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Delineation of suitable areas for potential temperate fruit crops in Himachal Pradesh under changing climatic conditions

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Abstract
The climatic changes with respect to rise in temperature, erratic precipitation and lack of chilling hours have affected the hill horticultural production system adversely. A study was conducted to identify the climatic suitability for optimum production of major temperate fruit crops in high and mid hills of Himachal Pradesh. Using Geographical Information System (GIS), the suitability analyses were performed with digital processing of geo-referenced data on topography, climate, soil and land cover. The potential production areas for each crop were identified by ArcGIS spatial analyst. The study revealed that the higher reaches such as Manali, Bhang, Naggar and Raisan in Kullu; Kotgarh, Jubbal, Kumarsain, Chopal and Rohru of Shimla and Kinnaur district covering Sangla, Kalpa, Sharbo and Pooh were highly suitable for growing apple. Whereas, the areas comprising of Bajaura and Bhuntar in Kullu; Karsog, Nagwain and Jhanjheli in Mandi; Theog area in lower parts of Shimla district were moderately suitable for apple cultivation. The suitability map for sub temperate fruit crops indicated that Kandaghat, Kunihar and Dharampur in Solan and Rajgarh area of Sirmaur district were highly suitable for peach, plum and apricot. However, Nalagarh in Solan and Rohru in Shimla district have become marginally suitable zones for sub temperate fruit crops. It was further revealed that out of the total area under apple cultivation in Himachal Pradesh, 26.89 per cent area was found to be highly suitable and 19.89 per cent was found moderately suitable. However, 24.76 percent area has now become non suitable for apple cultivation. Out of the total area for sub temperate fruit crops, 55.18 per cent has become highly suitable, 34.58 per cent has been converted into marginally suitable, 46.86 percent as moderately suitable and 42.24 percent has become non suitable for stone fruits.

Keywords: Agro-climatic suitability, apple, stone fruits, geographical information system

1. Introduction
The horticulture in Himachal Pradesh represents diverse farming systems including cultivation of fruits, vegetables and flower crops due to varied micro climatic conditions. All these crops grow best in locations where the climatic conditions meet their growth requirements. Sustainable agriculture involves producing quality products in an environmentally benign, socially acceptable and economically efficient way ensuring optimum utilization of the available natural resources. However, sustainable production in mountain regions is a challenging task because of the marginality, accessibility and fragile ecosystems. The high valued agriculture particularly horticultural crops are the catalysts for the next wave of growth in the farm sector and a better tool for the climate-smart agriculture (FAO, 2010) [12]. Horticultural crops in particular are sensitive to climate and commercial crops like apple in temperate, stone fruits in sub temperate and mango in sub-tropical regions have specific temperature requirements for their proper growth and development.
Various factors such as elevation, slope, water availability and soil fertility besides climate also affect crop growth and must be taken into consideration while determining the most suitable crop in an area under consideration. Some of the climate and soil constraints like water deficit and fertility of the soil can be improved by irrigation and fertilizer applications, respectively. However, other factors such as inadequate growing degree days, insufficient winter chilling and frost occurrence can make particular crops marginal or uneconomic in certain regions. The change in climate in the form of erratic precipitation, increase in temperature, lack of chilling hours have started affecting the horticulture based production system especially in the temperate region thereby threatening the farm income and food security of the people. The Apple belt has been found to be shifting towards higher altitudes (Jangra and Singh, 2011; Aditya *et al*., 2012) [17, 1] in want of chilling requirement (Darbyshire *et al.*, 2011) [10] and apple cultivation is expanding in the cold desert in recent decades (Rana *et al.*, 2008) [23].

Soil and climate based agro-climatic suitability can therefore be used to identify areas with permutation of homogenous climate and soil conditions where proper landuse planning strategies for various crops can be implemented. There are different ways to assess the cultivation potential of a particular geographical area and one such quantification is the land suitability classification. It evaluates and groups specific areas of land in terms of their suitability for a defined use (Bhagat *et al*., 2009) [8]. Crop-land suitability analysis consequently becomes a prerequisite to achieve optimum utilization of the available land resources for sustainable agricultural production. The main objective of the land evaluation through this method ushers the prediction of the inherent capacity of a land unit to support a specific land use for a long period without deteriorating the socioeconomic and environmental conditions.

Geographical Information System (GIS) offers a flexible and powerful tool of data processing by taking large volumes of different kinds of information through manipulating and combining into new datasets which can be displayed in the form of thematic maps (Foote and Lynch, 1996) [13]. Differences in the environmental characteristics of areas occupied by a variety can also be examined by modeling distribution that integrates locality data, GIS data and modeling algorithms (Phillips *et al.,* 2006) [22]. Use of GIS in addition allows the construction of models from which a new thematic map (e.g. climate suitability map) can be produced from a set of thematic maps (Harasheh, 1994) [15].

The land suitability analysis using GIS necessitates the use of different kinds of data such as topographic characteristics, climatic conditions and soil quality of an area as the most important determinant parameters for evaluation. Thus the estimating and mapping of climatic factors that can determine the suitability of a particular area for a selected crop can be done. The combined climatic information in a GIS system along with soil information and data about crop requirements can be used to identify areas with the maximum potential and lowest risk for a particular crop. The analysis also allows identification of the main limiting factors of crop production and enables decision makers to develop crop management system (Halder, 2013) [14]. Armed with such information, together with knowledge about market demand, farmers can make rational estimates of the likely economic benefit from a change in land use.

