

**GEOGRAPHICAL INFORMATION SYSTEM BASED
ASSESSMENT OF LOCATION SUITABILITY FOR APPLE
(*Malus × domestica* Borkh.) PRODUCTION**

Thesis

by

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(H-2011-17-D)**

submitted to



**Dr. YASHWANT SINGH PARMAR UNIVERSITY
OF HORTICULTURE AND FORESTRY,
NAUNI, SOLAN - 173 230 HP, INDIA**

in

partial fulfilment of the requirements for the degree

of

**DOCTOR OF PHILOSOPHY
FRUIT SCIENCE**

**DEPARTMENT OF FRUIT SCIENCE
COLLEGE OF HORTICULTURE
2016**

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CERTIFICATE-I

This is to certify that the thesis entitled “**Geographical Information System based assessment of location suitability for apple (*Malus×domestica* Borkh.) production**” submitted in partial fulfillment of the requirements for the award of degree of **Doctor of Philosophy Fruit Science** in the discipline of **Horticultural Sciences** to Dr. Yashwant Singh Parmar University of Horticulture & Forestry, Nauni, Solan (HP) - 173 230 is a bonafide research work carried out by **Mr Chaitanya R Belsare** son of Shri Ramdas Kisanrao Belsare under my supervision and that no part of the thesis has been submitted for any other degree or diploma.

The assistance and help received during the course of this investigation have been fully acknowledged.

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CERTIFICATE-II

This is to certify that the thesis titled, “**Geographical Information System based assessment of location suitability for apple (*Malus × domestica* Borkh.) production.**”, submitted by **Mr Chaitanya Ramdas Belsare (H-2011-17-D)** son of Shri Ramdas Belsare to Dr Yashwant Singh Parmar University of Horticulture & Forestry, (Nauni), Solan, H P - 173230 India in partial fulfilment of the requirements for the degree of **DOCTOR OF PHILOSOPHY FRUIT SCIENCE** has been approved by the student’s Advisory Committee after an oral examination of the student in collaboration with the external examiner.

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This is to certify that all the mistakes and errors pointed out by the external examiner have been incorporated in the thesis entitled, “**Geographical Information System based assessment of location suitability for apple (*Malus × domestica* Borkh.) production**”, submitted to Dr Yashwant Singh Parmar University of Horticulture & Forestry, Nauni, Solan (HP) by **Mr Chaitanya R Belsare (H-2011-17-D)**, in partial fulfillment of the requirements for the award of degree of **DOCTOR OF PHILOSOPHY FRUIT SCIENCE**.

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Needless to say, errors and omissions are mine.

Place: Nauni, Solan

Date: January 5, 2016

(Chaitanya R. Belsare)

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ABBREVIATIONS

Cm	Centimetre
mm	Millimetre
m amsl	Meter Above Mean Sea Level
g	Gram
RBD	Randomized Block Design
TSS	Total Soluble Solids
UV	Index Ultra Violet Index
ECU	Effective Chilling Units
GDH	Growing Degree Hours
DEM	Digital Elevation Model

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Introduction



Chapter-1

INTRODUCTION

Apple (*Malus × domestica* Borkh.) is one of the premier fruit crop of temperate zone of the world and occupies an area of 47,11,533 hectares with the production of 70,29,212 metric tonnes. In India, apple is cultivated in an area of approximately 3,13,000 ha with total production of about 24,97,700 metric tonnes (FAO, 2014). However, the commercial production of apple in India is confined mainly to the states of Jammu and Kashmir, Himachal Pradesh and Uttarakhand in North-Western Himalayan region. Himachal Pradesh has already carved a niche as a horticulture state. The state has been recognized as an “Apple state of India” for being the first to introduce ‘Delicious’ apples and for producing good quality fruits. The state having 55673 Km² area, is divided into twelve districts. Sutlej, Ravi, Chenab and Beas are the main rivers passing from the state. The state is having hilly terrain in which Shivalik hills occupy most of the area in the state with dense forests. The climate in the state varies from hot and sub-humid in lower regions, where the elevation is only 450 to 600 m to bitter cold of the alpine and glacial region in the northern parts, where elevation is from 4800 m upwards. Lahaul-spiti and Kinnaur regions of the state bordering Tibet have dry temperate or cold dessert climate, reflecting the arid nature of the region and extreme cold conditions of the area.

Apple was introduced into the country by the Britishers in the Kullu valley of the state in 1865, while the coloured ‘Delicious’ cultivars of apple were introduced to Shimla hills in 1917. There has been 5-6 fold increase in area under apple cultivation during the last 50 years from 3026 ha in 1960-61 to 109553 ha in 2014-15. Likewise, apple production has increased from 2497.70 MT in 1960-61 to 625199 MT in 2014-15 (Anonymous 2014). Although there are 226 varieties of apple in Himachal, ‘Delicious’ group constitutes the major share of about 83 per cent. Apple is the predominant fruit crop among the various temperate and subtropical fruits grown accounting for about 48 per cent of total area in the state (Anonymous, 2014). Presently, apple cultivation is spread over

nine out of the total twelve districts of the state, indicating that apple cultivation is not only the most suitable farming system for the fragile mountain ecosystem of the state but it is most remunerative avocation for economic upliftment of small and marginal farmers. Shimla district accounts for about 33.68 per cent of total area followed by Kullu and Mandi which accounts for 23.81 and 16.90 per cent area under apple, respectively. Among all apple producing districts, Shimla ranks first with 67.6 per cent production followed by Kullu 20.6 per cent (Anonymous, 2014).

Although, the absolute figures of area and production of apple in the state look impressive but lag far behind in comparison to other apple growing countries of the world in terms of its productivity and fruit quality. The average productivity of apple in Himachal Pradesh is 5.7MT/ha, which is lower than the national productivity of 10.0MT/ha and much lower than that of Jammu and Kashmir of 13.1MT/ha (NHB 2010) and far below than the international standard of 14.9MT/ha. The general decline in productivity of apple has become a matter of serious concern to all and calls for immediate and concerted efforts on the part of producers and researchers to fill up the gap between area and production.

Present day's global warming and climate change has become the matter of international concern. World over, the impact of global warming on glaciers, human health, sea level, global precipitation system, climate etc is hotly debated. Some view global warming and climate change as a natural process and others perceive it is due to the human interference in the natural environment. Whatever may be the reason behind this phenomenon, the impacts on global warming on the apple orchards of Himachal Pradesh is already visible. Due to increasing temperature, apple has frequently failed to meet chilling requirements in the lower areas of Himachal Pradesh, due to which its cultivation is shifting towards higher reaches of the mountains (Sharma, 2013). In lower regions, climate change has adversely affected flowering, fruit set, fruit quality and yield of apple (RandeV, 2009). Kullu valley of the state at one time was known for best quality apple in the country but now apple have become uneconomical, non-viable, less profitable and even unproductive in such a short period. Therefore, it is a matter

of great concern that apple orchards which at one time were very promising and productive have deteriorated both in productivity and quality of the produce. While, the cold desert of Lahaul and Spiti district once considered unsuitable for apple cultivation due to extreme cold conditions is currently witnessing increase plantation of apple sapling each year due to warming of climate in the region.

According to recent report (Asian Development Bank, 2010) on climate change adaptation in Himachal Pradesh, the apple belt is shifting upwards due to climbing regional temperatures, making the lower parts of the valley unsuitable and the upper valley hospitable for the apple crop. This brought a short period of economic decline in the lower valleys, but with government support, the farmers were able to diversify and regenerate their farm economics by introducing new crops and varieties into the area. A study carried out by the scientists of Himachal Pradesh Agriculture University gave some indications of higher than average impacts of climate change in Himachal Pradesh uplands than on the lowlands. From the studies covering over 30 years record, average air temperatures were found to be 0.7 to 2.4°C higher than that in the 1980s, as against the global average of 0.5°C; the Himachal Pradesh trend indicates an increase of 0.06°C per year. An analysis of rainfall data over the period from 1976 to 2006 shows increasing trends of rainfall in Lahaul-Spiti, Chamba and Kangra districts but decreasing trends in Shimla and Kinnaur. Study reveals that Himalayas are warming 5-6 times more than the global average. Temperature increases are more during winter and autumns than during summers, and clearly increases with altitudinal rise. It is predicted that due to changing climatic conditions, apple productivity is going to be adversely affected during the seasons encountering bad weather conditions as the majority of the area under apple is occupied by the climate sensitive 'Delicious' group (Jindal *et al.*, 2001).

The future prospects of apple cultivation in favourable agro ecological zones of the state are bright and promising in the light of introduction of advance technologies. Among the techniques and tools capable of assisting in resources identification, mapping and utilization of Geographical Information System (GIS) has the great potential in the present climatic scenario. In understanding the

regional impacts of climate change on apple, a technological approach incorporating GIS as the cornerstone of the research is required. Integration of GIS for land suitability analysis could be a useful methodology for future research on apple in the state. Location suitability analysis is a pre-requisite for sustainable crop production. Crops grow best in locations where the climatic conditions meet their growth requirements. Elevation, slope, soil and many climatic factors that affect crop growth, help in determining the most suitable crop growth areas. The process of land suitability classification is the evaluation and grouping of specific areas of land in terms of their suitability for a defined use (Bhagat *et al.*, 2009). The main objective of the land evaluation is the prediction of inherent capacity of a land unit to support a specific land use for a long period of time without deterioration, in order to minimize the socio-economic and environmental costs. There are various ways to estimate the extent of land with cultivation potential. Any quantification would depend upon a variety of assumptions. Science location suitability analysis requires the use of different kind of data and information (soil, climate, topography etc.) while, the geographical information system (GIS) offers a flexible and powerful tool than conventional data processing systems, as it provide a means of taking large volumes of different kinds of datasets and manipulating and combining the datasets in to new datasets which can be displayed in the form of thematic maps (Foote and Lynch, 1996). The topographic characteristics, the climatic conditions and the soil quality of an area are the most important determinant parameters of the location suitability evaluations. Use of GIS allows the construction of models from which a new thematic map (e.g. location suitability map) can be produced from a set of thematic maps (Harashes, 1994).

Considering the above aspects, the present investigation on GIS based location suitability assessment for apple was undertaken to delineate suitable production areas in the state with the following objectives:

1. To analyze the effects of environmental factors on production and quality of apple cv. Starking Delicious.
2. Mapping of suitable locations for apple cultivation.

Review of
Literature



Chapter-2

REVIEW OF LITERATURE

Apple is the most important fruit crop of Himachal Pradesh which can be grown at altitudes between 1500- 2700 m a.m.s.l., which experiences 1000-1500 hours of chilling. In this region, apple grows well when the temperature during the growing season is around 21-24° C and annual rainfall is between 100-125 cm, evenly distributed during the growing season. Out of six major apple producing districts, Shimla and Kinnaur are known for quality apple production, accounting for about 75 percent of total state's production (Anonymous, 2014). However, there has been a phenomenal increase in temperature during last 3-4 decades (Shrestha *et al.* 1999; Liu and Chen, 2000), which has affected temperate fruits' production. Climate change has affected the apple crop grown in the sub-temperate region and the effect has been noticed in more than one ways such as lack chill hours, early and erratic flowering, poor fruit set, deterioration in fruit size, shape and fruit quality, poor fruit colouration, decreased yield etc. (Sharma, 2015). Geographical information system (GIS) can be employed as technical tool along with ground truthing to examine suitable area for successful apple cultivation in the changing climatic scenario. However, information based on systematic studies how global warming has impacted apple production in the state is lacking. The available literature relevant to various aspects of the present studies on the geographical information system based assessment of location suitability for apple has been reviewed below under suitable headings.

2.1 Effect of environmental conditions on chilling units and growing degree days

The chilling requirement of a fruit is the minimum period of cold weather after which a fruit-bearing tree will blossom. It is often expressed in chill hours, which can be calculated in different ways, all of which essentially involve adding up the total amount of time in a winter spent at certain temperatures. Chilling unit in fruit crops is a metric of a plant's exposure to

chilling temperatures. Chilling temperatures extend from freezing point to 7 °C (45 °F) or even 16 °C (60 °F), depending on the model. Lack of such exposure results in delayed and substandard foliation, flowering and fruiting. One chilling unit, in the simplest models, is equal to one hour's exposure to the chilling temperature; these units are summed up for a whole season. The simplest model assigns one chilling unit for every full hour at temperatures below 7 °C (45 °F). A slightly more sophisticated model excludes freezing temperatures, which do not contribute to proper dormancy cycle, and counts only hours with temperatures between 0 °C (32 °F) and 7 °C (45 °F). The Utah model assigns different weight to different temperature bands; a full unit per hour is assigned only to temperatures between 3 °C (37 °F) and 9 °C (48 °F), wherein the maximum effect is achieved at 7 °C (45 °F). Temperatures between 13 °C (55 °F) and 16 °C (60 °F) (the threshold between chilling and warm weather) have zero weight, and higher temperature have negative weights: they reduce the beneficial effects of an already accumulated chilling hours.

The estimated chilling units and growing degree hours estimated by Utah model for the Delicious apple were 1208 and 8893 °C, respectively at Mashobra with an elevation of 2286m and 1130 chilling units and 9370 °C GDH at mid-hill conditions of Solan (Mankotia, 1987; Mankotia *et al.*, 2004). Sharma (2004) observed chilling requirement of 1204 chill units and GDH requirement of 11637.75°C for apple cultivar Starking Delicious at high elevation (Archandi) and 1208 chill units and 10930.34° C GDH for low elevation (Nagwain). Insufficient winter chilling in apple (>5°C day temperature) resulted into uneven fruit maturity and reduced yield in Okanagan valley in British Columbia (Caprio and Quamme, 1999). Jindal *et al.* (2000) noted that winter temperature and early precipitation in the form of snow in November, December and January were very crucial for induction of dormancy, bud break and flowering in apples at Mashobra. Tersoglio *et al.* (2006) observed that the vegetative bud break percentage increased in cherry trees whenever growing degree days (GDH) or chill units more. Alonso *et al.* (2005) found that most almond cultivars required about 400 and 600 chilling units, whereas the span of heat requirements was wider from 5500 to 9300 growing degree days to determine the blooming date.

At ideal apple growing conditions with an altitude of 2286m in Shimla, the days required for bud break were reduced with an increase in chilling exposure (Jindal and Mankotia, 2004). Mohamed and Omran (2004) observed that grapevines cultivars Perlett, Superior and Flame Seedless required 72, 167 and 63 chill units and 173, 291 and 161 chill units according to total hours, respectively to achieve 50% bud break, whereas, 39122, 37394 and 43 336 heat units, respectively were required for these cultivars for fruit ripening and recommended that these cultivars can be planted successfully under Assiut (Itlay) climatic conditions.

El Sese and Mohamed (2003) observed that the average accumulated chill units for grape cultivar Red Roomy were 147 and 360 over the two seasons, which were sufficient for over 50 per cent bud break. Mimoun and DeJong (1999) found a strong correlation between the accumulation of the growing degree hours during thirty days after bloom and harvest date.

For satisfactory growth and development, chilling time between 750-1400 hours and heat requirements between 8852-15420 growing degree hours (GDH) were required in different pistachio cultivars (Rahemi and Pakkish, 2009). Ruiz *et al.* (2007) examined a range of chilling requirements of different apricot cultivars and noted that chilling requirements between 800 to 1200 chilling units were most appropriate. However, the heat requirements for flowering ranged between 4078 and 5879 growing degree hours (GDH) and results indicated a high positive correlation between chilling requirements and flowering date. Singh and Bhatia, (2011) carried out an experiment at horticulture research station, Seobag (Kullu) and found that on an average apple required 330 GDD from bud bust to petal fall with 4 degree C as base temperature. However, in seven-year-old apple cultivars Anna and Dorsett Golden, more accumulated heat units (G.D.H) were required to reach full bloom and fruit set (Agamy *et al.*, 2000).

Reginato *et al.* (2010) in an investigation on grapevine development to characterize dormancy breaking based on growing degree hours (GDH) and degree days (DD) and found that heat requirement from rest completion up to full bloom were 9451 GDH, 252 DD and 145 days and 16,101 GDH, 713 DD or 77

days were required from 4 mm berry up to harvest. In *Vitis vinifera*, accumulation of 1250 chilling units were required for bud break (Andreini *et al.*, 2010). Bloom and fruit maturity data analysis for the 'Improved French' prune cultivar for several years from two locations in California revealed clear relationship between the length of the fruit growth period and accumulation of growing degree hours 30 days after full bloom (DeBuse *et al.*, 2010). Lopez and Dejong (2008) studied the number of days between full bloom date (FBD) and harvest date in peach previously related to accumulated growing degree hours during the first 30 days after full bloom (GDH) and found that fruit development rate was substantially increased in years when GDH 30 accumulation values were higher than 6000 compared to when GDH 30 was less than 6000. A study was conducted in Czech Republic to find a suitable base temperature for different phenological stages (bud break, flowering, fruit set, fruit ripening) in jujube and on the basis of active hourly temperatures (7, 9 and 11 °C), the statistically analyzed average one day differences during 2006 and 2007 were computed from the previous 10 days to determine the differences between the suitable and recorded dates of the start of each phenological phase in days. In most cases, the suitable base temperature for jujube was 11 degree C (Mishra and Krska, 2009).

