56	0.10 0.63	0.329	-0.32 0.11	-0.04 0.87	0.30 0.13	0.14 0.49	**0.183**
5.	**Apricot**	Coefficient p-value	0.07 0.72	0.07 0.74	-0.01 0.96	-0.21 0.31	**0.198**	-0.38 **0.05**	-0.44 **0.02**	-0.11 0.61	0.13 0.5	0.389	-0.26 0.20	-0.02 0.91	0.25 0.23	0.14 0.49	**0.16**

CONCLUDING POINTERS

Crop Variations:
Pear, Peach and Apricot crops should statistically significant increase in productivity as per Mann Kendal test results

Productivity of Apple and Plum did not show any statistically *significant changes from 1990-2016 as per results of Mann Kendall Test*

Apple Crop - minimum productivity of 2.50 t ha-1 in 1994 and maximum of 17.41 t ha-1 in 2010 there after declining to 12.14 t ha-1 by 2016

Climatic Variations:
Higher variability in temperature and rainfall parameters observed during ***pre flowering period*** *as compared to* ***flowering and fruit setting period*** *from 1990 to 2016*

Flowering period *- Maximum temperature increased by 0.02°C per year from 1990 to 2016*

Pre-Flowering period *- Maximum temperature and Diurnal temperature increased by 0.01°C per year from 1990 to 2016*

Fruit-setting period *– Maximum temperature increased by 0.04°C per year from 1990-2016*

Higher anomalies in maximum and minimum temperature reported during all three phenological stages indicating a warming trend

Climate Crop Juxtaposition:
Highly significant correlation between climate variability and productivity was observed during the pre-flowering stages, with a predominant impact on the productivity of Apple crop. Apple (with diurnal temperature and rainfall variations in productivity exhibited statistically significant correlation with changes in considered climatic parameters of temperature and rainfall during pre-flowering stage; while for flowering stage and fruit setting stage fewer statistically significant correlation was witnessed between fruit crops productivity and climatic parameters.

Amongst all temperate fruit crops, ***Apple*** *found to be most vulnerable to impact of climatic variability at all three phenological stages while* ***Pear*** *was least vulnerable.*

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 Shimla.

Higher variability in temperature and rainfall parameters observed during ***pre flowering period*** *as compared to* ***flowering and fruit setting period*** from 1990 to 2016. During ***pre flowering period*** maximum temperature and diurnal temperature increased by 0.01°C per year from 1990 to 2016. Maximum temperature increased by 0.02°C per year from 1990 to 2016 during ***flowering period.*** Meanwhile, the maximum temperature increased by 0.04°C per year from 1990-2016 during ***fruit setting period.***

The statistical assessment of variations in climatic parameters of temperature and rainfall with changes in horticulture productivity registered maximum impact during the ***pre-flowering*** phenological stage i.e. for Apple crop with diurnal temperature and rainfall, while for flowering stage and fruit setting stage fewer statistically significant correlation was witnessed between fruit crops productivity and climatic parameters.

Amongst all the studied crops, Apple productivity showed maximum sensitivity to climatic variations during all three stages (24%, 26.3%, 25.5%) with significant correlation observed for Apricot (19.8%, 38.9%, 16%), Peach (11.9%, 32.9%, 18.3%), Plum (18.7%, 17.9%, 11%), and Pear (17.6%, 7.6%, 19.7%). With respect to individual crops, this means that the observed variations in productivity for Apple crop from 1990-2016 is explained by the variations in climatic parameters only to the extent of 24 % during pre-flowering stage, 26.3% during the flowering stage, and 25.5% during the fruit setting and development stage. Similar interpretations are valid for Apricot, Peach, Plum and Pear.

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