The present study was therefore undertaken to delineate suitable production areas in Himachal Pradesh for temperate (apple) and sub temperate (peach, plum and apricot) fruits using the relevant variables of soil, climate, land use/land cover and topographic factors.

2. Material and Methods

2.1 Study area

Himachal Pradesh is a mountainous state in Indian Himalayas, covering an area of about 55, 672 sq. km. It comprises of intricate mosaic of mountain ranges, hills and valleys, exhibiting an altitudinal variation from 350 m to 6975 m above mean sea level, endowed with myriad of climatic niches. The state exhibits considerable variation in the distribution of rainfall and temperature due to varying aspects and altitudes. The climate varies from hot and sub-humid tropical in the southern tracts to cold, alpine and glacial in the northern and eastern mountain ranges with more elevation. The study area mainly traverses three agro-climatic zones namely, High-Hills Wet Temperate- Zone III (District Shimla and Kullu) and Mid-Hills Sub-humid- Zone II (District Solan) and Sub-Montane & Low Hills Sub-tropical- Zone I (Kangra district) serving as fruit growing belts for temperate and sub temperate fruits (Fig 1).

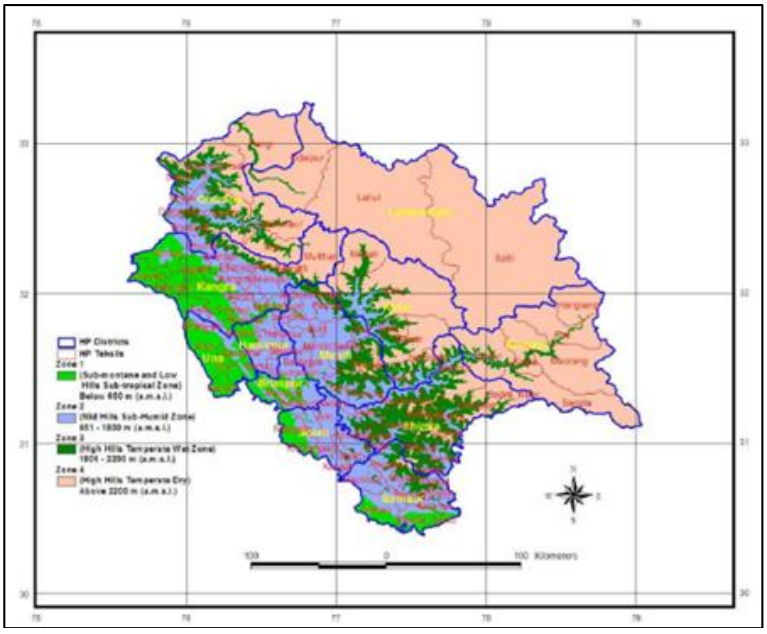

Fig 1: Agro-climatic zonation of Himachal Pradesh

2.2 Data and methodology used

The methodology for the characterization of crop suitability map for the study area was based on the processing and combination of a set of criterion layers which were considered as the main determinants for crop suitability:

- Climate- precipitation and temperature (maximum and minimum temperature)
- Soil- physical and chemical properties
- Topography- latitude, longitude and elevation

In order to delineate suitable areas for temperate and sub temperate fruit crops the different geophysical parameters of study area viz. specific topography (elevation) coupled with climatic and soil requirement of apple, peach, plum and apricot (Table 1) as recommended in the literature were used

(Anon, 2014) [5]. The climatic data (maximum temperature, minimum temperature and rainfall) for the duration of 30 years (1985-2015) of different places of the study area was collected from the respective meteorological stations and from India Meteorological Department (IMD). The latitude, longitude and elevation information of various fruit growing belts of the study sites and some adjoining areas were generated by ground truth surveys using GPS. The soil thematic layers obtained from NBSSLUP, Nagpur as basis for soil classes under different fruit growing belts have been reclassified using the GIS technology to be used as one of the parameters for suitability criteria.

Table 1: Climate and soil requirement criteria used for delineating suitability of temperate and sub temperate fruits in Himachal Pradesh

Parameter	Temperate fruits (Apple)	Sub temperate fruits (Peach, Plum and Apricot)
Elevation (m)	1500-2700	900-2000
Rainfall (mm)	1000-1250	1000-1600
Temperature (ºC)	21-24	25-30
Soil texture	Loam soil	Sandy loam soil
Soil pH	5.8-6.2	5.5-6.5
Chill hours (<7 ºC)	1000-1500	300-900
Land Use	Cultivated land	Cultivated land

2.3 Computation of chilling hours

The chilling requirement refers to temperature below 7 ºC for certain specific number of hours after which a fruit-bearing tree will blossom. Apple and stone fruits namely, peach; plum and apricot require a specific amount of chilling hours or chilling unit. The effective apple and stone fruit chill units were worked out with the daily maximum and minimum winter temperature data during November to February using UTAH model (Byrne and Bacon, 1992) [9]. In this study temperature of 7 ºC was used as upper limit of chilling temperature for calculating chilling hours.

2.4 Analyses for thematic and suitability maps

Layers of different meteorological parameters were generated using spatial analyst extension of ArcGIS software and employing interpolation technique. Inverse Distance Weighted (IDW) method was used for the interpolation. The IDW methods are based on the assumption that the interpolating surface should be influenced most by the nearby points and less by the more distant points. Layers of average temperature and chilling hours were corrected using Digital Elevation Model (DEM). The soil attribute data were assigned to the polygons and was attributed for preparation of thematic maps. The mentioned layers were the criterion addressing the suitability of land for the crop cultivation in a given area. All thematic layers were integrated in the GIS using the weighted overlay method. Suitable weights were assigned to each thematic feature after taking into account their characteristics. Ground truth knowledge based weight assignment was carried out for each layer and weightage was given to the different parameters (Table 2).