Pawasut *et al.* (2004) found that chilling units were positively correlated with the mean flowering dates at 20 per cent and 80 per cent full bloom. Further, these results suggested that chilling units for breaking dormancy responded to prolonged chilling units up to 350 and GDH degrees C determined the flowering periods of ornamental peaches. Stenzel *et al.* (2006) studied the effect of thermal summation on the fruit quality of orange and observed an increase in fruit TSS content in relation to GDD accumulation. Luedeling *et al.* 2009 carried out an experiment at six sites in California's central valley, in which chilling models predicted substantial decreases in winter chill at all sites, mean chilling was predicted to decrease by 33 % (Chilling Hours), 26% (Utah Model) and 14 % (Positive Utah Model). In mild-winter regions, insufficient chilling prolonged dormancy and caused abnormal patterns in bud break and development and thereby resulted in a lower commercial production in grapes (Nir and Lavee, 1993; Mohamed 2008).

In Western Cape of South Africa, significant warming trends were found for mid to late-summer and winter end to spring for daily minimum temperature and for mid-summer, autumn and spring for daily maximum temperature, thereby chill unit accumulation decreased significantly, particularly in autumn, affecting chilling accumulation and dormancy in apple (Midgley and Lotze, 2011). In *Prunus avium*, exposure to increasing levels of chill units resulted in an increased number of flowers per tree, enhancement in the remaining flowers ability to fruit set, larger fruit size and higher yield (Mahmood *et al.*, 1999). Grebeye and Berg (2000) observed that the fruit size of *Malus × domestica* cv. Royal Gala decreased with limited winter chilling in South Africa.

In aonla, heat unit summation in terms of growing degree-days (GDD) was calculated based on data collected from peak of fruit set to the time of maturity (Shukla *et al.*, 2007). Further, the peak fruit set was noted during the last week of April and the time of maturity varied from the last week of November to the first week of December. The mean GDD ranged from 5136.52 in cultivar NA7 to 535.82 in cultivar NA10. In grapevine, relative low chilling requirement of buds to overcome winter dormancy (50-400 hours at < 7 degree C) caused irregular bud break when it did not satisfy its chilling requirement and caused poor uniformity of fruit development, while bud break usually improved with increased exposure to chilling requirement of 1250 chilling units (Andreini *et al.*, 2010). Padilla *et al.* (2012) carried out an investigation to study the phenological development of guava trees and their relationships with ambient temperature at three locations of Mexico having different climatic conditions and observed that annual mean temperature fluctuated from 25 to 18 degrees C at the hottest and coolest sites, respectively, phenological development of guava trees was greatly influenced by temperature conditions (elevation) at each location. They further observed that guava trees required about 800 to 850 and 1950 to 2000 heat units for stages from pruning to flowering and flowering to beginning of harvest, respectively, wherein the heat units were calculated using the residual method with a threshold temperature of 9.0 degrees C. In strawberry cultivars Korona, Elsanta and Clery, the GDD values (growing degree days 3 °C base temperature)

were found independent from latitude and calculated as 334-355 for Elsanta, 301-385 for Korona and 320-434 for Clery (Kruger *et al.*, 2012).

Razavi *et al.* (2011) carried out a study on chilling and heat requirements using the Utah chill unit model for breaking dormancy and flowering in five peach and four apricot cultivars and observed that peach and apricot cultivars chilling requirements ranged between 746 to 868 and 652-826 chill units, respectively and heat requirements ranged between 4099 to 4543 GDH and 2987 to 3465 GDH, respectively. Apricot cultivars with low chilling and heat requirements showed earlier flowering dates and bloomed 15- 16 days before peach cultivars. However, heat requirements were found to be more important for regulation of flowering time than were chilling requirement.

The study on evaluation of basal temperature, thermal sum at different phenological stages, phenological phase duration, yield and seasonality of one nectarine and 14 peach cultivars revealed that the minimum basal temperatures required from pruning to sprouting, was 8 degrees C, sprouting to flowering 10 degrees C, flowering to fruiting 12 degree C and 14 degrees C ripening irrespective of the cultivars; whereas, the maximum basal temperatures were 30, 34 and 28 degrees C, respectively for Turmalina, Marli and Tropic Beauty peach cultivars (Souza *et al.*, 2011). The cultivars differed for their total cycle and for the accumulated thermal sums which varied respectively, from 245 days and 1881.4 degree days to 144 days and 1455.7 degree days. In another study on suitable base temperature for different phenological stages (bud break, flowering, fruit set, fruit ripening) in *Ziziphus jujuba* in Czech Republic, one day difference during 2006 and 2007 were computed on the basis of active hourly temperatures (7, 9 and 11°C) from the previous 10 days to determine the differences between the suitable and recorded dates of the start of each phonological phase in days (Mishra and Krska, 2009). In most cases, the suitable base temperature for Jujube was 11 degrees C.

Urhausen *et al.* (2011) investigated relationship between climate variability and variations in phenological events in viticulture and found that for the budburst event; the significant predictors are the accumulated degree days in

March, the mean daily maximum temperature in April and the accumulated frost days from January to March. They further found that the flowering event is best predicted by the accumulated degree days in May and April and the mean daily maximum temperature in June and the date of the budburst event. In ‘Thompson Seedless’ grapevine, the Utah model was least variable model for rest estimation, with 430 chilling units up to dormancy break occurred between June 6 and June 17 for the years between 2000 and 2003 (Reginato *et al.*,2010). They further indicated that heat requirement from rest completion up to full bloom were 9451 GDH, 252 DD or 145 days, and from 4 mm berry up to harvest 16101 GDH, 713 DD or 77 days.

Mounzer *et al.* (2008) described the heat requirement of peach for each stage as growing degree hours (GDH) and growing degree days (GDD) and further reported that post dormancy breaking 225 chilling units and 6244 GDH were required to reach full bloom and 27106 GDH before the fruit could be harvested. In case of GDD, the heat requirements were 329 and 1246 for full bloom and fruit harvest, respectively. Kuden *et al.* (2012) investigated the chilling requirements of two different cherry cultivars Pozanti and Adana growing at 1100 and 50 m elevations, and found that calculating the hours below 45 degrees F, Pozant (1100 m elevation) gave 3 or 4 times higher chilling accumulation comparing to subtropical conditions of Adana (50 m elevation). In an experiment on the growing degree days (GDD) with base temperature of 4.4 degrees C of *Prunus persica* var. Nectarine the difference between the earliest and latest cultivars for full bloom dates was only 4 days or 26.7 degrees C GDD, while the range for harvest dates was 68 days or 1097.1 degrees C GDD (Fallahi *et al.*, 2009).

2.2 Effect of environmental conditions on flowering phenology

Flowering has been closely correlated with a warming trend in mean air temperature through March and April (Fujisawa and Kobayashi, 2010). Yoshiro and Park, (1996) analyzed flowering dates of cherry blossoms in relation to air temperature in March or as a function of latitude, longitude, coldness/warmth indices and found that mean flowering dates for cherry were 3 to 4 days earlier

when the mean air temperature in march increased by 1 degree C. An analysis of the historical meteorological data for UK confirmed that a trend towards warmer winter changed the flowering trails of berry fruit crops, which adversely affected by a succession of mild winters, leading to insufficient winter chill and poor bud development (Jones and Brennam, 2009).

Cosmulescu *et al.* (2010) studied phonological changes in plum tree species *Prunus domestica* L. and noted that flowering time duration is influenced by climatic factors and local ecological conditions. Atkins and Morgon, (1990) found that an increase in 1.5 degree C temperature delayed full bloom of apple and pear and lead to inferior flower quality. Legave *et al.* (2009) studied flowering dates for apple cv. Golden Delicious to understand the impacts of global warming on flowering time and found significant advancement in flowering time in the current warm climatic conditions.

Wolfe *et al.* (2005) examined mid bloom dates for apple and grape for mid and high altitude regions and indicated advanced spring development with slopes for mid bloom dates verses year of -0.20 day/year and -0.146, respectively. In apple and pear, the advancement of mean flowering dates could be the result of more pronounced increases of temperatures from January to April (Atauri *et al.*, 2010). Stanica *et al.* (2008) monitored the flowering period in grapes in order to investigate air and soil temperature influence on timing of the main spring phenophases and found significant correlation of flowering time with air and soil temperature.

Romanouskaja and Baksiene (2009) observed that the time of the beginning of apple tree flowering was strongly influenced by the annual changes in thermal regime of April. Mariko and Karuhiko (2010) noted that flowering in peach was closely correlated with a warming trend in mean air temperature throughout March and April. In Africa, significant correlations were observed in respect of mean full bloom dates in apple with temperature and rainfall (Grab and Craparo, 2011). Study carried out at five geographically distinct locations to predict the effects of chilling, diurnal temperature difference and their interaction with day length on flowering time of strawberry revealed that flowering time was

influenced by accumulated chilling hours with effective temperatures ranging from -2 to 15 degrees C (Tanino and Wang, 2008). Snsteby and Heide (2008) studied the effect of night temperature on different strawberry cultivars and observed that the flowering response of cultivars 'Florence' and 'Korona' increased significantly with increasing night temperature from 9 to 18 degree C, while an optimum temperature of 15 degree C was noticed in the cultivar 'Frida' under cool environmental conditions in Norway.

Kadir *et al.*, (2006) studied the flowering behaviour of strawberry following the exposure to different temperature regimes and found that quadratic relationship between flower development and duration of exposure to 30/25 degree C was detrimental to flower development. A high day/night temperature of 30/25 degrees C reduced the number of inflorescences and flowers in strawberry cvs. 'Nyoho' and 'Toyonoka' compared with plants grown at 23/18 degree C, hence high temperature stress negatively affected the reproductive process in strawberry (Ledesma *et al.*, 2008). An experiment on the effects of temperature prior to flowering stage on flowering behavior in strawberries revealed that temperature fluctuation affect the flower quality as well as fruit set (Nekoonam *et al.*, 2012). The mean daily temperature of 22.5 to 29 degree C and day length (sunrise to sunset) of 12.2 to 13.1 hours were most useful for flowering of June bearing strawberries (Yoshida *et al.*, 2012). In apricot, low chilling early flowering cultivars were prone to spring frost damage and their flower quality was also affected due to temperature fluctuation during early spring (Nekoonam *et al.*, 2012). Romanovskaja and Baksiene (2011) observed that the climate change influenced the beginning of apple tree flowering in Lithuania and spring plant phenological phases can be used for the prediction of apple tree flowering. They further observed that air temperature regime of early spring predetermined the beginning of the apple tree flowering, depending on the weather changes during this month.

Sahli *et al.* (2012) in an experiment on the comparison of the flowering dates between years due to high year to year variability of climate conditions, the chilling requirements for breaking dormancy and threshold temperature and heat

requirements for flowering of ‘Chemlali’ olive cultivar observed that flowering dates varied between 17 April and 7 May and for the same period, the simulated start day of chilling accumulation varied between 21 November and 10 January. Further, the winter conditions in the period after chilling accumulation had correlation with yearly differences in flowering date for a given fruit tree species and cultivar. Flowering and fruit maturation were advanced and yield increased in raspberry (*Rubus idaeus* L) with the raising of temperature over the 15-25 degree C (Sonsteby and Heide, 2012).

In black currant (*Ribes nigrum* L.), temperature of 15 – 21 degree C were required for flowering of ‘Ben Hope’ cultivar (Heide and Sonsteby, 2012). In ‘Koroneiki’ olives, trees flowered profusely at 2.5 degrees C and 8.3 degrees C night temperatures and 23.9 degrees C day temperature, however, 26.6 degrees C day temperature inhibited the flowering (Malik and Bradford, 2009).

In the warmest locations of Denmark, the phenology of almond cultivars was nearly a month ahead of the coldest areas, even though the bloom period was very similar for all two varieties ‘Rhizlane-1’ and ‘Rhizlan-2’ (Serrano *et al.*, 2011). In contrast, clear varietal differences were observed in maturation dates of strawberries at an altitude of 2200 m above mean sea level wherein, the days from full bloom to harvest were however, reduced to 30.4 days in comparison to 36.8 days under lower altitude conditions (Biswajit *et al.*, 2012). The low temperature of 14 degrees C and short day length promoted plant growth and advanced flowering stage and maturity by 7-12 days in strawberry cultivars Xuemi and Fengxiang (Zhao MiZhen *et al.*, 2009). In an investigation on the impact of climatic variability on phonological change of mangosteen during years 2008- 2010, a marked change in rainfall distribution affected the phonological change in flowering in 2010, a prolonged drought in summer followed by rains during July-August caused leaf flushing instead of flowering and this resulted in off season fruit production (Apiratikorn *et al.*, 2012).

Wei *et al.* (2011) found that 30, 40 and 80 lux relative light intensity was needed for good quality attributes and higher yields in Fuji apples. Schrader *et al.* (2011) observed that fruit surface temperature of 46, to 52 degrees C increased

flesh firmness and soluble solids concentration (SSC) and decreased titratable acidity but caused sunburn in ‘Gala’ apples. Phonological data of sweet cherry (*Prunus avium* L.) cultivars Burlat and Germersdorfer revealed that higher mean temperatures from January to March influenced earlier date of flowering (Usenik and Stampar, 2011).

2.3 Effect of environmental conditions on fruit set, fruit development and fruit maturity

Greybe *et al.* (1998) observed enhanced fruit development and fruit size following the occurrence of higher temperatures 30-40 days after full bloom. Poldervaart (2004) observed increase in temperature in March-May by 3-4 degree C accompanied with other climatic changes including higher humidity, more precipitation and more extreme weather conditions (such as hailstorms, rain and heat) adversely affected the fruit setting of apple cv. Golden Delicious. Calderon *et al.* (2004) observed that the higher temperature (33/38 degree C) later than 3 weeks after full bloom was detrimental for fruit growth. Kadir *et al.* (2006) in a study on the fruit set of strawberry exposed to different temperature regimes found that 40/35 degree C was the temperature regime most detrimental to fruit set. Another study on the effect of climate variables namely, air temperature, sunshine hours, relative humidity on ‘Golden Delicious’ apple in the southern part of Romania revealed that the percentage of fruit set was positively influenced by an increase in sunshine hours, while the relative air humidity and rainfall during the growing period exerted a negative influence (Paltineanu and Chitu, 2006)

The soil temperatures in the range of 11 degree C to 15 degree C was most ideal for bud burst till fruit set in ‘Satohnishiki’ sweet cherry (Beppu *et al.*, 2008). In strawberry cultivars ‘Nyoho’ and ‘Toyonoka’, a high day/night temperature of 30/25 degrees C reduced the number of inflorescences, flowers and per cent fruit set compared with plants grown at 23/18 degree C (Ledesma *et al.*, 2008).

The apple fruit growth rates have been correlated to daily temperature regimes, wherein warmer temperatures can induce faster growth in the initial stages, and can thus result in larger fruit at harvest (Grappadelli and Lakso, 2005). Chang-ChihSheng and Wang-NienTzu (2008) observed that the increase in air temperature affected the required accumulated temperature and shorten the period of fruit development. Furthermore, a higher ambient temperature impaired the fruit appearance and quality. Kawanobu *et al.* (2010) noted that the fruit maturation period had a high correlation with solar radiation and high temperature, due to which the fruit maturation period decreased significantly in strawberry fruits. Hedhly *et al.* (2007) in an investigation whether warm temperatures at flowering could have a detrimental effects on fruit set in sweet cherry (*Prunus avium*) naturally adapted to high latitudes and cold climates subjected two cultivars under field conditions to a slight increase in temperature at bloom over two different years. While the minimum temperature remained stable, the maximum temperature increased 5-7 degree C resulting in a moderate increase of the average temperature of 1-3 degrees C and this was sufficient to drastically reduce fruit set in both years and cultivars. Zhang *et al.* (2007) investigated the effect of low temperature in winter on loquat flowering and fruit set during 2004 and 2005 in order to evaluate the possibility of cultivating loquat in Shanghai and observed that all young fruit turned brown and aborted when temperatures dropped to -5 to -7 degrees C.