The final model was run with the calibrated weights to generate the spatial suitable areas across the state. The reclassified thematic maps/layers of each variable were weighted using the weights derived and assigned to each factor/criterion. The weighted maps/layers were combined by performing the weighted overlay using spatial analyst tools. Finally, the suitability maps were prepared which provided spatial representation of the inherent capability of the land to support a particular fruit crop. The suitability zones of apple and stone fruits (peach, plum and apricot) were mapped on the basis of climate and soil requirement. Entire area of Himachal Pradesh was divided in to four zones based on the criterion of Food and Agriculture Organization viz., highly suitable (S1), moderately suitable (S2), Marginally suitable (S3) and Not suitable (N) (FAO, 1993) [11].

The present land use/land cover map under fruit cultivation and the suitability map for fruit crops were overlaid to identify the differences between the present land use and the potential land use. In comparison to the actual area under fruit crops, the possibility of further expansion under each temperate and sub temperate fruit crops was assessed.

Table 2: Per cent weightage given to the parameters under study

Input theme	Weightage (%)
Chilling Hours	35
Average Temperature	30
Rainfall	15
Landuse	15
Soil pH and nutrients	5

3. Results and Discussion

The state has some unique growing climates for different fruit crops available at different times of the year. Further, altitudinal variations provide growing seasons with varied climate and topography which support the growth of such crops fairly well. Thus, in the present study, crop suitability analyses were performed for different elevations and suitable areas for growing these crops were delineated by integrating various spatial information files (temperature, rainfall, soil, elevation and land-use).

3.1 Thematic map of average temperature in Himachal Pradesh

The thematic map of average temperature revealed that a large area of the state had an average temperature in the range of 18 to 23 ºC. The districts falling in the lower altitude belts like Una, Bilaspur and Hamirpur experienced high average temperature ranging from 34 to 41 ºC. The mid hill region comprising parts of Solan, Mandi, Kangra and Shimla district recorded average temperature which ranged between 14 and 28 °C. However, the distribution of annual average temperature in the thematic map showed that the higher reaches of Kullu, Shimla, Kinnaur, Chamba and Kangra (Bada Bhangal) districts experienced low temperature ranged between 10 and 14 °C. The northern part of the state representing dry temperate region of Lahaul Spiti and some parts of Kinnaur district had very low temperature (< 10 °C) prevalent in that area (Fig 2). The vast variation in temperature is attributed to the fact that temperature has an inverse relationship with the height of a place above the mean sea level i.e. temperature decreases with increase in altitude. Therefore, the state having mountainous topography experienced a wide range of variation in temperature.

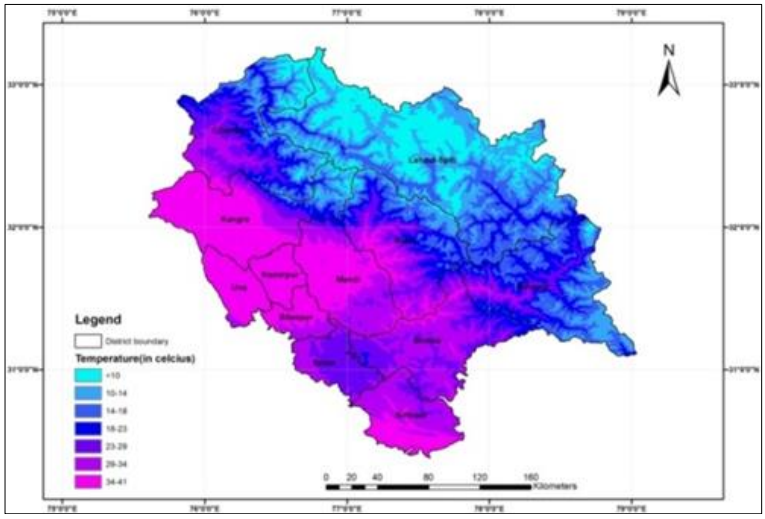

Fig 2: Thematic layer of average temperature in Himachal Pradesh

3.2 Thematic map of rainfall in Himachal Pradesh

The analysis of thematic map for rainfall showed that the state can be distinguished into mainly high rainfall and low rainfall areas. The higher elevation areas comprising of Lahaul Spiti, upper reaches of Kinnaur and low elevation areas of Bilaspur and Hamirpur can be categorized into the dry regions receiving annual rainfall as low as 250 mm. The thematic layer further indicated that the average annual rainfall to the tune of 1000-1200 mm was observed in the mid hills of Kullu and Mandi district (Fig 3). The annual rainfall value as high as 1900 mm was observed in the higher regions of Kangra and Chamba district. The Shimla (Fig 4), Solan (Fig 5) and lower reaches of Kinnaur district (Fig 6) received annual rainfall varied between 1100 mm to 1500 mm. Therefore, as per the perusal of thematic map for rainfall in the state almost entire region except for few reaches under cold dry temperate region and low dry regions have the capability to support the cultivation of fruit plants.

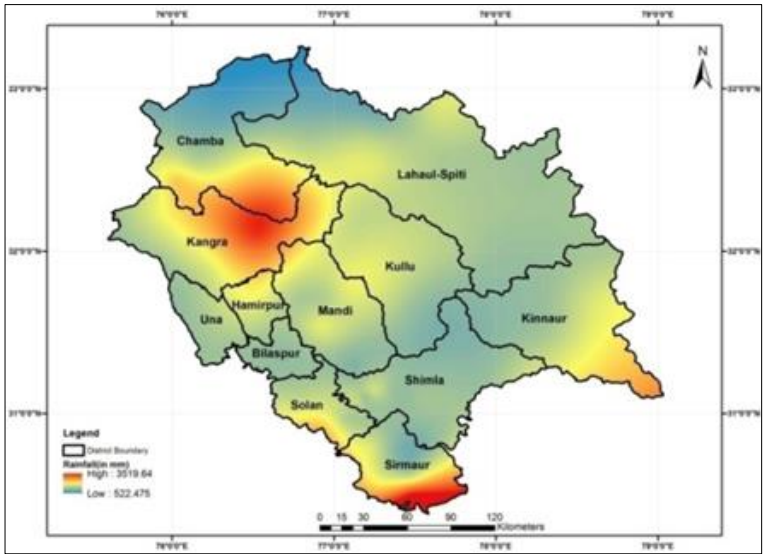

Fig 3: Thematic layer of annual rainfall in Himachal Pradesh

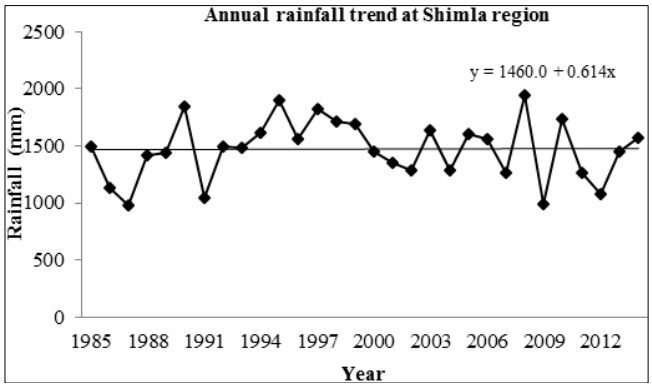

Fig 4: Annual Rainfall trend at Shimla region (1985-2015)

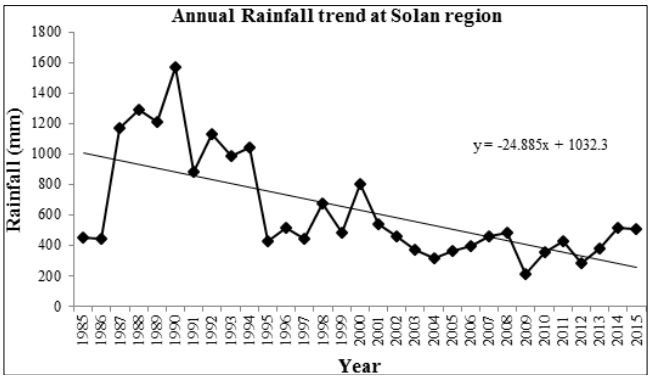

Fig 5: Annual Rainfall trend at Solan region (1985-2015)

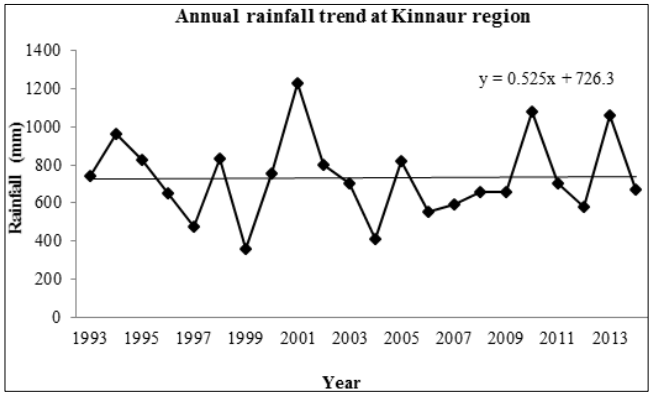

Fig 6: Annual Rainfall at Kinnaur region (1985-2015)

3.3 Thematic map of chill hours in Himachal Pradesh

The thematic layer signified the availability of required chilling hours for apple in only few selected districts of the state. In the higher elevations of Lahaul Spiti and some pockets of Chamba district, the chilling hours were recorded as high as 1650 chill units. These areas exceeded the required limit of chill accumulation for the apple cultivation. The majority of area in districts of Kullu (Fig 7), Kinnaur (Fig 8), Chamba and some parts of Shimla (Fig 9) recorded lower values ranging between 1050 and 1650 chill units which fall in pertinent count of the preferred chill hour accumulation. Next lower elevation area consisted of pockets of Solan, lower belts of Kullu and Shimla with a range of 750 to 1050 chill units exhibiting suitability for the commercial cultivation of low chill spur varieties of apple and mid hills varieties of stone fruits such as peach/nectarine (Snow queen and July Elberta), plum (Santa Rosa and Mareposa) and apricot (New Castle). The thematic map indicated that the parts of Mandi district such as Nagwain, Kangra district such as Kangra and of Kullu district namely Bajaura, Bhuntar, Seobagh and Banjar also recorded the same range. The low altitude regions like Una, Hamirpur and Bilaspur have low chilling hours (< 100 chill units) due to very high temperature as compared to the higher elevations (Fig 10). Therefore, the results showed that the chilling requirements of apple and stone fruits varied which can be satisfied by the climatic conditions of some higher elevations in Himachal Pradesh.