In high quality peach cultivar Hujingmilu, fruit set is usually adversely affected by bad weather at flowering stage and fruit rotting occur due to excessive rains during fruit ripening period and too high temperature (Shen YuYing *et al.*, 2006). In 'Tainong 1' mango cultivar, to gain a higher fruit set rate, the average temperature from bloom to 14 days after blossom should at least be 20.6 degrees C, however the optimum temperature was found to be 24.7 degrees C (Ou ShiJin *et al.*, 2007). The temperature changes in early spring did not significantly influenced the survival of bud and rate of anthotaxy fruiting, but affected the rate of fruiting and sepal falling in "Dangshan" pears (Yi XingKai and Xu-YiLiu, 2012). In a study to understand the impacts of climate change on wine grape in large proportion of Australia's growing regions, it was observed

that in 2010-11 season due to climate warming all the cultivars (Cabernet Sauvignon, Shizar and Chardonnay) showed advancement of phenology with budburst and fruit set occurring earlier in each case (Edwards *et al.*, 2012). Liu Ping *et al.* (2012) found that annual average temperature of 12-14 degrees C and rainfall of about 400 mm was most suitable for fruit setting in Chinese jujube cultivar Chenguang in Shanxi, Hebei and Shandong Province. Nesmith, (2012) observed the flowering period of four rabbiteye blueberry cultivars following freeze damage and found that detrimental temperatures of -4.2 and -3.5 degrees C occurred on March 9 and March 5, respectively resulted in corolla browning 3 to 4 days following the last freeze and eventually in a moderate to severe crop loss.

In Iran, late spring frost occurred on 14th March and 1st April with temperature falling to -3.5 and -3 degrees C damaged all mid flowering cultivars in almond (Imani *et al.*, 2011). In grape wine, soil temperature of 15 degree C or 26 degree C was found to be optimum at which the availability of current photo assimilates for inflorescence development and fruit set was conditioned by the simultaneous demands for shoot and root growth, as well as the restoration of root carbohydrate reserves (Rogiers *et al.*, 2011). Nava *et al.* (2011) found that high temperatures during the pre-flowering and flowering were the causes of low productivity of 'Granada' peach at Charqueadas. Li JinXue *et al.* (2010) found significant relations ($P < 0.05$) between soil temperature, humidity, sunlight and the fruit set and yield in lemon trees. Kviklya and Robinson (2010) observed that trees high temperature (29/22.5 °C) had more pronounced negative effect with on fruit set than the cool temperatures (22/15 °C) in 'Empire' apple. High temperature (≥ 25 degrees C) at blooming period of peach cultivars Maciel and Granada negatively affected the fruit set (Couto *et al.*, 2010). DeCeault and Polito (2010) noted that temperatures between 22.2 to 24.0 degrees C were sufficient to enhance fruit set in *Prunus domestica* cultivars Improved French and Muir Beauty. Keller *et al.* (2010) observed that flower number per inflorescence had an inverse relation with pre-budburst temperature. Conversely, flower size, per cent fruit set and berry size increased with higher temperatures. Further, they concluded that temperature variation near budburst affected directly the floral development. Chen PoAn *et al.* (2013) investigated the factors affecting fruit set

in 'Yu Her Pau' litchi (*Litchi chinensis* Sonn.) in Taiwan and found that the size of the inflorescence increased as flowering was delayed, while the rate of fruit set decreased possibly because of cool weather during flower development. Trees Persimmon cultivar Triumph showed significantly lower fruit set under day/night temperatures of 35/18 degrees C compared to 22/18 degrees C (Zilkah *et al.*, 2013). However, the decline of fruit set was more evident when the trees were exposed to the high temperatures during development of flowers and fruit set (March 15- April 16). In plum, the percentage of fruit set was positively influenced by an increase in sunshine hours and precipitation during May and minimum temperature and air humidity during April, while negative influence was exerted by the minimum temperature during May (Iancu *et al.*, 2013). Further, the fruit yield was more intensively correlated with the fruit number per tree than with the average fruit weight. In strawberry cultivars Korona, Elsanta and Clery, duration of fruit development was negatively related to daily mean temperature but increased with higher latitude (Kruger *et al.*, 2012).

Remberg *et al.* (2012) studied the influence of post flowering temperature (12, 18 & 24 °C) on berry maturation of 'Glen Ample' red raspberry and found that fruit maturation and harvest were advanced in the order of increasing temperature. Usenik and Stampar (2011) analysed the phenological data of sweet cherry (*Prunus avium* L.) cultivars Burlat and Germersdorfer revealed that higher mean temperature from January to March shortened period of fruit development. On the contrary, fruit maturation in passion fruit was increased at high temperature regimes, with fruits at 30/30 degrees C day/ night temperature fruits were harvested at only 53.5 days after pollination and those grown under 30/20 degrees C took 73 days to mature (Kozai *et al.*, 2007).

2.4 Effect of environmental conditions on fruit quality

Moisture stress in mid season followed by more favorable weather favoured rapid growth of the fruits in citrus (Pola *et al.*, 1991). High respiration and low accumulation of carbohydrates due to high night temperature during the maturing stages has been related with the early softening of fruits (Choi-Dong Genu *et al.*, 2001). Josuttis *et al.* (2011) found that increase in air or the soil

temperature decreased the average fruit weight and increased the ascorbic acid concentrations and p-coumaroyl glucose in fruits grown in cooler climates. Kim Seungttevi *et al.* (2004) found that altitude of orchard was curvilinearly correlated with fruit skin anthocyanin content and fruit shape index, and the further suggested that hilly apple orchards located at higher elevation had more chances for production of quality fruits.

Yamada *et al.* (2004) found positive correlation between the mean and daily maximum temperature with fructose, glucose and total sugar contents in apple. Wang *et al.* (2010) elucidated the effects of photosynthetic rate, leaf temperature and relative humidity on fruit quality of apple in middle Guizhou Province of Italy and found that photosynthetic rate, leaf temperature and relative humidity were positively correlated with the fruit weight, soluble sugar content and sugar ratio. Liu XingJun *et al.* (2000) found that apple cultivar Golden Delicious exhibited red blush colour on the fruit at higher altitude due to more ultraviolet rays, more sunshine hours and larger daily temperature deviation. Ito (2003) reported that low air temperature reduced the weight of mature fruits, but did not affect sugar content, acidity and firmness in Japanese pear. At the fruitlet stage, atmospheric CO₂ enrichment increased the fruit size and enhanced sugar accumulation during maturation, further, CO₂ enrichment improved photosynthesis and assimilate partitioning in fruits.

In apple cultivar Fuji, lesser sunshine from June to August and the higher temperature over 30 degree C for more than 15 days resulted in smaller sized fruits in comparison to those developed during the normal climate year (WongLiXin and FengShiHai, 2006). In a study on effect of high temperature stress on the fruit weight of strawberry cultivars Nyoho and Toyonoka, Ledesma *et al.*, (2008) found that fresh weight and fruit diameter of primary, secondary and tertiary fruits were greater at 23/18 degrees C than at 30/25 degrees C in both cultivars. In peach cultivar Juinxiu, the yearly temperature of 15.4 degree C and yearly rainfall of 2023 mm was found most suitable for high production, high eating quality and high returns (Liu YuFang, 2006). Rainfall during fruit

development and harvest time induced fruit cracking in sweet cherry (Caprio and Quamme, 2006).

Keller *et al.* (2005) observed that highest concentrations of sugars, acidity and colour were found in grapevines under cool temperatures (ambient +10 °C). Blanke and Balmer (2008) observed that despite increased day air temperature and soil temperature (by up to 15 and 5 °C, respectively) there was marked increase in both sugar and acidity with sugar: acid ratios of 25:1 to 30:1 in cherry fruits. Sugiura, (2010) observed a negative influence of global warming on apple, as an increase in 1.06 degree temperature caused colouring disorder, reduction in acidity, softening of apple fruits. In pomegranate cultivars ‘Ganesh-I’ and ‘Kandhari’, maximum fruit cracking was observed between the fourth week of May to the third week of July, which coincided with a rapid fruit development period and depended upon climatic conditions like relative humidity, rainfall and temperature (Singh *et al.*, 2011).

Increasing solar radiations improved fruit weight, soluble solids content, sugar content and sugar acid ratio in cherry (Li JinQiang *et al.*, 2010). In another experiment on variations in canopy microclimate of guava, higher solar radiation penetration, and better microclimatic conditions led to better fruit yield and quality (Brar *et al.*, 2013).

Heuvel and Autio (2008) in a study on correlations of temperature with fruit composition of total anthocyanin, total flavonols and total phenolics at harvest in ‘Early Black’ cranberry observed that warmer temperatures early in the season (around bloom and fruit set) had the most positive impact on total anthocyanin and total phenol contents. Further, total phenolic concentration in the harvested fruit was also impacted by air temperature during the preharvest period and that relationship was again positive.

In strawberry cultivars cultivars Korona, Elsanta and Clery, the fruit quality standards, dry matter, soluble solids and titratable acidity were influenced by latitude, in general northern sites had the highest values. Fruits grown at the southern sites were however, redder compared to those of the north (Kruger *et*

al., 2012). An investigation on the effect of climate change factors on mangosteen with 30 years weather data from 1981 to 2010 revealed that a marked change in rainfall distribution affected the phenological change in flowering, productivity and fruit quality (Apiratikorn *et al.*, 2012). Remberg *et al.* (2012) studied the influence of post flowering temperature (12, 18 & 24 °C) on berry quality of red raspberry cultivar Glen Ample and found that berry weight decreased throughout the harvesting period at all temperatures, but the decrease was markedly faster at high temperatures.

Blanke and Kunz (2011) analyzed the meteorological data for more than 50 years (1958-2010), including air and soil temperature as well as precipitation to study the climate change effects for a range of apple and pear cultivars and found that 50 mm less precipitation in the summer during the fruit growing period to spring resulted in smaller fruit size. Gong *et al.* (2009) studied the relationship between the ecological factors and sugar/acid ratio and observed that that annual sunshine hours, the mean temperature in the period from fruit swelling to maturity and percent of sunshine hours were the main ecological factors affecting fruit quality. The annual sunshine hours, the percent of sunshine 60-90 days after flowering and sunshine percentage from 120 to 150 days after flowering were the key factors affecting the sugar/acid ratio.

In raspberry (*Rubus idaeus* L), the highest yield of 640 g /plant with large fruit of good flavour and firmness were obtained with the average mean temperature of 20 degrees C, 22 degrees C and 26 degrees C (Sonsteby and Heide, 2010). In ‘Granny Smith’ apples, 53 per cent of full sun photosynthetic photon flux (PPF) and fruit surface temperature of on average 5 degrees C above ambient resulted in red blush on fruits (Fouche *et al.*, 2010). In ‘Fuji’ apple, greater sugar (up to 0.7 g/100 g TSS) and acid content, i.e. the better fruit quality and consistent taste (sugar: acid ratio), the firmer fruit (by up to 0.6 or 0.8 g/100 g TSS) were obtained with temperature 25- 27 degrees C and relative humidity of 60 percent (Zarifneshat *et al.*, 2010). Kaack and Pedersen (2010) determined the relationship between fruit size, fruit weight, fruit quality and climatic factors and the interaction of these factors at harvest in order to predict the optimal harvest

date of 'Elstar' apples and found that degree days and relative humidity were highly correlated. Solomakhin and Blanke (2010) observed that apple fruit colouration was dependent on photosynthetically active radiation (PAR) and UV radiations respectively.

In strawberry fruits, the anthocyanin content decreased at higher temperature [35/20 °C (day/night)] as compared those developed at lower (25/20 °C) temperature (Ikeda *et al.*, 2009). Gao Hua *et al.* (2009) found that recorded effective accumulated temperature of 3210 degrees C, annual average daylight duration of 2573 hours, daylight duration from April to October 1680 hours, average precipitation from April to October 484 mm, average temperature from April to October 15.5 degrees C and average temperature diurnal range from April to October 10.8 degrees C with annual average temperature of 12.2 degrees C, and these were the optimum values of the meteorological factors for expression of the highest fruit quality in 'Pink Lady' apple.

In blueberries, annual average temperature, annual solar hours and annual precipitation had the most important relationship with fruit quality and yield; temperature had a negative influence on content of soluble sugar, a positive influence on content of total acid (Wang *et al.*, 2009). Further, annual solar hours had shown a positive influence on content of soluble sugars but a negative influence on total acid content. Garriz *et al.* (2008) investigated the effects of harvest date on the fruit quality of 'Abbe Fetel' pears from the initial commercial harvest (ICH) for five weeks and observed that at initial commercial harvest (ICH), the range values for fruit weight, fruit diameter, fruit firmness, starch index and soluble solids concentration (SSC) were 208.3 to 232.9 g, 63.4 to 68.8 mm 53.3 to 61.7 N, 2.50 to 3.50 and 11.4 to 12.1 degrees Brix, respectively.

Snelgar *et al.* (2007) observed that the average dry matter concentration (DMC) in blueberries varied substantially from year to year and linked this variation to variations in temperature. Average DMC of fruit from several orchards in Te Puke varied from 16.3 to 17.4 percent during 7 growing seasons and the seasonal variation was highly correlated with variations in temperature. Cool weather during spring resulted in fruit having a low DMC while, cool

weather during summer resulted in higher DMC. The colour development in apple has been found to be mostly influenced by day and night temperature, and the day and night temperature had an important role on fruit quality parameters on sugar content vitamin C content and on acidity (Lakatos *et al.*, 2012).

Studies on phenological observations of sweet cherry (*Prunus avium* L.) cultivars Burlat and Germersdorfer as influenced by different weather parameters revealed that higher mean temperature from January to March shortened the period of fruit development and reduced the fruit quality in sweet cherry (Usenik and Stampar, 2011). Li XianMing *et al.* (2010) revealed that lower average daytime temperature and higher relative humidity in pear orchards lead to better fruits appearance, increased fruit firmness, higher soluble solids content and higher solid acid ratio and lower titratable acid contents. Kozai *et al.* (2007) observed that 30/25 degrees C day/ night temperature regimes increased sugar: acidity ratio in passion fruit. Vangdal *et al.* (2007) studied the correlation between climatic factors and fruit quality in plum cultivars in Norway and noticed that the soluble solids content was positively influenced by high temperatures in April and June and cool and wet weather in May and titratable acidity was found higher with high precipitation in August. The soluble solid contents in apple fruits were however, correlated with the percentage of full sunlight (Bessho *et al.*, 2007).

Nilsson and Gustavsson (2007) revealed that high temperatures resulted in a significantly higher content of soluble solids in apple and also increased the difference in peel colour between outside and inside fruits. Red coloured apples probably contribute to improved fruit quality but the difference seems to be strongly dependent on the growing conditions, especially the sum of heat units. In Robertson Navel orange, soluble solid content and SSC/ titratable acid ratio were positively correlated with annual accumulated temperature, annual mean temperature, January temperature and sunshine hours but negatively correlated with annual rainfall (Zeng *et al.*, 2006).

2.5 Effect of environmental conditions on fruit yield

Caprio and Quamme (1999) observed that high temperature during flower bud initiation and flower bud development lead to poor production in apple. Mattioli (1998) found that fluctuation in temperature at critical stages of fruit development was the main limiting factor affecting productivity in apple. Singh and Singh (2007) observed that high internal relative humidity of leaf and canopy temperature at 27 degree C increased the fruit yield in rejuvenated guava orchard to the tune of 75 to 80 per cent. Kadir *et al.* (2006) found that high night temperature (40 degree C day/35 degrees C night) was more detrimental to productivity in strawberry than the moderate or low temperature (30/25 or 20/15 degree C) and suggested that better source to sink relationship at 20/15 degree C than at 30/35 degree C. Varga *et al.* (2006) reported that a 2 degree C decrease in temperature caused 10% reduction in the yield in apple; though warmer periods increased the expected yields, however it was also influenced by humidity. In apricot, yield had a positive correlation with low temperature in winter (Jay and Lichou, 2007). Doving (2009) however, observed that 1 degree rise in temperature in February gave 6.9% lower yield in plum and showed that the yield level was negatively correlated to high temperatures in January and February. At North Sinai, Egypt, analysis of meteorological data of the site for 10 or 30 years revealed that increase of air temperature and humidity played a positive role in enhancing the yield of pomegranate trees (Varga *et al.*, 2001). Seidhom and Rahman (2011) observed that high midday temperatures in subtropical citrus growing region lead to excessively high leaf temperature mediated drastic reduction in growth and yield (Otero *et al.*, 2011).

A study conducted by Li-Hong *et al.* (2010) to examine the influence of the solar irradiance (IIR), temperature and soil water content (SWC) on strawberry and to quantify correlations with fruit yield showed that soil water content and lower temperature stimulated strawberry fruit bearing and strawberry fruit yield was positively correlated to normalized difference vegetation index (NDVI). Muster (2009) observed that increased temperature with 0.5 to 1 degree C increased the fruit yield, fruit weight and growth index in raspberry. In a study

(Esitken *et al.*, 2009) on the impact of climate change on strawberry yield in Turkey, long term 2006-07 and 2007-08 meteorological data was analyzed and it was inferred that the winter before the harvest of 2008 had only 78 snow covering days in contrast to the 110 days in the winter 2006-07 and on the other hand, the 2008 summer was unusual because the night temperatures increased by 4 degree C compared to 2007. However, the warmer conditions in 2008 did not have positive effect on fruit yield, because the decrease in snow covering days during the previous winter negatively affect the production (13t/ha in 2008 & 19t/ha in 2007). Millan *et al.* (2009) indicated that the lack of low temperature in winter often resulted in early bud burst and caused a significant decrease in yield of cherry.