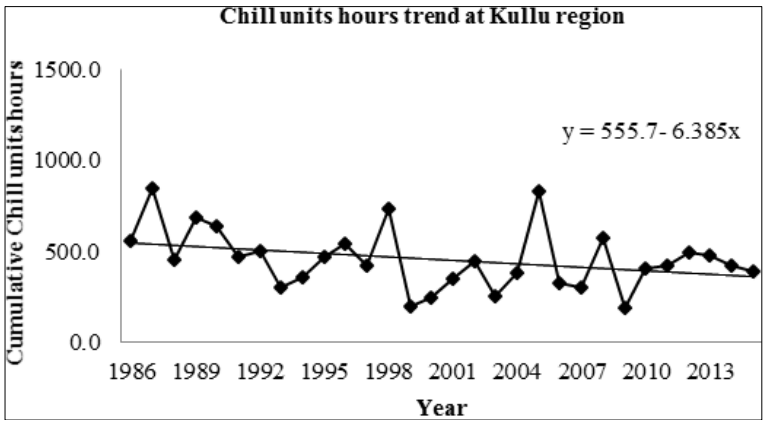

Fig 7: Chill unit hours trend at Kullu region (1985-2015)

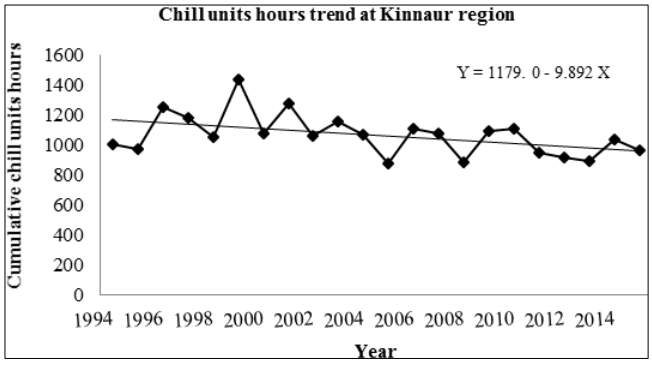

Fig 8: Chill units hours trend at Shimla region (1985-2015)

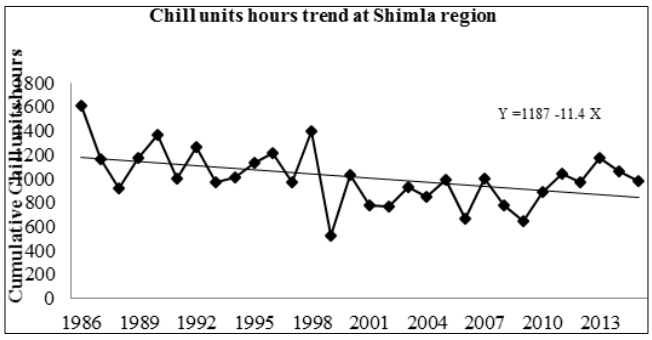

Fig 9: Chill units hours trend at Shimla region (1985-2015)

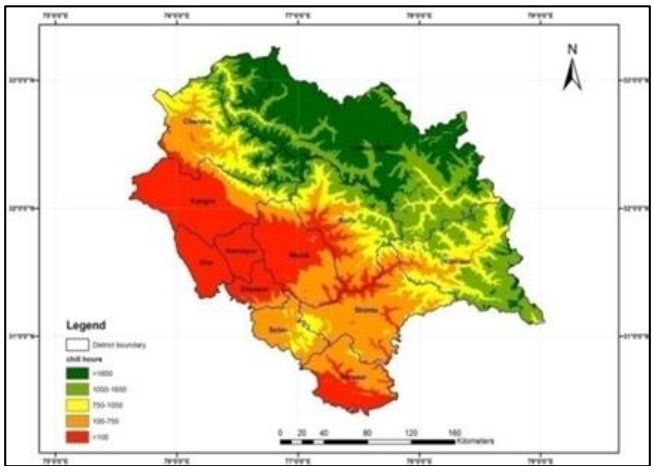

Fig 10: Thematic layer of chilling hours in Himachal Pradesh

3.4 Thematic map of soil in Himachal Pradesh

Soil classification depicted in the soil thematic map indicated that the soils in general contained higher amounts of coarser fractions (sand and silt) compared to clay. The soil found in the districts of Mandi, Kangra, Bilaspur, Una, Solan, Hamirpur and Sirmaur was generally brown, alluvial and grey brown podzolic. Kullu and Shimla district had greywooded podzolic soils, while Kinnaur, Lahaul and Spiti and some

parts of Chamba district had humus mountain skeletal soils (Fig 11). The soils in the state were found to have a moderately acidic reaction, where the majorities of soils recorded pH values in the range of 6.0-6.5. This range of value is moderately suitable for most fruit crops cultivated in the state. Kaistha and Gupta (1994) [19] also reported the same observations on some soils of the North-Western Himalaya. The soils were found to have medium availability of available nitrogen, phosphorus and potassium and low to high organic carbon status in different regions. Most of the areas had the deficiency of micronutrients particularly zinc. The similar results for soils in Shiwalik range have also been indicated by Rao *et al* (1997) [24].