Popescu *et al.* (2009) indicated that higher average grape production was favoured mainly by the average temperature in September, total annual rainfall, average temperatures in the 1st and 2nd weeks of June, average temperatures in July and August. The rainfall during the period of active vegetative growth had a deep impact upon grape production. Esitken *et al.* (2009) found that the decrease in snow covering days in winter negatively affected the strawberry yield.

The study carried out at five geographically distinct locations in Italy to predict the effects of chilling, diurnal temperature difference and their interaction with day length on yield of strawberry and found that accumulative diurnal temperature unit of 180 degree days resulted in 30 per cent enhancement in the yield of strawberry (Tanino and Wang, 2008). Sitompul *et al.*, (2013) in their study on the analysis of air temperature as a limiting factor for the productivity of apple trees recorded air temperature and relative humidity during the day (0.06, 12.00 and 18.00 H) at the different orchard locations and noted that the air temperature was closely related to the altitude and declined as a rate of 0.679 degree C 100m⁻¹ of altitude close to a wet lapse rate. A high variation was found in the relationship between temperature and productivity which showed, on average, a tendency to decline with an increase in the temperature.

Bosc (2012) indicated that a day time temperature of 16 degrees C during 68 day chilling period results in lower yield in strawberry after the first flowering

than a diurnal temperature of 11 degrees C. Furthermore, day temperature of 11 degrees C during the half period, followed by a daytime temperature of 16 degrees C in the second half, appeared to result in higher initial yields. In ‘Burlat’ and ‘Germersdorfer’ sweet cherry (*Prunus avium* L.), higher mean temperature from January to March shortened period of fruit development and decreased the fruit yield (Usenik and Stampar, 2011).

2.6 Role of geographical information system (GIS) in evaluation of location suitability for fruit crops

Van-Chuong (2007) successfully carried out multi criteria analysis for physical land suitability evaluation and socio-economic, environmental suitability evaluation for fruit crops using geographical information system (GIS) as technical tool in the hilly region of central Vietnam. Wu-Ren *et al.* (2009) established land suitability maps with use of GIS for fruit crops, which were classified as suitable area, sub-suitable area, possible area and unsuitable area on the basis of annual temperature.

Panda *et al.* (2010) developed the GIS spatial model using various fruit crop characteristics such as chilling hours, soil permeability, drainage and soil pH and land cover to determine the best sites for growing blueberry in Georgia, US. Aggelopoulou *et al.* (2011) suggested that flowering distribution maps can be used for site specific management decisions of apple orchards by use of image processing analysis. Wei-Wu *et al.* (2011) in a site specific management of citrus used the geographic information system to investigate the potential growing areas for citrus on the basis of topography, land use, soil types and climate in the area. Wu-RenYe *et al.* (2009) established model which calculate the value of annual extreme minimum temperature, the map of spatial distribution about mean annual extreme minimum temperature intuitively represented with 50 m × 50 m resolution by GIS. According to the map, they further divided the Zhangzhou city into four fruit planting areas, as suitable, sub-suitable, possible and unsuitable area. Belykh (2006) used the GIS technology for the agro ecological modeling of optimal sites for fruit and berry crops in various natural environments in Novosibirsk province, Siberia to further develop agro-ecological map of the

province. Yehia *et al.* (2010) carried out the study to identify the soil mapping units using remote sensing techniques and to evaluate each soil mapping unit for different fruit crops (capability and suitability) to select the best crop pattern. They recognized four main soil units namely, slightly saline, non calcareous sandy loam, slightly saline calcareous sandy and moderately saline non calcareous loamy in the study.

Wrege *et al.* (2010) performed simulations to assess the effect of increasing minimum air temperature by 1 degree C, 3 degree C and 5.8 degree C on the chilling hours of temperate fruit crops. The generated model was used into the geographical information system (GIS) to create regression equations, information plans of the actual average minimum temperature (May to September) and actual annual average minimum temperatures. Accordingly these data were used to generate maps with the help of GIS of actual and future chilling hours. Balderacchi *et al.* (2013) developed the software VIGNETO (Vineyard environmental impact indicator) to assess the environmental impact on the viticulture with the use of web-GIS system to improve the user experience and in particular the data input management and the data visualization. Manfrini *et al.* (2012) used the spatial statistical techniques in which maps of apple crop production and quality parameters and fruit growth were generated by punctual kriging with a global variogram on a common grid.

Konopatzki *et al.* (2012) in a research aimed at mapping the yield of pear trees in order to study the spatial variability of yield as well as its comparison with spatial variability of soil pH and plant attributes (fruit length, diameter and yield) found that yield had low correlation with soil and plant attributes. An index of spatial variability was suggested in this study that helped in classifying levels of spatial dependence of various soil and plant attributes. Ferraz *et al.* (2012) used geo-statistical analysis to evaluate the spatial variation in the detachment force of coffee fruit and coffee yield by variograms and kriging, wherein the yield data were obtained from manual harvesting and geo-referenced. Maps of coffee yield was created to enable farmers to manage harvesting either manually or mechanically at different locations. In addition, maps of detachment force of

coffee fruit can enable farmers to harvest coffee selectively by choosing the appropriate places and the right time to start harvesting. Swain *et al.* (2010) developed an automated yield monitoring and mapping system for real time fruit yield estimation for wild blueberry, further yield maps along with topography were developed to precise site specific programs for wild blueberry production. Mann *et al.* (2011) mapped the productivity of a citrus grove with variation in tree growth to delineate zones of productivity based on several indicator properties. These properties were fruit yield, ultrasonically measured tree canopy volume, normalized difference vegetation index (NDVI), elevation and apparent electrical conductivity (ECa). The spatial patterns of soil series, soil colour and ECa, and their correspondence with variation in yield emphasized the importance of variation in the soil in differentiating the productivity of the grove. Citrus fruit yield was positively correlated with canopy volume, NDVI and ECa, and yield was negatively correlated with elevation. They further suggested that productivity of citrus groves can be mapped using various attributes that directly or indirectly affect citrus production. Gebbers and Zude (2010) carried out an approach for recording spatio-temporal crop and soil data by means of optical and geo-electrical sensors. Monitoring of apple was undertaken on 200 trees. High resolution geo-electrical soil mapping was done with a resistive meter to identify drought stress zones in the apple orchard and they found that in sandy drought zones, fruit size was reduced, leading to increased fruit flesh firmness, soluble solids content and enhanced blush pigments. Variation in fruit quality and maturity should be considered when determining the optimum harvest date in a site specific way. The combination of geo-electrical methods and optical fruit sensing provide sensitive data to predict spatial variation in fruit development.

Aggelopoulou *et al.* (2010) considered the potential for site specific management based on yield and quality of apples from a 0.8 ha apple orchard located in northern Greece over two growing seasons. Yield was measured by weighing all fruit harvested from groups of five adjacent trees and the position of the central tree was recorded by GPS. Apple quality at harvest was evaluated from samples of the two cultivars in both years for which fruit mass, flesh firmness, soluble solids content, juice pH and acidity of the juice were

determined. The variation in tree flowering was also measured in the spring of the second season using a stereological sampling procedure. The results showed considerable variability in the number of tree flowers, yield and quality across the orchard for both cultivars. The number of flowers was strongly correlated with the final yield. These data could potentially be used to plan for early prediction of yield. Several quality characteristics, including fruit juice soluble content and acid content were however, negatively correlated with yield. The spatial variation in several variables suggested that changes in topography and aspect had important effects on apple yield and quality.

Kohno *et al.* (2009) carried out the study on concept of a mobile citrus fruit grading robot having NIR inspection system measures for internal sugar content and a GPS for recording robot location. Data on fruit colour, size, shape, defect and sugar content, tree leaf colour and canopy size were accumulated into a database corresponding to tree location. Adding to this robots information, analysis of satellite images was conducted and field server information was collected. The producers' operation records were the input to the database with the satellite and field server information. This database was used both for farming guidance to conduct tree management and for food traceability in relationship to safety and security in food distribution. Perry *et al.* (2009) used airborne imagery to map the canopy vigor in vineyards, which enabled selective harvest of wine grapes, which in turn enabled higher quality grapes to be processed separately into higher quality wines.

Wang Zhi *et al.* (2009) followed hyper spectral remote sensing technology to predict the yield of peach by applying the spectral characteristics of tree canopy before fruit maturity and could predict the yield indexes of fruit. The key was to study the correlation among the spectral reflectivity or its derivative indexes and the yield indexes and the yield indexes of fruit by which the prediction model was made.

Rosseti *et al.* (2008) produced coloured maps by infra red sensors in conjunction with GPS, in which yellow indicates low, green optimal, red high and blue excessive vine vigour with the maps of homogeneous areas in a

vineyard near Pisa which allows grower for picking in the different areas separately as grapes matured, improved general grape quality and saved working time. Zaman *et al.* (2008) generated prescription maps of soil properties, bare spots, topographic features and fruit yield for site specific production of blueberry in North America. (Garcia *et al.*, 2008) used the computer program named Clustering Assessment (CLUAS) for environmental characteristics of olive tree orchards from remote sensing images and found that remote images with spatial resolution from 0.25 to 1.5 m were suitable for olive grove characterization. Further, CLUAS can contribute to the site specific management of tree groves, providing quantitative information on each tree, small areas of an orchard or whole orchards.

Tisseyre *et al.* (2008) studied the temporal stability of within field variability (TSWFV) for most routinely measured vine parameters for site specific management. The TSWFV enable to know whether or not it is relevant to use the within field variability of the year 'n' to design a site specific management strategy for the year 'n+1'. They included indicators of a vine capacity to produce biomass (yield and size of the canopy) as well as indicators of harvest quality (sugar content, pH & titratable acidity) with the (TSWFV) analysis and classified type 1 parameters (yield & canopy size) which present a significant TSWFV and type 2 parameters (sugar, total titratable acidity, pH) which present no TSWFV. They showed that yield or vigour (size of canopy) maps of the previous years are relevant in designing site-specific management strategies in the year 'n+1' or subsequent years. Conversely, maps of quality parameters from previous years were not found to be useful in determining how to manage harvest quality in the year 'n+1'.

Panagopoulos *et al.* (2007) applied the geographical information systems (GIS) and geo-statistics to generate information that can be used to optimize physical and financial aspects of kiwifruit production systems. They selected 15 geo-referenced orchards in which soil analysis and fruit production and quality parameters were determined. Variation of kiwifruit quality and production factors, graphical interpretation of these properties was done using GIS, geo-

statistics and principle component analysis (PCA). Areas with highest potential production and quality were located and accordingly site specific management methods were adopted to improve productivity and quality. Those maps can help the producer to make decisions about harvesting time or localized correlation of production factors and to choose the best place for vineyard installation in the region. They further found a strong correlation between the map of yield and quality factor.

Cortell *et al.* (2004) used the geographical information system (GIS), GPS and areal infra-red photography in grape to create spatial maps of soil characteristics (type, and pH) and fruit quality parameters (cluster & berry weights, sugars & phenolics). Ojeda *et al.* (2005) used spatial, high resolution systematic measurements to produce site specific management of the vineyard regarding quality improvement. Manfrini *et al.* (2012) analyzed the relationships between the within season and harvest measurements using both traditional and spatial statistical techniques. Maps of crop production and quality parameters and fruit growth were generated by punctual 'kriging' with a global 'variogram' on a common grid.

***Materials and
Methods***



Chapter-3

MATERIALS AND METHODS

The present investigation entitled “Geographical Information System based assessment of location suitability for apple (*Malus×domestica* Borkh.) production” was carried out in the Department of Fruit Science, Dr Y S Parmar University of Horticulture and Forestry, Nauni- Solan, Himachal Pradesh, during the years 2012-14. The materials used and methods adopted during the course of investigations have been described as under:

LOCATION

The present study was undertaken in Shimla and Kinnaur districts of Himachal Pradesh. The geographical extent of the districts are between 30° 51’00’’ North latitude and 77° 06’04’’ East longitudes and altitude ranges from 700-6200 meters above the mean sea level, but the habitation is only up to 3500 meters (Fig. 1). Three blocks of district Shimla namely, Mashobra, Kotkhai and Rohru and two blocks of district Kinnaur, Reckong Peo and Kalpa, representing different elevations and dominant by apple cultivation were selected for the study. In Shimla district, the average maximum temperature varied from 12.8 degree Celsius in January to 32.8 degree Celsius in June, whereas the average minimum temperature ranged from 21.1 degree Celsius in July to as low as 2.7 degree Celsius in January, whereas in Kinnaur District, the average maximum temperature varied from 7.7 degree Celsius in January to 24.8 degree Celsius in June, and the minimum temperature ranged from 18.7 degree Celsius in July to as low as 1.9 degree Celsius in January.

PLANT MATERIAL

The present studies were undertaken on 15-year-old trees of apple cultivar Starking Delicious raised on seedling rootstocks at spacing of 7.5×7.5m in Shimla district and at 6m×6m in Kinnaur district. At the respective elevations of each block, five trees having uniform vigour and size were selected for the study.

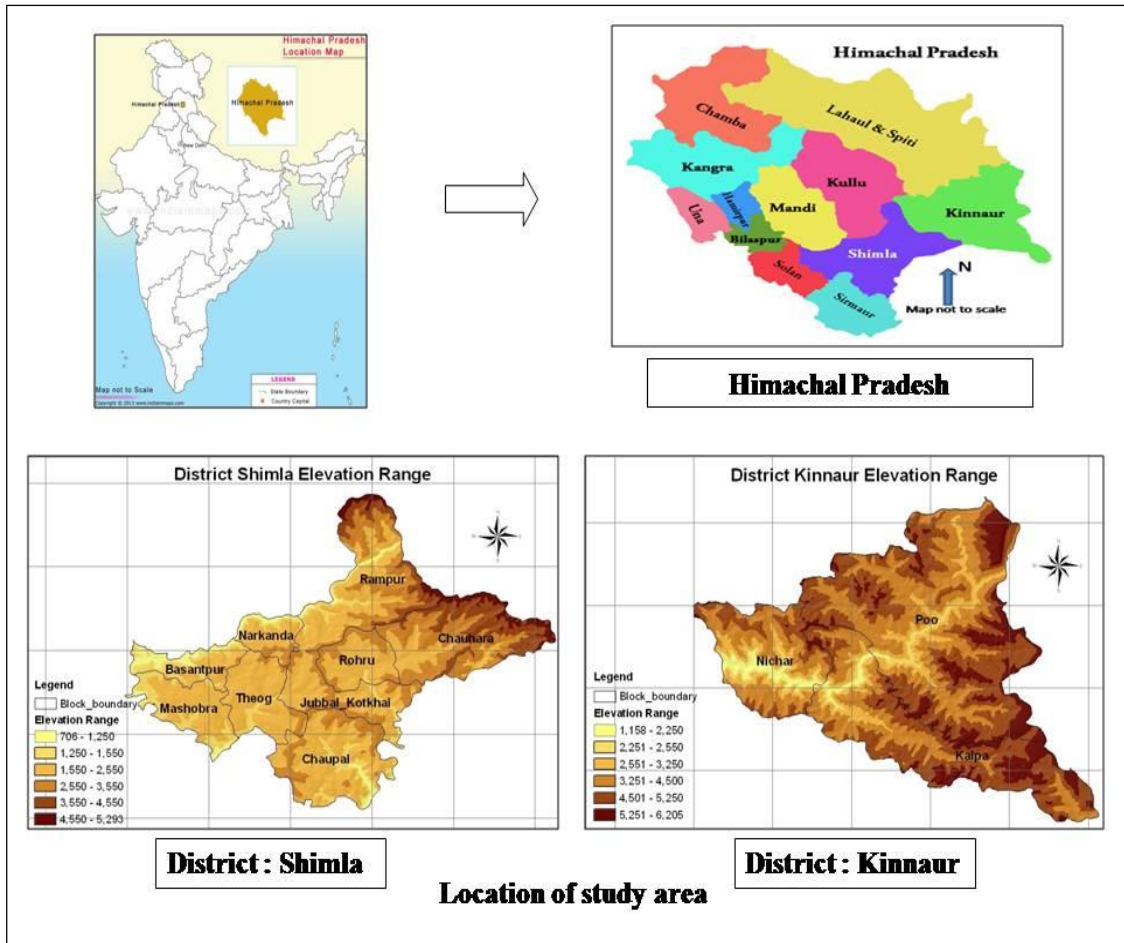


Figure 1 Indicating the study location

3.3 EXPERIMENTAL DETAIL

The study was accomplished using two experiments as below:

Experiment 1: Effects of different environmental factors on production and quality of apple cv. Starking Delicious.

Experimental details:

Cultivar : Starking Delicious

Locations : 7

At each location of the study area except Mashobra, two orchards were selected, one at higher elevation (altitude) and another at lower elevation as per details below.

Location	Higher elevation (m amsl)	Lower elevation (m amsl)
Mashobra	2245	---
Kotkhai	1950	1670
Rohru	2124	1690
Kalpa/Reckong Peo	2780	2547

Number of trees per orchard: 5

Experimental Design : RBD (Randomized Block Design)

Correlation of weather parameters with flowering intensity, fruit set and yield of apple was worked out.

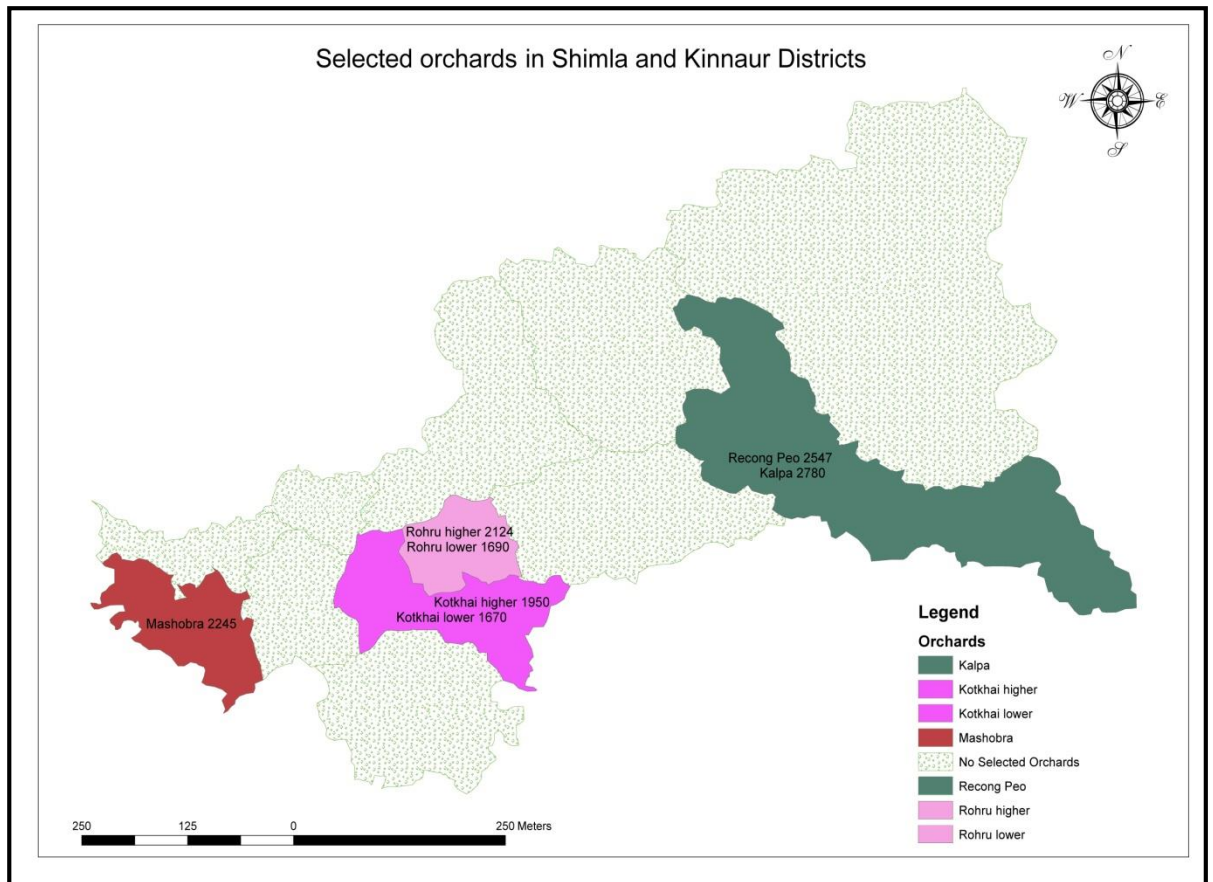


Figure 2 Selected orchards in Shimla and Kinnaur Districts

Experiment 2: GIS based assessment of location suitability for apple production in Himachal Pradesh.

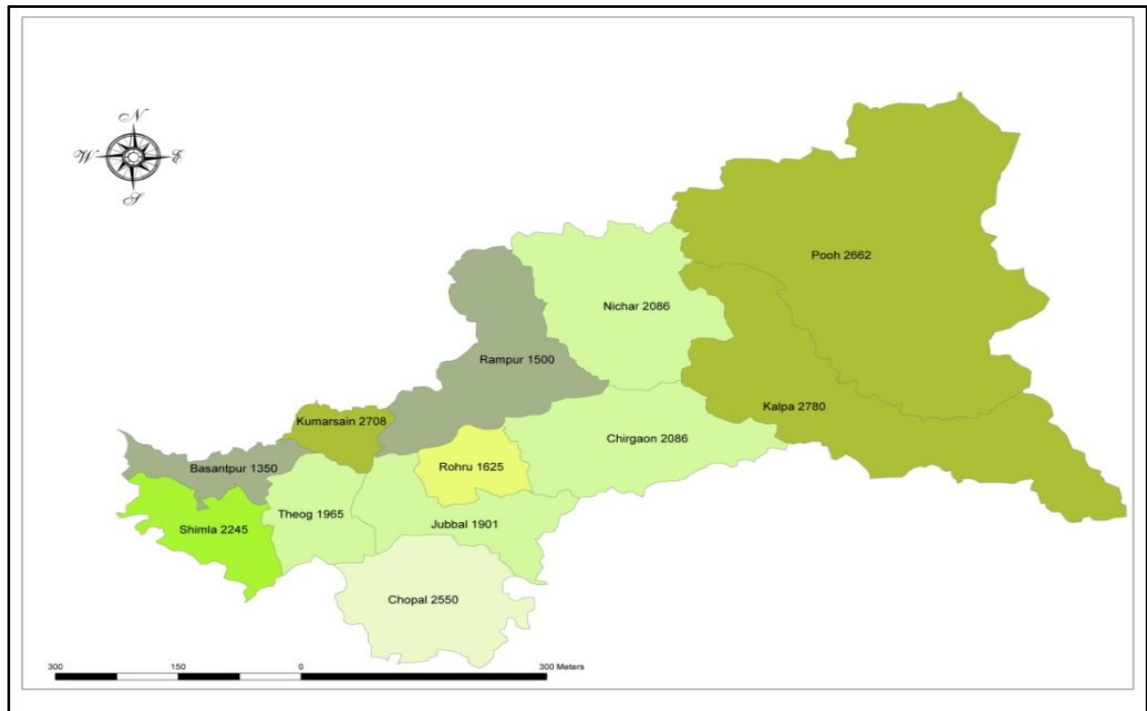


Figure 3 Block (representing different altitudes) level suitability analysis

Data source:

- 1) Terrain data: Terrain parameters were derived using digital terrain model (DEM). For this, the NASA Shuttle Radar Topographic Mission (SRTM) was used which provides digital elevation data (DEMs) for over 80 % of the globe. Data had been downloaded using earth explorer browser. This data had been collected by USGS (United States Geological Survey) and downloaded from the National Map Seamless Data Distribution System.
- 2) Attribute data: The main attribute data needed for this study included the climatic data which was acquired from the weather stations in the study area and around and by data installing loggers at the experimental sites. Besides, four more attribute data as mentioned below were recorded.
 - A. Weather parameters
 - B. Geological parameters
 - C. Socio-economic parameters

D. Quality parameters

Programme:

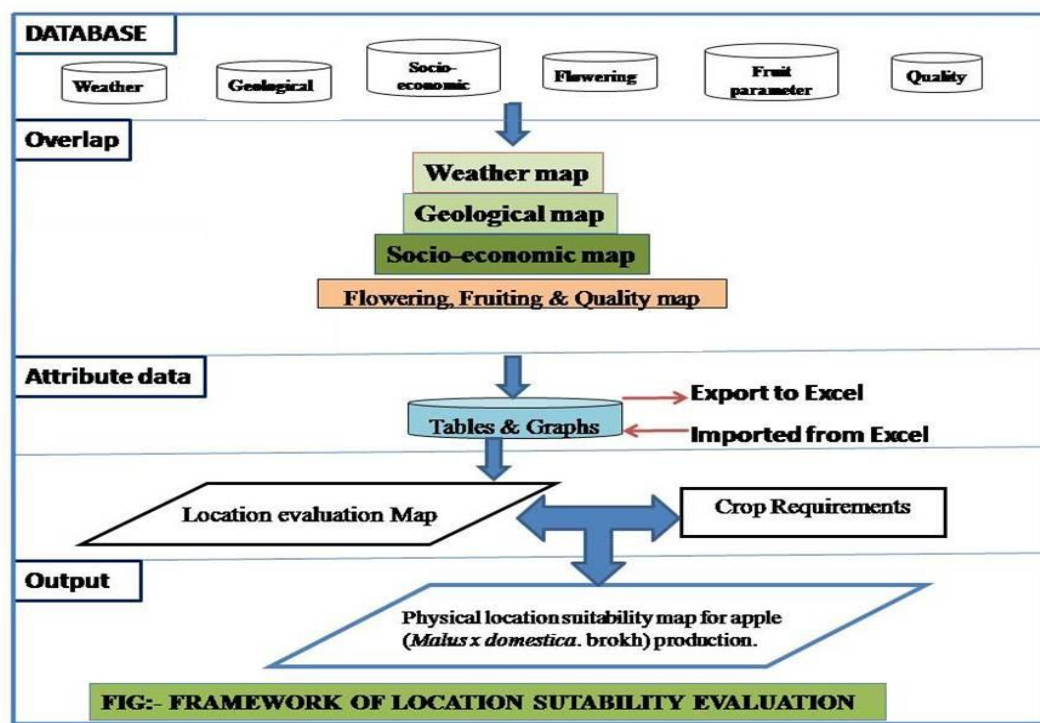
ArcGIS (version 10.2) programme was used for suitability analysis.

Analysis:

In this study, six parameters (Table 1) were used to evaluate location suitability of apple cultivation. After establishing the criteria and parameters, location suitability was divided into three zones, the best suitable zone, fairly suitable zone, and not suitable.

Table 1 Suitability parameters of apple

Parameter	Suitable	Fair	Not suitable
Temperature	21-24°C	24-27°C	>27°C
Chilling units	1200-1500	1000-1200	<1000
Rainfall	100-125cm	125-200cm; 60-100cm	>200cm
Elevation (altitude amsl)	1500-2700m	1200-1500m	<1200m
Slope	20-40%	40-60%	>60%
Aspect	North-East ; North-West	South-East	South-West



Framework for location suitability evaluation

3.4 OBSERVATIONS RECORDED

3.4.1 Weather Parameters

3.4.1.1 Temperature and humidity

Air temperature and relative humidity data for the study area were obtained from India Meteorological Department, Shimla and local meteorological stations and pre-installed EL-USB self-recording dataloggers.

3.4.1.2 Precipitation

Precipitation data for the study areas were acquired from India Meteorological Department, Shimla and local meteorological stations.

3.4.1.3 Solar elevation angle

The solar elevation angle, a measure of the altitude of the sun, the angle between the horizon and the centre of the sun's disc and was taken from NOAA (National oceanic and atmospheric administration) site by providing data pertaining to the latitude and longitude values of the orchard site. The approximate values were calculated with the following formula:

$$\sin \alpha_s = \cos h \cos \delta \cos \varphi + \sin \delta \sin \varphi$$

Where;

α_s is the solar elevation angle, $\alpha_s = 90^\circ - \theta_s$

h is the hour angle, in the local solar time.

δ is the current declination of the Sun

φ is the local latitude.

3.4.1.4 Solar Influx

Light illumination was recorded by Luxmeter under and outside the tree canopy at the selected orchard sites at various elevations separately during day time and the value in percentage of light intensity under canopy to that in the open was calculated as under (Rao, 1998).

$$\text{Solar Influx (\%)} = \frac{\text{Total solar radiation beneath the canopy}}{\text{Total solar radiation in open}} \times 100$$

3.4.1.5 Canopy temperature

Canopy temperature was determined by infrared canopy thermometer at various growing stages.

3.4.1.6 Ultra violet index

Ultra violet index data for selected orchard locations were acquired from the site of surface meteorology and solar energy, NASA (<https://eosweb.larc.nasa.gov/sse/>)

3.4.1.7 Determination of chilling units and growing degree hours:

For the determination of chilling units, the data on maximum and minimum temperatures were recorded daily from the onset of rest to full bloom in apple cv. Starking Delicious to calculate the chilling units at each locations. The hourly temperatures needed for calculating chill units were obtained according to method of synthesizing hourly values (Ramina, 1982). The hourly temperatures were calculated by dividing differences of maximum and minimum temperature of 12 hour intervals by 11. The chilling hours were worked out by adopting a ‘Utah’ model (Richardson *et al.*, 1974) and ‘North Carolina’ model (Shaltout and Unrath, 1983). The model for converting the selected temperatures to chill units is reproduced below in Table 2 and 3.

Table 2 Conversion of selected temperatures to chill units using Utah model

Temperature		Chill unit contribution
(Degree Celsius)	(Degree Fahrenheit)	
1.4	34	0
1.5-2.4	35-36	0.5
2.5-9.1	37-48	1
9.2-12.4	49-54	0.5
12.5-15.9	55-60	0
16-18	61-65	-0.5
18	65	-1

Table 3 Corresponding temperatures and chill units values of North Carolina model

Temperature (Degree Celsius)	Chill unit contribution
-1.1	0.0
1.6	0.5
7.2	1.0
13.0	0.5
16.5	0.0
19.0	-0.5
20.7	-1.0
22.1	-1.5
23.3	-2.0

The dates of rest completion were calculated through temperature data and full bloom dates. The two constants namely chill units (CU) and growing degree hours (GDH) were estimated as per method (Ashcroft *et al.*, 1977) described below.

1. Estimated a reasonable chilling unit requirement.
2. Used the estimated chill units' requirement to calculate an estimated date of end of rest period.
3. Calculated the GDH °C accumulation starting at the estimated date for the end of rest till the observed date of full bloom.
4. Repeated steps 1-3 for different year's data.
5. Determined the SD's for the GDH °C accumulations.
6. Added or subtracted 20 chill units to or from the value of the chill units requirement estimated in the step 1.
7. Repeated steps 2-6 until, several SD's were available for several estimated chill unit values.
8. Plotted SD versus estimated chill unit requirement.
9. Evaluated the first constant (chill unit) by selecting the chill unit value corresponding to the minimum SD.
10. Used the first constant (evaluated in step 9) to calculate the end of rest dates for several years.
11. Calculated GDH °C accumulations beginning at calculated dates for the end of rest and ending at observed dates of full bloom.

12. Evaluated the second constant (GDH°C) by averaging the values calculated in step 11.

3.4.2 Geological parameters

3.4.2.1 Elevation

Elevation (altitude) of the orchard locations were determined by global positioning system which triangulates its location in reference to multiple satellites and as well as with the use of altimeter.

3.4.2.2 Slope and aspect

The topographic variables (slope and aspect) of each location were extracted from the digital elevation model (DEM), which were in conformity to the topographic information of Google Earth software.

3.4.3 Socioeconomic parameters

The data on different size of apple orchards, area under irrigated and unirrigated orchards were acquired from the records of Himachal Pradesh revenue department.

3.4.4 Physical parameters

3.4.4.1 Tree height and spread

The height and spread of the trees from each replication was measured with the help of a measuring tape. Tree height was measured in meter from the soil surface to top of the tree. Tree spread was measured across the tree in North-South and East-West directions and average of both the measurements in meter was worked out.

3.4.5 Flowering parameters

3.4.5.1 Date of flowering stages

The dates relating to flowering stages with respect to dates of bud swell, green tip, pink bud, anthesis, full bloom and petal fall were recorded from the five selected trees at each orchard locations.

3.4.5.2 Flowering intensity

Three uniform branches on different sides of each tree were marked and 100 flower buds (spurs) were selected on each branch. Total number of flower clusters were counted from pink bud to the onset of flowering and extent (intensity) of flowering was calculated as:

$$\text{Flowering intensity (\%)} = \frac{\text{Number of flower clusters}}{100 \text{ buds}}$$

3.4.6 Fruit parameters

3.4.6.1 Fruit set

Three branches on different aspects of the tree were tagged for counting flowers and number of fruit set. Fruit set was recorded three weeks after petal fall and percent fruit set was calculated by using the formula (Westwood, 1993) given below:

$$\text{Fruit set (\%)} = \frac{\text{Number of fruit set}}{\text{Number of flowers clusters}} \times 100$$

3.4.6.2 Fruit yield

The yield of the fruits per plant was recorded at the time of harvest and expressed in kilograms (kg/plant).