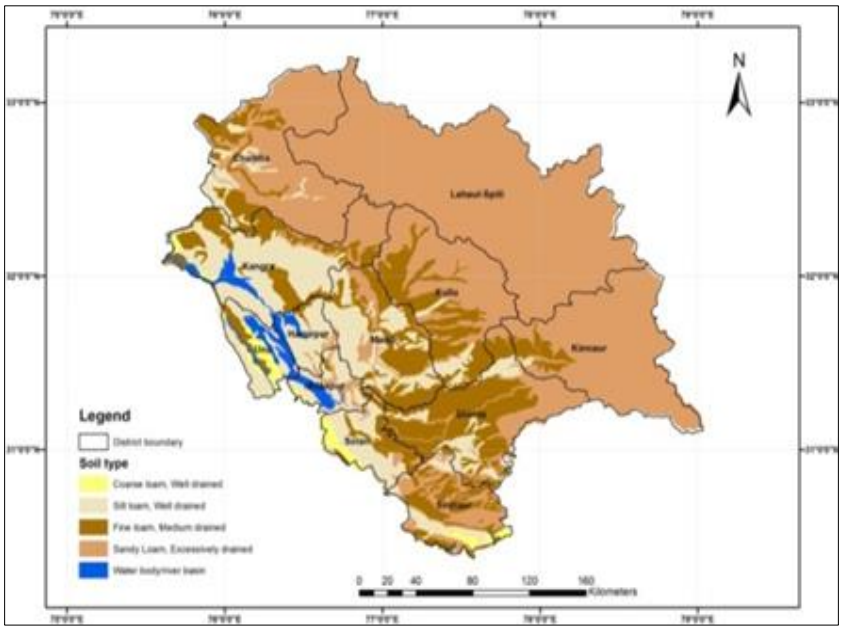

Fig 11: Thematic layer of soil classes in Himachal Pradesh

3.5 Suitability analysis for temperate fruit crops (apple)
The suitability analysis classified the suitable areas for apple as follows:

3.5.1 Highly suitable and Moderately suitable zones (S1 and S2): there was a high correspondence between climatic conditions of the area and the climatic requirements of apple such as temperature, chilling hours, physiographic (elevation) and soil characteristics in these regions. The suitability analysis revealed that the classes of S1and S2 were predominant only in the higher reaches such as Manali, Bhang, Naggar and Raisan in Kullu district; Kotgarh, Jubbal, Kumarsain, Chopal and Rohru of Shimla district and Kinnaur district covering Sangla, Kalpa, Sharbo and Pooh. Some areas of Lahaul and Spiti comprising of Tabo and Kaza were also found under the category of highly suitable areas for apple (Fig 12). The highly suitable apple production areas observed in higher hills and dry temperate zones of Kinnaur and Spiti areas could be attributed to the rising temperature in the upper reaches of Kinnaur (Fig 13) and Lahaul Spiti district and the attainment of production stage in early planted orchards. Similar changes have also been noticed by Bhardwaj and Sharma (2013) [16]; Verma *et al* (2006) [25] and Meena and Kumar (2008) [20] while assessing the impact of climate change on horticultural crop production in Himachal Pradesh.

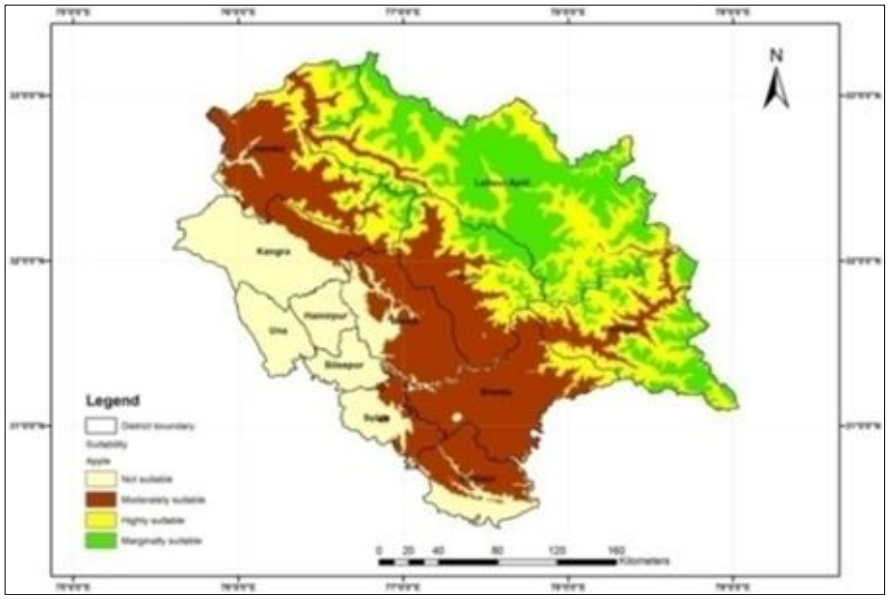

Fig 12: Suitability map for temperate fruit crop (apple) in Himachal Pradesh

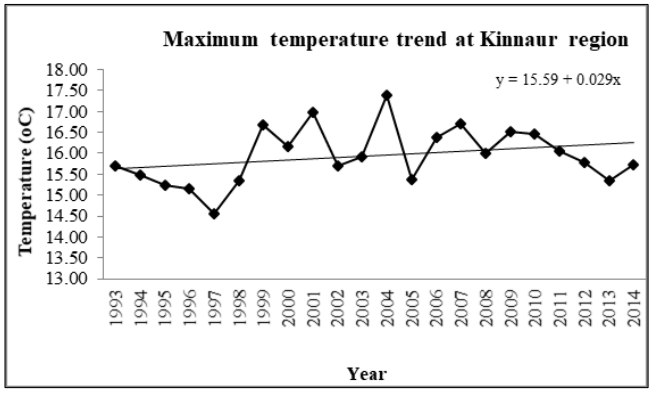

Fig 13: Maximum temperature trend at Kinnaur region (1985-2015)