3.4.6.3 Date of harvesting

The time at which fruit attained full size, proper shape, and colour and other physio-chemical characteristics, was considered as date of fruit harvest and it was calculated for each replication and mean value was noted from full bloom.

3.4.6.4 Number of days taken for harvesting

Time duration from full bloom stage to harvest for each replication at each location was recorded and mean value was expressed as number of days taken for harvesting.

3.4.7 Quality parameters

3.4.7.1 Fruit size (length and diameter)

The size of five fruits was measured in terms of length and diameter. The length was measured from calyx end to styler end and diameter was recorded by measuring distance between the cheeks of the fruit with the help of digital Vernier Caliper and expressed in millimeter (mm).

3.4.7.2 Fruit shape index (length/ diameter ratio)

Fruit length/diameter ratio was worked out by dividing the values of average length with the average diameter of five fruits from each plant.

3.4.7.3 Fruit weight

The weight of five fruits selected for recording fruit size was taken on a top pan balance. The fruit weight was expressed in grams per fruit (g/fruit).

3.4.7.4 Fruit colour

Fruit colour was determined with the help of fruit colour chart of Royal horticulture society, London.

3.4.7.5 Total soluble solids (TSS)

The total soluble solids of the juice were determined with Erma-hand refractometer (0 to 32°B range) by putting a few drops of juice on the prism. The refractometer was calibrated with distilled water before use. A temperature correction was applied when it was above or below 20°C (AOAC, 1980). The total soluble solids were expressed as per cent of fresh juice.

3.4.7.6 Titratable acidity

Twenty five grams of fruit was thoroughly homogenized in an electric blender and the volume was made with distilled water to 250 ml in volumetric flask. Out of it, 50 ml extract was taken for the estimation of acidity and the rest were used for determining the total and reducing sugars. The extract as obtained above was then filtered through Whatman No1 filter paper. Twenty five milliliters of extract was then titrated against N/10 NaOH solution using phenolphthalein as an indicator till it gave pink coloured end point. The total titratable acidity was calculated in term of malic acid on the basis of 1 ml of N/10 NaOH equivalent to 0.0067 gram of anhydrous malic or per cent malic acid (Ranganna, 1995). The remaining filtered solution was used for sugar estimation.

3.4.7.7 Total soluble solids / acid ratio

The ratio was obtained by dividing the corresponding values of total soluble solids with the malic acid content of the fruit.

3.4.7.8 Total Sugars

To the remaining 200 ml filtered stock solution (left from titratable acidity), 10 ml of 45 per cent saturated lead acetate was added, contents of flask were then shaken and filtered. Ten ml of 22 per cent potassium oxalate was later added to precipitate the excess of lead and the contents were again filtered and volume was made to 250 ml. One hundred ml of filtrate was taken in 250 ml of volumetric flask and 5 ml concentrated HCl was added to it and left overnight for hydrolysis at room temperature. The excess of HCl was neutralized with saturated NaOH solution and final volume was made 250 ml with distilled water. The total sugars were then estimated by titrating a boiling mixture of 5 ml each of Fehling A and Fehling B against hydrolyzed solution using methylene blue as an indicator (Ranganna, 1995). The end point was indicated by the appearance of brickred colour and total sugars were expressed as percentage of fresh weight of fruit.

3.4.7.9 Reducing sugars

The remaining unhydrolysed, delead and clarified solution obtained from the total sugars estimation was titrated against a boiling solution of 5 ml each of Fehling A and B using methylene blue as an indicator (Ranganna, 1995). Reducing sugars contents were expressed as percentage of fresh weight.

3.4.7.10 Non reducing sugars

The amount of non-reducing sugars was calculated by subtracting the reducing sugars from total sugar and multiplying the difference by a standard factor i.e. 0.95. The results were expressed as per cent of fresh weight.

3.4.8 Soil parameters

3.4.8.1 Soil texture

Soil texture was determined by international pipette method (Black, 1965).

Procedure:

- 1) For determination of soil texture, 50g of air dry soil (passed through 2 mm sieve) was taken in 500 ml bottle.
- 2) Shaken a set of sample bottles at regular intervals for half an hour on shaking machine for preparing homogeneous solution.
- 3) Transferred the above soil sample solution to 1000 ml glass measuring cylinder and 1000 ml solution was made by adding water.
- 4) As per International approved system, the sample solution was shaken for 30 seconds depending on the solution temperature and sedimentation chart, first pipetting was done with 50 ml pipette at 10 cm depth. In first pipetting, 50 ml solution was sucked and transferred in 60 ml china dish. This sample solution contained mixture of clay and silt partials.
- 5) Depending on the solution temperature and sedimentation chart (Table 4), second pipetting was done with 50 ml pipette at 10 cm depth. In second pipetting, 50 ml solution was sucked and transferred in 60 ml china dish. This solution contained clay particles in soil sample.

- 6) Transferred remaining soil solution in 1 litre measuring cylinder by using 0.02 mm sieve and washed the material through the sieve using jet of water. Sand particles on sieve were collected in china dish.
- 7) Transferred the pipette solution in 3 dishes and dried overnight in an oven at 105°C, cooled in a desiccator and weighed quickly.
- 8) The weight of fine sand was determined by deducting the weight of clay, silt and coarse sand particles from 100.

Table 4 Details of pipetting time of silt and clay

Temperature (°C)	Pipetting time upper limit of silt (0.02 mm dia.) min-sec	Pipetting time upper limit of clay (0.002 mm dia.) hrs- min
15	5-30	9-05
16	5-20	8-50
17	5-10	8-35
18	5-00	8-25
19	5-00	8-10
20	4-48	8-00
21	4-40	7-50
22	4-30	7-40
23	4-30	7-25
24	4-20	7-15
25	4-15	7-07
26	4-10	6-55
27	4-05	6-45
28	4-00	6-40
29	3-55	6-30
30	3-50	6-20
31	3-45	6-15
32	3-40	6-10
33	3-35	5-55

3.4.8.2 Soil pH

Procedure:

1. Dug out the top 2 inches of soil with a shovel at several locations of the orchard, because soil pH can vary widely, even in the same orchard.
2. Loosen the soil with a garden trowel to about 5 inches deep and added a scoop to the beaker, making sure to get soil from more than just the top layer
3. Added soil from each sample site to the beaker.

4. Mixed all the soil samples together thoroughly, removed any rocks or pieces of debris.
5. Measured out 2 cups of the mixed soil and transferred it in a clean container.
6. Added distilled water to the soil until it was damp enough that could firmly compacted it inside the container.
7. Cleaned the probe on the digital soil pH meter with the included pad or a paper towel.
8. Turned the digital soil pH meter on and inserted it into the soil, twisting it to make sure it had good contact with the soil. But kept it away from the bottom of the container.
9. Kept it in contact with the soil for 60 seconds.
10. Noted the reading. Soil pH was expressed on a 14-point scale, with 7.0 value indicating neutral pH. Numbers higher than 7 were considered alkaline and lower numbers as acidic.

3.4.8.3 Soil temperature

Soil temperature was determined by analogue soil thermometer by inserting titat 30 cm depth in soil and reading was recorded.

3.4.8.4 Soil moisture

Soil moisture was determined by digital soil moisture meter (Aqua Pro soil moisture profiler) at 30 cm. The probe was inserted in soil and reading was recorded in terms of percentage.

Time of recording weather and soil parameters

During the study, observations on solar influx, canopy temperature, soil moisture and temperature were recorded at different growing stages (Plate 1 a & b):

- **Green tip stage:** Fruit buds broken at tip, showing about 1/16 inch (1-2 mm) green.
- **Pink bud stage:** The king blossom in the centre of the cluster first to show unopened pink petal.

- **Flowering stage:** The time when the apple trees displayed their blossoms attracting bees and other insects and the whole orchard caught up in the act of procreation.
- **Fruit set stage:** This stage occurred 10-12 days after the end of bloom.
- **Walnut stage:** At this time fruit was one inch in diameter.
- **Fruit development stage:** This stage represent the fruit development period when fruit expansion rate is highly responsive to temperature.
- **Pre-harvest stage:** This stage occurs 20-25 days before harvest.

3.5 STATISTICAL ANALYSIS

The observations recorded on various parameters of soil, weather and trees were subjected to analysis of variance (ANOVA) using randomized block design at given five per cent level of significance (Gomez and Gomez, 1984). Variability analysis was computed as given by (Gupta and Kapoor, 1996).

Results and

Discussion



Chapter-4

RESULTS AND DISCUSSION

The present investigation on the Geographical Information System based assessment of location suitability for apple (*Malus × domestica* Borkh.) production was carried out during the years 2012- 2014. The results obtained during the course of study have been presented below experiment wise under appropriate heads:

4.1 EXPERIMENT-I EFFECTS OF ENVIRONMENTAL FACTORS ON PRODUCTION AND QUALITY OF APPLE CV. STARKING DELICIOUS

4.1.1 Temperature conditions at different locations of study area

4.1.1.1 Maximum temperature

It is evident from data presented in Table 5 and Figure 4 that in the year 2013, the average annual maximum temperature ranged from 14.64 to 25.35°C at different locations. The annual maximum temperature (14.64°C) was recorded significantly lowest at the highest altitude (Kalpa, Dist. Kinnaur). The second lowest value of maximum temperature was observed at Reckong Peo (T₇). However, the highest maximum temperature (25.35°C) was found at the lowest altitude of the study area (lower altitude of Kotkhai), which was significantly higher than all other locations except, lower altitude of Rohru (T₅). During the year 2014, the average annual maximum temperature ranged from 13.99 to 24.43°C, the lowest value again pertained to Kalpa followed by Reckong Peo (19.13°C) and the highest value to lower elevation of Rohru, which was however, statistically at par with higher altitude of Rohru (T₄) and lower altitude of Kotkhai (T₃).

The pooled data (Table 5) also revealed that the maximum temperature almost decreased linearly with a corresponding increase in altitude. The minimum temperature (14.34°C) was recorded at the higher altitude of Kinnaur (Kalpa) which was significantly lowest, and was followed by Reckong Peo and

Table 5 The maximum temperature at different locations in Shimla and Kinnaur districts of Himachal Pradesh

Treatment	Location	Elevation	Altitudes (m amsl)	Maximum temperature (°C)		
				2013	2014	Pooled
T ₁	Mashobra	E1	2245	19.94	20.31	20.12
T ₂	Kotkhai	E1	1950	21.12	22.18	21.65
T ₃	Kotkhai	E2	1670	25.35	23.17	24.26
T ₄	Rohru	E1	2124	22.97	23.58	23.28
T ₅	Rohru	E2	1690	24.01	24.43	24.22
T ₆	Kalpa	E1	2780	14.64	13.99	14.34
T ₇	Reckong Peo	E2	2547	19.01	19.13	19.07
Mean				21.01	20.97	20.99
S. Em. ±				1.35	1.36	1.34
S. D.				3.58	3.60	3.55

E1- Higher altitude, E2- Lower altitude

Mashobra in the increasing order. The lower altitude of Kotkhai registered the highest maximum temperature (24.26 °C), which was however, statistically at par with the higher altitude of Rohru. According to India Metrological Department, Mashobra, Kotkhai and Rohru fall under high hills wet temperate zone (HP-3) where average annual maximum temperature ranges between 21 to 32°C. The present data revealed that the maximum temperature recorded at different sites in Shimla exactly matched the suitable range (21 to 24 °C) for apple cultivation (Chadha, 2009). Whereas, Kalpa and Reckong Peo comes under high hills dry temperate zone (HP-4) where average annual average maximum temperate ranges between 14 to 21°C (IMD, 2011), and the present studies affirmed the prevalence of similar temperature range at the two locations of study area.

4.1.1.2 Minimum temperature

It is revealed from the data presented in Table 6 and depicted in Figure 5 that the average annual minimum temperature ranged from 3.64 to 16.07°C at different locations, in the year 2013. The experimental site located at the highest altitude Kalpa (T₆) recorded significantly lowest average annual minimum temperature (3.64°C) followed by Reckong Peo (5.80°C) and Mashobra (9.76°C). The highest minimum temperature (16.07°C) was recorded at higher altitude of Rohru (T₄), which was however, statistically at par with lower altitude of Rohru but, significantly greater than the remaining locations. In the year 2014, the mean annual minimum temperature decreased by 0.24°C compared to 2013. At

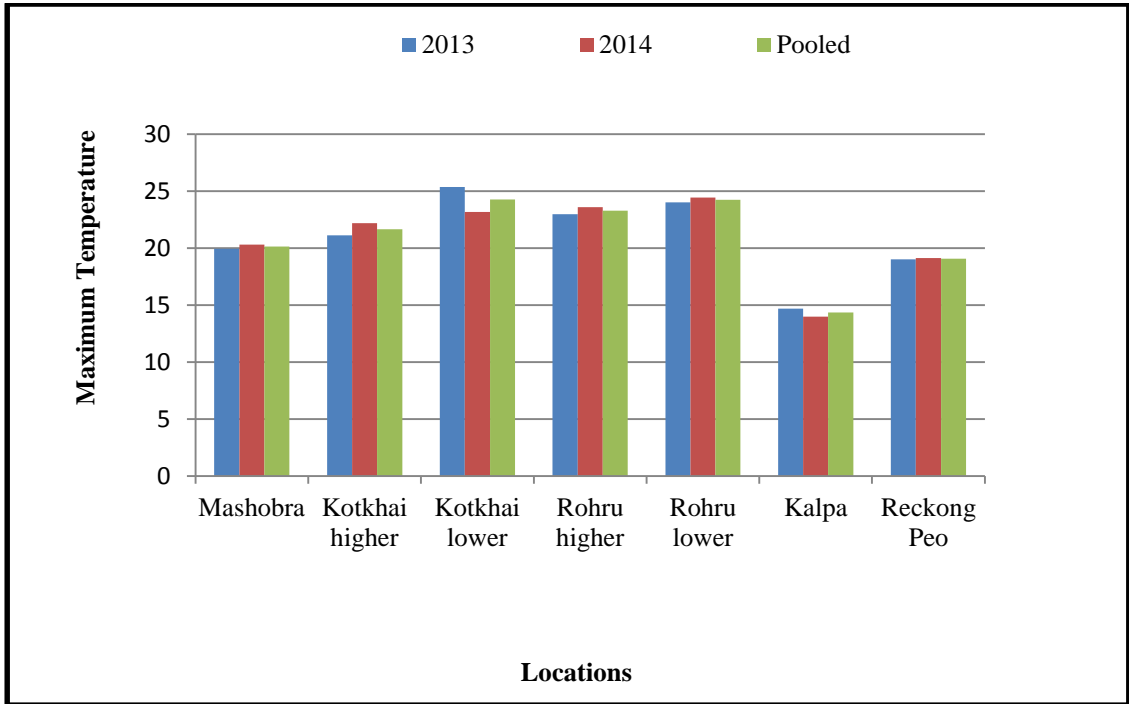


Figure 4 Maximum temperature at different locations in Shimla and Kinnaur districts of Himachal Pradesh

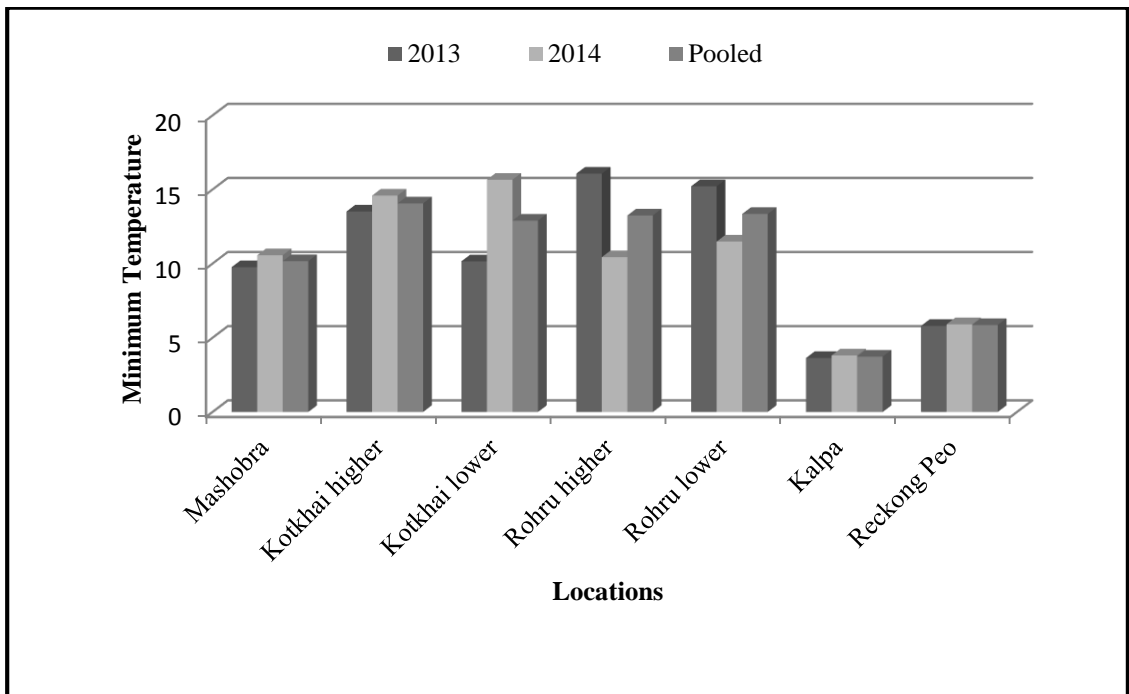


Figure 5 Minimum temperature at different locations in Shimla and Kinnaur districts of Himachal Pradesh

different locations, average annual minimum temperature ranged from 3.81 to 15.66°C. The minimum temperature was observed significantly lower at Kalpa (3.81°C) (higher altitude of Kinnaur) (T₆) and Reckong Peo (T₇) than the remaining locations. The highest minimum temperature (15.66°C) was recorded at lower altitude of Kotkhai (T₃), which was however statistically at par with T₂, T₄, and T₅.

Table 6 The minimum temperature at different locations in Shimla and Kinnaur districts of Himachal Pradesh

Treatment	Location	Elevation	Altitudes (m amsl)	Minimum temperature (°C)		
				2013	2014	Pooled
T ₁	Mashobra	E1	2245	9.76	10.56	10.16
T ₂	Kotkhai	E1	1950	13.52	14.59	14.06
T ₃	Kotkhai	E2	1670	10.15	15.66	12.90
T ₄	Rohru	E1	2124	16.07	10.43	13.25
T ₅	Rohru	E2	1690	15.22	11.49	13.35
T ₆	Kalpa	E1	2780	3.64	3.81	3.73
T ₇	Reckong Peo	E2	2547	5.80	5.91	5.86
Mean				10.59	10.35	10.47
S. Em. ±				4.69	4.28	4.12
S. D.				1.77	1.62	1.56

E1- Higher altitude, E2- Lower altitude

The pooled data (Table 6 & Fig. 5) also revealed that the minimum temperature was lower at higher altitudes and higher at lower altitudes. The higher altitude of Kinnaur at Kalpa (T₆) recorded significantly lowest minimum temperature (3.73°C) followed by Reckong Peo while, highest minimum temperature (14.06°C) was noted at higher altitude of Kotkhai (T₂) as compare to other locations of study area. According to India Metrological Department, the average annual minimum temperature in the high hills wet temperate zone (HP-3) falls between 9.5 to 12.5°C however, actual recorded minimum temperature at Mashobra, Kotkhai and Rohru showed an increasing trend at higher altitude of Kotkhai (14.06°C) and lower altitude of Rohru (13.5°C). Even though, present studies at Kalpa and Reckong Peo in the high hills dry temperate zone (HP-4) revealed no deviation in the minimum temperature from the IMD values (4.8 to 5.8 °C).

4.1.2 Effect of locations and altitudes on different parameters of ECU and GDH and blooming time in apple cultivar Starking Delicious

4.1.2.1 Effective chilling unit accumulation during 2012-13

The examination of data in Table 7 indicates that during the first year of study (2012-13), time of chilling unit initiation, completion of rest and end of chilling accumulation in apple cv. Starking Delicious varied greatly with locations and altitudes. Chilling unit initiation varied from October 5 to 22, 2012 at different locations. The onset of chilling unit initiation was recorded earliest at higher altitude of Kotkhai, followed by Kalpa (Oct. 7). However, the last date for the chilling unit initiation was registered at Mashobra (Oct. 22). The completion of rest occurred between February 10 to March 31, 2013 at different locations. The earliest date for the completion of rest was recorded at higher altitude of Kotkhai, followed by Mashobra (Feb. 14, 2013) and higher altitude of Rohru (Feb. 18, 2013). However, completion of rest occurred in the last (March 31, 2013) at Kalpa, followed by Reckong Peo (March 20, 2103). The time of completion of chilling unit accumulation was noticed earliest on 5th March at lower altitude of Kotkhai, which extended up to 24th April, 2013 at Reckong Peo.

It is evident from the data presented in Table 7 that the maximum duration for the completion of rest period (175 days) was recorded at Kalpa, followed by Reckong Peo (160 days). The duration for the completion of rest period was however, observed to be greatly shorter in all the locations of Shimla district (115 to 139 days) in comparison to Kinnaur district; the least time duration pertained to Mashobra.

The durations of chilling period varied with locations and altitudes. The maximum chilling duration (195 days) was noted jointly at Kalpa and Reckong Peo. The minimum chilling duration of 140 days was however, recorded at lower altitude of Kotkhai, and distantly followed by Mashobra (151 days) and higher altitude of Kotkhai (156 days).

Total effective chilling unit accumulation (ECU) during the chilling period (chilling unit initiation to the end of ECU accumulation) varied from 1526 CU at higher altitude of Kinnaur (Kalpa) to 1898 CU at lower altitude of Kotkhai, as

per the Richardson's "Utah Chill Model". The rest of locations *viz.*, Mashobra, higher and lower altitude of Rohru, and Reckong Peo (lower altitude of Kinnaur) recorded 1853, 1892, 1795 and 1621CU, respectively. However, according to 'North Carolina model', the maximum chilling units were noted at higher altitude of Kotkhai (2498 CU) and the minimum (1466 CU) at Kalpa (higher altitude of Kinnaur). The chilling unit recorded at Mashobra, higher and lower altitude of Rohru, and Reckong Peo (lower altitude of Kinnaur) were 1941, 1964, 1902 and 1711, respectively.

Further, it is evident from the data presented in Table 7 that according to Utah Model, ECU accumulations during peak winters were significantly highest at Mashobra (1306 CU) and lowest (419 CU) at Kalpa (higher altitude of Kinnaur). The other locations namely higher and lower altitude of Rohru, higher and lower altitude of Kotkhai and Reckong Peo (lower altitude of Kinnaur) recorded 964, 820, 1234, 1139 and 633 CU, respectively. As per 'North Carolina model', during peak winter, significantly higher chilling unit were noted at Mashobra (1358 CU) than all other locations. The second higher CU level was noted at higher altitude of Kotkhai (1205). However, the chilling unit accumulation at Kalpa (higher altitude of Kinnaur) was recorded significantly lowest (409 CU), followed by Reckong Peo (767 CU).

4.1.2.2 GDH°C accumulation

Data presented in Table 7 pertaining to GDH°C accumulations revealed that during the chilling unit initiation to rest completion, GDH accumulation was found significantly higher at lower altitude of Rohru (16584 GDH°C) in comparison to all other locations whereas, the least GDH accumulation (14896 GDH°C) was observed at Reckong Peo (lower altitude of Kinnaur). Rest of the locations *viz.*, Mashobra, higher altitude of Rohru, higher and lower altitude of Kotkhai and Kalpa exhibited 15862, 16084, 15743, 15612 and 15107 GDH accumulation, respectively. During the peak winter, the GDH°C was recorded highest (5894) at lower altitude of Kotkhai, however, the lowest GDH (2479) was noted at Kalpa (higher altitude of Kinnaur). The next higher and lower GDH

accumulations were observed at higher altitude of Kotkhi (5831) and Reckong Peo (2741), respectively.

During the period of the rest completion to full bloom stage, the maximum GHD accumulation (8219 GDH°C) corresponded to lower altitude of Kotkhai while, the minimum accumulations (4951 GDH°C) pertained to Kalpa (higher altitude of Kinnaur). Whereas, at Mashobra, higher and lower altitude of Rohru, higher of Kotkhai and Reckong Peo GDH values were computed as 8109, 8114, 8194, 8102.5 and 5091 GDH°C, respectively.

During the year 2012-13, the time of full bloom of apple cv. Starking Delicious varied from 18th March to 4th May at different locations (Table 7). The earliest full bloom time was noted at lower altitude of Kotkhai followed by higher altitude of Kotkhai (March 31, 2013), and lower altitude of Rohru (April 2, 2013). The latest full bloom time pertained to Kalpa, followed by Reckong Peo (18th April, 2013).

4.1.2.3 Effective chilling unit accumulations during 2013-14

The data on the initiation of chilling unit accumulation, rest completion, end of chilling unit accumulation, rest period, chilling period, effective chilling unit, GDH°C accumulation and full bloom recorded at different location of selected apple orchard during 2013-14 are presented in Table 8. It is revealed from the data that during 2013-14, the dates pertaining to chilling unit initiation, rest completion, end of chilling unit and full bloom, ECU accumulation and GDH°C accumulation showed discrepancy from results of the previous year (2012-13). The chilling unit initiation commenced earliest (October 9, 2013) at lower altitude of Rohru and in the last (October 27) at Mashobra. At rest of the locations, chilling unit accumulation initiated between 10th October (Kalpa) and 20th October (higher altitude of Kotkhai). The date of rest completion varied from February 12 to April 6, 2014 at different locations. The earliest date pertained jointly to higher altitude of Rohru and Kotkhai and the latest date to Kalpa. The chilling period ended earliest at lower altitude of Kotkhai on 7th March, 2014 and extended up to 29th April at Kalpa (Table 8).

Perusal from the data presented in Table 8 showed that the time requirement for the completion of rest period differed from location to location. The maximum time (178 days) for rest accumulation was noted at Kalpa and the minimum time taken for rest completion was 114 days at Mashobra. The descending order of time requirement for rest period was 159, 139, 126, 119 and 115 days at Reckong Peo, lower altitude of Rohru, lower altitude of Kotkhai, higher altitude of Rohru and higher altitude of Kotkhai, respectively.

The chilling period extended from 140 days at lower altitude of Kotkhai to 201 days at Kalpa. The remaining locations *viz.*, Mashobra, higher altitude of Rohru, lower altitude of Rohru, higher altitude of Kotkhai and Reckong Peo (lower altitude of Kinnaur) required 153, 169, 169, 144 and 188 days of chilling period, respectively.

In the year 2013-14, total effective chilling unit (ECU) accumulation during the chilling period (chilling unit initiation to end of ECU accumulation) varied from 1415 CU at Kalpa to 1942 CU at lower altitude of Kotkhai. As per the Richardson's "Utah Model", the CHU was recorded significantly higher at lower altitude of Kotkhai (1942 CU) in comparison to all other locations and significantly lowest chilling units (1415 CU) were recorded at Kalpa. According to Unrath's 'North Carolina model', the maximum chilling unit was noted at higher altitude of Kotkhai (2508 CU) and the minimum CU (1367) at Kalpa. As per this model, ECU at remaining locations ranged from 1661 (higher altitude of Rohru) to 2048 (lower altitude of Rohru).

Further, it is evident from the data presented in Table 8 that according to Utah Model, ECU accumulation during peak winters was significantly higher at Mashobra (1209 CU) than all other locations, and lowest (337 CU) at Kalpa. The other locations *viz.*, higher and lower altitude of Rohru, higher and lower altitude of Kotkhai and Reckong Peo recorded 900, 755, 1164, 1063 and 504 CU, respectively. As per 'North Carolina model', the maximum ECU during peak period were noted at Mashobra (1277 CU), whereas, the minimum chilling

Table 7 Chilling unit initiation and completion, rest completion, rest and chilling period, ECU and GDH accumulation and full bloom in apple cv. Starking Delicious at different altitudes during 2012-13

Location	Chilling unit initiation (Date)	Rest completion (Date)	End of chilling unit (Date)	Rest period (Days)	Chilling period (Days)	ECU Accumulation				GDH Accumulation			Full bloom (Date)
						Chilling period*		Peak period**		Chilling initiation to rest completion	Peak winter	Rest completion to full bloom	
						UTAH CU chilling period	NORTH CAROLINA CU	UTAH CU peak period	NORTH CAROLINA CU				
Mashora-E1	22-10-2012	14-02-2013	22-03-2013	115	151	1853	1941	1306	1358	15862	4521	8109	06-04-2013
Kotkhai-E1	05-10-2012	10-02-2013	10-03-2013	128	156	1874	2498	1234	1205	15743	5831	8103	31-03-2013
Kotkhai-E2	16-10-2012	19-02-2013	05-03-2013	126	140	1898	1938	1139	1154	15612	5894	8219	18-03-2013
Rohru-E1	12-10-2012	18-02-2013	06-04-2013	129	176	1892	1964	964	1021	16084	4608	8114	07-04-2013
Rohru-E2	11-10-2012	27-02-2013	24-03-2013	139	164	1795	1902	820	849	16584	5099	8194	02-04-2013
Kalpa	07-10-2012	31-03-2013	20-04-2013	175	195	1526	1466	419	409	15107	2479	4951	04-05-2013
Reckong Peo	11-10-2012	20-03-2013	24-04-2013	160	195	1621	1711	633	767	14896	2741	5091	18-04-2013
MEAN				138.86	168.14	1779.86	1917.14	930.71	966.14	15698.21	4453.29	7254.36	
SD				21.22	21.43	147.57	312.74	326.61	319.56	571.95	1369.24	1526.86	
SE				8.02	8.10	55.77	118.21	123.45	120.78	216.18	517.53	577.10	

ECU- Effective chilling unit

GDH- Growing degree hours

* Chilling period – ECU accumulations were summed up from the chilling unit initiation stage to the day after which the continuous chilling negation started to accumulate. ECU's during peak winters were also computed for each of the fall/winter season.

** Peak period – December 15 to February 15

units (315 CU) were recorded at Kalpa. This value of ECU at rest of the locations ranged from 681 (higher altitude of Rohru) to 1122 (higher altitude of Kotkhai).

Depending upon the climatic variations at different locations during the course of study, dates of chilling unit initiation, rest completion, end of chilling period and full bloom stages of Starking Delicious apple showed discrepancy among the locations and between the years. Mankotia (2005) also revealed year to year variations with respect to timing of chilling unit initiation, rest completion, end of chilling period and full bloom stages in apple. Mankotia *et al.* (2004) determined that 1208 CU were required for rest completion for 'Delicious' apple at Shimla and according to present findings all the locations in Shimla and Kinnaur fulfilled the basic chilling requirement. The chilling period (days) were found to be lower in Kalpa and Reckong Peo than all other locations in Shimla district, because, these two locations falls under dry temperate zone where, temperature falls below freezing point during the months of December and January, which do not contribute to chilling units accumulations as per both the models (Appendix II). In the present study, chilling unit accumulation had no relation with altitudes in wet temperate and dry temperate zones, which is contrary to the findings of Mankotia (2004) conducted at warmer locations (Solan) and Mashobra.

4.1.2.4 GDH°C Accumulation

Perusal of the data presented in Table 8 revealed that GDH accumulation between the chilling unit initiation to rest completion was computed significantly higher at lower altitude of Rohru (16032 GDH°C) in comparison to all other locations, while it was observed to be least (14982 GDH°C) at Reckong Peo. During peak winter, higher GDH accumulation was recorded at lower and higher altitude of Kotkhai (5988 GDH°C and 5951 GDH°C, respectively). The GDH accumulation during this period was however, noted significantly least (2591 GDH°C) at Kalpa.

Between the period of rest completion to full bloom stage, the maximum value of GDH was computed in respect of lower altitude of Kotkhai (8362 GDH°C) and the minimum for Kalpa (4892.5 GDH°C). During the same

Table 8 Chilling unit initiation and completion, rest completion, rest and chilling period, ECU and GDH accumulation and full bloom in apple cv. Starking Delicious at different altitudes during 2013-14

Location	Chilling unit initiation (Date)	Rest completion (Date)	End of chilling unit (Date)	Rest period (Days)	Chilling period (Days)	ECU Accumulation				GDH Accumulation			Full bloom (Date)
						Chilling period		Peak period		Chilling initiation to rest completion	Peak winter	Rest completion to full bloom	
						UTAH CU chilling period	NORTH CAROLINA CU	UTAH CU peak period	NORTH CAROLINA CU				
Mashora-E1	27-10-2013	18-02-2014	29-03-2014	114	153	1761	1892	1209	1277	15131	4371	7957	19-04-2014
Kotkhai-E1	20-10-2013	12-02-2014	13-03-2014	115	144	1832	2508	1164	1122	15257	5951	7989	04-04-2014
Kotkhai-E2	18-10-2013	21-02-2014	07-03-2014	126	140	1942	1922	1063	993	15331	5988	8362	21-03-2014
Rohru-E1	16-10-2013	12-02-2014	03-04-2014	119	169	1806	1661	900	681	15792	4547	8170	14-04-2014
Rohru-E2	09-10-2013	25-02-2014	27-03-2014	139	169	1876	2048	755	904	16032	5122	8263	11-04-2014
Kalpa	10-10-2013	06-04-2014	29-04-2014	178	201	1415	1367	337	315	15019	2591	4893	06-05-2014
Reckong Peo	17-10-2013	25-03-2014	23-04-2014	159	188	1561	1736	504	581	14982	2879	5127	22-04-2014
MEAN				135.71	166.29	1741.71	1876.14	847.29	839.00	15363.36	4492.71	7251.43	
SD				24.55	22.57	187.28	355.00	333.38	333.16	400.27	1353.81	1539.44	
SE				9.28	8.53	70.78	134.18	126.00	125.92	151.29	511.69	581.85	

ECU- Effective chilling unit

GDH- Growing degree hours

* Chilling period – ECU accumulations were summed up from the chilling unit initiation stage to the day after which the continuous chilling negation started to accumulate. ECU's during peak winters were also computed for each of the fall/winter season.