3.5.2 Marginally suitable zones (S3): the analysis of suitability map (Fig 12) revealed that there was a weaker correspondence between climatic conditions and requirements of apple in these areas compared to the first zone. The areas comprising of Bajaura and Bhuntar in Kullu; Karsog, Nagwain and Jhanjheli in Mandi; Theog in lower parts of Shimla were found to be marginally suitable for apple cultivation. The perusal of Fig 12 further revealed that few pockets namely, Salooni and Bharmaur in Chamba; Bara Bhangal area in Kangra district were also found to be marginally suitable. The lower elevation areas in Kullu district such as Bajaura and Bhuntar once considered as highly suitable for apple cultivation have shifted to the moderately suitable zone. The changing temperature regime (Fig 14), over the years decline in the cumulative chill hours (Fig 7) along with the prolonged hot and dry spells during summers have aggravated the shifting of cultivation areas from previously highly suitable to marginally suitable. The results are in corroboration with the findings of Aditya *et al* (2012) [1] and Jangra and Sharma (2013) [16] who have also advocated the delineation of these areas to be marginally suitable for apple cultivation because of the rise in average temperature, long spells of drought during summer and less snowfall during winter.

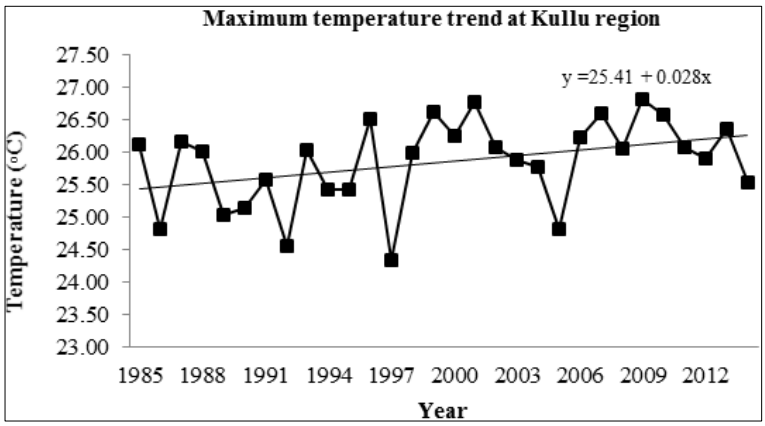

Fig 14: Maximum temperature trend at Kullu region (1985-2015)

3.5.3 Unsuitable zones (N): a perusal of Fig 12 indicated that the areas including Bilsapur, Una, Hamirpur, majority of Kangra, and some parts of Solan and Sirmaur district were not suitable for apple cultivation. The unsuitability for apple cultivation in these regions could be ascribed to high average temperature (Fig 15) beyond optimum requirement for apple, low rainfall (Fig 5) leading to non-fulfillment of chill units for major apple varieties such as Royal delicious, Vance delicious and Gale gala. The results are in line with the results of Basannagari and Kala (2013) [6] who concluded higher temperature and deficiency of chilling hours in low altitudinal gradients of Himachal Pradesh as a reason for delay in bloom period of apple rendering these areas unfit for cultivation.

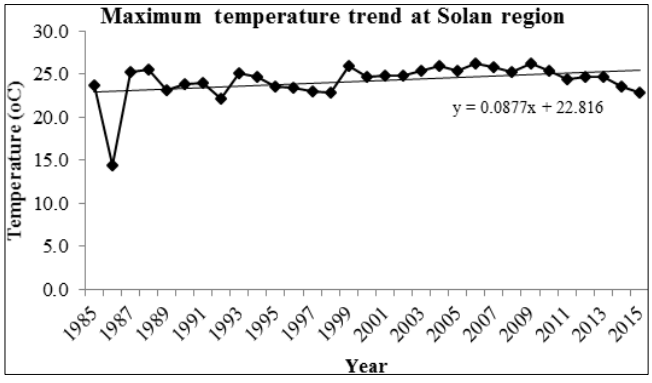

Fig 15: Maximum temperature trend at Solan region (1985-2015)

3.6 Suitability analysis for Sub temperate fruits (peach, plum and apricot): the suitability analysis classified the suitable areas for sub temperate fruit crops as follows:

3.6.1 Highly suitable and Moderately suitable zones (S1 and S2): the analysis of suitability map (Fig 16) for sub temperate fruit crops indicated highly suitable and moderately suitable zones representing Kandaghat, Kunihar and Dharampur and Nalagarh in Solan; Rohru in Shimla, and Rajgarh of Sirmaur district which were highly suitable for these fruit crops because these regions were best suited for optimum temperature required (25-30 ºC) (Fig 15) and the required optimum chill units (300-900 mm) which was in the optimal range of these regions. The Spiti of Lahaul Spiti district and Pooh, Namgia and Chango areas of Kinnaur district were also observed to be highly suitable for the cultivation of stone fruits especially, sweet kernelled apricot varieties such as Suffaida, Shakarpara and Kaisha which thrive better in dry temperate region up to 3000 m above mean sea level (Anon, 2005) [3].

3.6.2 Marginally suitable zones (S3): the perusal of Fig 16 illustrated that the low chill varieties suitable for mid hills such as Snow Queen, July Elberta (peach and nectarine); New castle and Early Shipley (apricot); Mareposa and Santa Rosa (plum) were found to be suitable for cultivation in these areas. These included areas of district Kangra, Kullu, Mandi (Karsog and Seraj), Shimla, Chamba and Kinnaur. The

average temperature (Fig 13) in these regions was found in the optimum range for the fulfillment of chill accumulation for stone fruits. The lower regions of Kullu and Mandi district which were earlier under the apple cultivation have now shifted to the stone fruit cultivation. The results are in conformity with the findings of Joshi and Joshi (2011) [18] suggesting that in mid hill zone apple growing belt has been replaced with stone fruits because of less precipitation and increasing temperature rendering noncommercial production of apple.

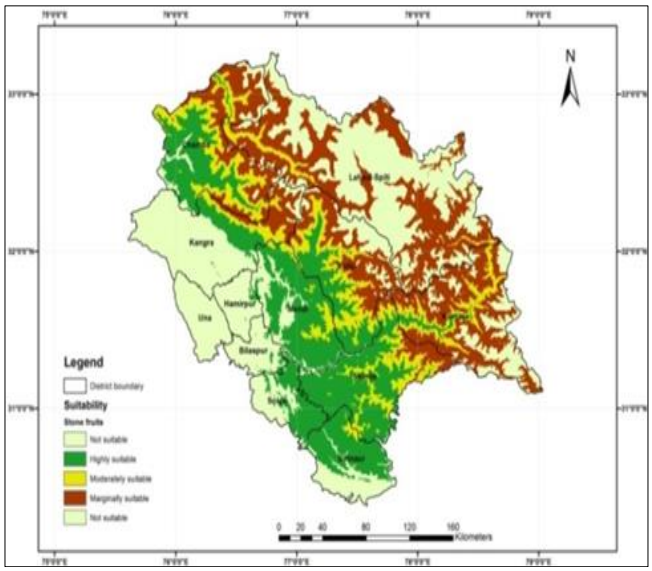

Fig 16: Suitability map for sub temperate fruit crop (stone fruits) in Himachal Pradesh

3.6.3 Unsuitable zones (N): the assessment of Fig 16 indicated that this zone included higher reaches of Lahaul and Spiti district. The unsuitability for Snow Queen, July Elberta and New castle in these areas can be attributed to the presence of skeletal soils, chilling injury and low average temperature (below 4ºC) causing spring frosts for most of the varieties. More and Bhargava (2010) [21] in their studies on sub temperate fruit crops also suggested that low temperature and frost conditions during fruit maturity period cause sub lethal injury or shriveling of fruits. The lower belts of Kangra, Una, Hamirpur and Bilaspur district were also found unsuitable for the cultivation of these varieties. The high average temperature prevailing in these areas resulted in meager fulfillment of chilling hours causing delayed foliation, reduced fruit set and fruit quality. However, low chill varieties such as Pratap, Florida Prince and Early Grande for peach (Table 3) were suitable for the frost prone low hill areas of Himachal Pradesh. The findings are in line with the conclusions of Allan (2004) [4] suggesting high temperature as a reason for non fulfillment of chill units leading to staggered growth and poor quality of fruits.

Table 3: Chilling requirements of different temperate fruit crops

Name of variety/fruit crop	Chill units
Snow Queen Nectarine	650
Santa Rosa Plum	150
Florida Prince Peach	300
New Castle Apricot	300
Starking Delicious Apple	1320
Golden Delicious Apple	1277

3.7 Overlay of present land use/cover and the suitability map

The information concerning the spatial distribution of different suitability levels allowed the fine tuning of results, because the resultant layer provided the information about the areal extent and predicted the potential distribution of various fruit crops across the different land suitability zones. The total area under the temperate fruit (apple) cultivation in Himachal Pradesh is 107686 ha and under sub temperate (peach, plum and apricot) was 17288 ha. The suitable area under the high, moderate and non-suitability was computed to be 26.89, 19.89 and 24.76 per cent respectively. Under the major apple growing pockets in Shimla, Kullu Kinnaur and Chamba district the corresponding cultivated area was 37542, 25624, 10487 and 12997 ha respectively (Anon, 2013) [4]. Presently, out of the total area for apple crop in Himachal Pradesh, 26.89 per cent was highly suitable and 19.89 per cent represented moderately suitable. However, 24.76 per cent area has now become non suitable for apple cultivation. Out of the total area for sub temperate fruit crops, 55.18 per cent was regarded as highly suitable, 34.58 per cent has been converted into marginally suitable, 46.86 per cent as moderately suitable and 42.24 per cent has become non suitable for stone fruits. The present area under stone fruits cultivation in Solan, Sirmaur and Kangra district was calculated to be 37.43, 26.56 and 14.65 per cent respectively. The percentage of suitable area under each fruit crop indicated that the cultivable land for these potential fruit crops could be further increased after the assessment of suitable areas in the present study.

4. Conclusion

Climate suitability analysis is a prerequisite for sustainable horticultural production system and it plays a fundamental role in the niche based horticultural planning in mountainous state. The study has delineated the potential suitable areas for fruit production in Himachal Pradesh. The highly suitable areas for apple production included higher elevation parts of Kullu, Mandi, Shimla and some pockets of Chamba and Kangra district. The higher altitudes of the state such as Kinnaur and Lahaul Spiti demonstrated the availability of zones presently marginally and moderately to become highly suitable for apple fruit cultivation in future. It can be inferred from the above results that the present fruit growing belts specifically low altitudinal gradients of Kullu and Shimla region have become unsuitable for growing apple due to lack of chill accumulation. The prevailing thermal conditions, distribution of precipitation and soil characteristics of these regions were however in good coordination with the requirements of sub temperate fruits. This entails that there is a possibility of harnessing climatically suitable areas with introduction of new crops and varieties to utilize the changed situation effectively in terms of productivity.

5. Further applications

This article has focused on the use of climate mapping as an input to agricultural land-use decisions. However, the resulting maps and GIS surfaces can be used for purposes such as merging short-term and long-term data to estimate climate percentiles useful in identifying potential effects of climate change and for exploring adaptation options.

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