** Peak period – December 15 to February 15

period, the corresponding values at rest of the locations viz, Mashobra, higher and lower altitude of Rohru, higher altitude of Kotkhai and Reckong Peo were 7957, 8170, 8263, 7989 and 5127 GDH°C, respectively. Full bloom dates of apple cv. Starking Delicious varied from 21th March to 6th May 2014. The earliest time of full bloom was recorded at lower altitude of Kotkhai, followed by higher altitude of Kotkhai (4th April, 2014) and lower altitude of Rohru (11th April, 2014). However, the latest time of full bloom was recorded at Kalpa (6th May) followed by Reckong Peo (22nd April).

Kalpa and Reckong Peo which are at distinctly higher altitude recorded lowest GDH accumulation during chilling initiation to rest completion period. The summation of GDH were less at these locations as temperature often goes below 4.5°C during this period (Appendix II). Whereas, higher GDH accumulations were recorded at different locations in Shimla district during chilling initiation to rest completion, where, in respect of this attribute the same trend was observed during peak winter and rest completion to full bloom. In 10-years study in Shimla, Mankotia (2004) observed variability in GDH accumulations among the years during the chilling unit initiation to rest completion, and obtained its maximum value (17750 GDH°C) was obtained in 1998- 1999 and least value (7055 GDH°C) in 1997-1998. Similar trends were observed with respect to GDH°C accumulations during peak winters. During the period of rest completion to full bloom stage, the maximum GDH accumulations (9878 GDH°C) corresponded to 1996-1997 whereas, its minimum value (7167 GDH°C) was computed for the 2000-2001 season.

4.1.3 Annual rainfall

It is revealed from data presented in Table 9 and Figure 6 that the average annual rainfall ranged from 66.42 to 126.25 cm at different locations, in the year 2013. The lowest and highest rainfall values pertained to Reckong Peo (T₇) and Mashobra (T₁), respectively. The second lowest rainfall (72.25 cm) was recorded at Kalpa (T₆), which was however, statistically at par with Reckong Peo, but significantly lesser than all the locations in district Shimla. In the year 2014, again significantly lower rainfall was recorded at Reckong Peo (64.85 cm) and Kalpa

(69.79 cm) in comparison to all the locations in district Shimla. The highest amount of rainfall was recorded at Mashobra (123.75 cm), followed by higher altitude of Rohru (T₄) and lower altitude of Kotkhai (T₃) in the decreasing order.

Table 9 Annual rainfall at different locations in Shimla and Kinnaur districts of Himachal Pradesh

Treatment	Location	Altitudes (m amsl)	Rainfall (cm)		
			2013	2014	Pooled
T ₁	Mashora-E1	2245	126.25	123.75	125.00
T ₂	Kotkhai-E1	1950	106.08	104.15	105.11
T ₃	Kotkhai-E2	1670	113.00	110.86	111.93
T ₄	Rohru-E1	2124	114.67	112.45	113.56
T ₅	Rohru-E2	1690	95.83	96.38	96.11
T ₆	Kalpa	2780	72.25	69.79	71.02
T ₇	Reckong Peo	2547	66.42	64.85	65.64
Mean			99.21	97.46	98.34
S. Em. ±			8.48	8.41	8.44
S. D.			22.44	22.25	22.34

The pooled data (Table 9 & Fig. 6) also revealed that the rainfall was significantly lower at both the locations of district Kinnaur in comparison to all the locations of district Shimla. However, in Shimla district, the maximum rainfall was recorded at highest altitude (T₁), whereas lower altitudes of Rohru recorded lesser rainfall (96.11cm) as compare to other locations in the district. Present recorded values of annual rainfall at Kalpa and Reckong Peo matched well with those given by India Metrological Department for high hills dry temperate zone of the state (65 to 70 cm). At Mashobra, Kotkhai and Rohru locations in the high hills wet temperate zone (HP-3), annual rainfall during the study period also persisted within the range given by IMD (100-140 cm). Optimum range of annual rainfall for apple cultivation is 100 to 125 cm (Randev, 2009) and it seems that all the locations in Shimla barring lower altitude of Rohru are suitable for apple cultivation, which recorded the rainfall in the optimum range during the study period. During the study, annual rainfall was much below the optimum range at Kalpa and Reckong Peo and therefore irrigation facilities are must to maintain desirable level of soil moisture for the successful apple cultivation at these locations.

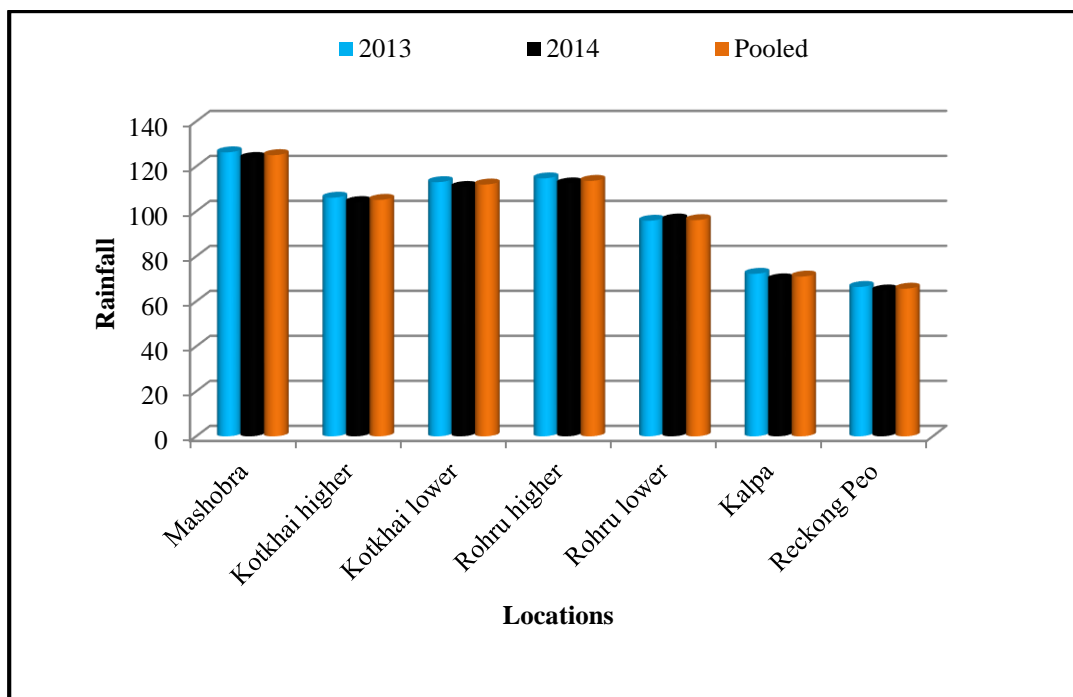


Figure 6 Annual rainfall at different locations in Shimla and Kinnaur districts of Himachal Pradesh

4.1.4 Soil moisture and soil temperature at different locations

4.1.4.1 Soil Moisture

4.1.4.1.1 Soil moisture level during different stages of fruit development in apple during 2013

It is evident from the data (Table 10) that soil moisture content was significantly variable at different locations in Shimla and Kinnaur Districts. The comparison of data on soil moisture content at different stages of growth revealed that in the year 2013, at green tip to pink bud stage, it was registered maximum (29.33%) at higher altitude of Kinnaur (Kalpa) followed by lower altitude of Kinnaur (Reckong Peo). During this period, soil moisture content was found minimum at higher altitude of Rohru (11.96%) followed by higher altitude of Kotkhai (11.84%). During the period between flowering to fruit set, it was again found maximum (34.20%) at higher altitude of Kinnaur (Kalpa) followed by lower altitude of Kinnaur (Reckong Peo) (29.09%), however, it was recorded minimum (14.68%) at lower altitude of Rohru. At walnut stage, it was again found maximum (29.84%) at higher altitude of Kinnaur (Kalpa) followed by Reckong Peo (27.90%), however, it was registered minimum (13.09%) at lower altitude of Rohru. During fruit development period, soil moisture level was found highest (43.04%) at Kalpa followed by Reckong Peo (39.52%). It was however observed to be lowest at lower altitude of Rohru (28.26%). At pre harvest stage, it was registered maximum (43.73) at Kalpa, followed by lower altitude of Kotkhai (39.65%) and Mashobra (39.42%) in the decreasing order.

Table 10 Soil moisture content at different growth stages of apple cv. Starking Delicious at different locations, in the year 2013

Location	GP-PB*	Fl-FS**	Walnut stage	Fruit development	Pre harvest	Mean
Mashora-E1	19.69	26.68	23.26	35.45	39.52	24.10
Kotkhai-E1	11.96	17.94	17.42	32.45	34.43	19.03
Kotkhai-E2	12.24	14.68	13.09	28.26	31.15	16.57
Rohru-E1	20.16	27.69	24.26	37.35	39.65	24.85
Rohru-E2	11.84	18.34	18.34	34.15	38.12	20.13
Kalpa	29.93	34.20	29.84	43.04	43.73	36.67
Reckong Peo	25.78	29.09	27.90	39.52	39.02	32.46
Mean	18.80	24.09	22.02	35.75	37.95	

*GP-PB: Green tip to pink bud; Fl-FS**: Flowering to fruit set

During the year 2013, mean soil moisture level (Table 10) was observed lowest (18.80%) between green tip to pink bud stage and highest (37.95%) at pre harvest stage (Table 28). Among the locations, soil moisture level was observed highest at Kalpa (36.67 %) and the lowest at lower altitude of Kotkhai (16.57 %).

4.1.4.1.2 Soil moisture level during different stages of fruit development in apple during 2014

In the year 2014, periodic observations on soil moisture level (Table 11) showed the similar pattern, as in the previous year it was observed constantly higher at higher altitude of Kalpa during different stages of fruit development (33.09, 35.25, 35.16, 37.42, 40.72 & 44.87 % during green tip to pink bud, flowering to fruit set, walnut, fruit development & pre-harvest stage, respectively) than all other locations. The next higher soil moisture levels during all the stages of development except, pre-harvest stage was recorded at lower altitude of Kinnaur (Reckong Peo). Lowest soil moisture content was recorded at lower altitude of Kotkhai during green tip to pink bud (9.85%), flowering to fruit set (10.52), fruit development (28.35%) and pre-harvest (32.92%) stage and at higher altitude of Kotkhai at walnut stage (13.77%).

Table 11 Soil moisture content at different growth stages of apple cv. Starking Delicious at different locations, in the year 2014

Location	GT-PB*	Fl-FS**	Walnut stage	Fruit development	Mean
Mashobra-E1	21.96	26.65	28.40	35.12	25.37
Kotkhai-E1	13.02	13.95	13.77	31.87	17.67
Kotkhai-E2	9.85	10.52	16.32	28.37	16.33
Rohru-E1	17.48	18.48	20.92	31.47	21.15
Rohru-E2	14.55	17.88	17.82	35.37	20.84
Kalpa	33.09	35.25	35.16	37.42	37.75
Reckong Peo	27.62	29.05	29.85	35.14	32.91
Mean	19.65	21.68	23.18	33.54	

*GP-PB: Green tip to pink bud; Fl-FS**: Flowering to fruit set

During the year 2014, the average soil moisture content (Table 11) gradually increased from green tip stage (19.65%) to pre harvest stage (37.28%). Among locations, soil moisture level was observed highest at Kalpa (37.75%) and lowest at lower altitude of Kotkhai (16.33 %).

Despite of lower rainfall (Table 9), frequent irrigation (Appendix II) during apple growing period might have maintained the higher soil moisture level in Kinnaur in comparison to rain fed orchards in Shimla district.

4.1.4.2 Soil temperature

4.1.4.2.1 Soil temperature during different stages of fruit development in apple during 2013

The data on soil temperature at different locations are enumerated in Table 12. It is evident from the data that in the year 2013, soil temperature increased with the progress in development stages in apple from green tip stage (12.79°C) to pre harvest stage (28.24°C). Among locations, mean soil temperature during the growing period was observed highest at Kalpa (22.14°C) and lowest (17.65°C) at Mashobra.

Table 12 Soil temperature at different growth stages of apple cv. Starking Delicious at different locations, in the year 2013

Location	*GP-PB	Fl-FS**	Walnut stage	Fruit development	Pre harvest	Mean
Mashobra-E1	12.20	18.60	22.40	25.40	27.30	17.65
Kotkhai-E1	13.20	19.30	23.40	26.00	29.80	18.62
Kotkhai-E2	13.70	19.60	24.90	26.60	30.40	19.20
Rohru-E1	12.80	19.10	23.60	25.80	28.40	18.28
Rohru-E2	13.40	19.20	23.90	26.20	29.70	18.73
Kalpa	12.22	18.40	22.90	24.20	26.20	22.14
Reckong Peo	12.00	18.20	22.60	23.70	25.90	21.63
Mean	12.79	18.91	23.39	25.41	28.24	

*GP-PB: Green tip to pink bud; Fl-FS**: Flowering to fruit set

4.1.4.2.2 Soil temperature during different stages of fruit development in apple during 2014

During the year 2014, soil temperature (Table 13) showed an increasing trend with the progress in growing period. Its lowest mean value (12.84°C) was recorded at green tip to pink bud stage and highest (27.23°C) at pre harvest stage. Among the locations, higher mean soil temperatures were recorded at Reckong Peo and Kalpa in Kinnaur district. However, minimum soil temperature (17.65°C) was observed at Mashobra. In this study, soil temperature had somewhat inverse relationship with

rainfall (Table 9) as Kalpa and Reckong Peo recorded lower rainfall and higher soil temperatures. On the contrary, higher rainfall at Mashobra might have decreased the soil temperature. During the study period, higher soil temperature at both the locations of Kinnaur could also be due to warming effect of greater solar influx (Appendix II).

Table 13 Soil temperature at different growth stages of apple cv. Starking Delicious at different locations, in the year 2014

Location	*GP-PB	Fl-FS**	Walnut stage	Fruit development	Pre harvest	Mean
Mashobra-E1	12.90	17.20	21.60	24.70	26.33	17.12
Kotkhai-E1	12.60	17.80	21.80	25.70	28.00	17.65
Kotkhai-E2	13.80	19.20	22.90	25.40	29.40	18.45
Rohru-E1	12.80	17.60	22.40	25.32	27.30	17.57
Rohru-E2	13.20	17.90	23.10	26.54	29.60	18.39
Kalpa	12.40	17.40	21.40	24.10	24.23	21.12
Reckong Peo	12.20	18.20	21.60	23.70	25.72	21.54
Mean	12.84	17.90	22.11	25.07	27.23	

*GP-PB: Green tip to pink bud; Fl-FS**: Flowering to fruit set

4.1.5 Plant height and spread

During 2013, the minimum plant height (4.85 m) was recorded at higher altitude of Kinnaur (Kalpa) which was however, statistically at par with Reckong Peo (Table 14). The maximum tree height was recorded at higher altitude of Kotkhai, followed by higher altitude of Rohru. During 2014, trees at higher altitude of Kinnaur (Kalpa) registered significantly shorter height (5.15 m) than all other locations except, lower altitude of Kinnaur (Reckong Peo) (5.27 m). The tree height was however, recorded greatest (6.69 m) at higher altitude of Kotkhai, which was however, comparable to the remaining locations in Shimla district. Pooled data revealed that minimum plant height (5.00 m) was recorded at higher altitude of Kinnaur (Kalpa) which was however, statistically at par with lower altitude of Kinnaur (Reckong Peo) and the maximum height was recorded at higher altitude of Kotkhai (6.63 m) which was comparable to Mashobra.

It is evident from the data in Table 14 that the plant spread was significantly influenced by different altitudes during both the years of study. During the year

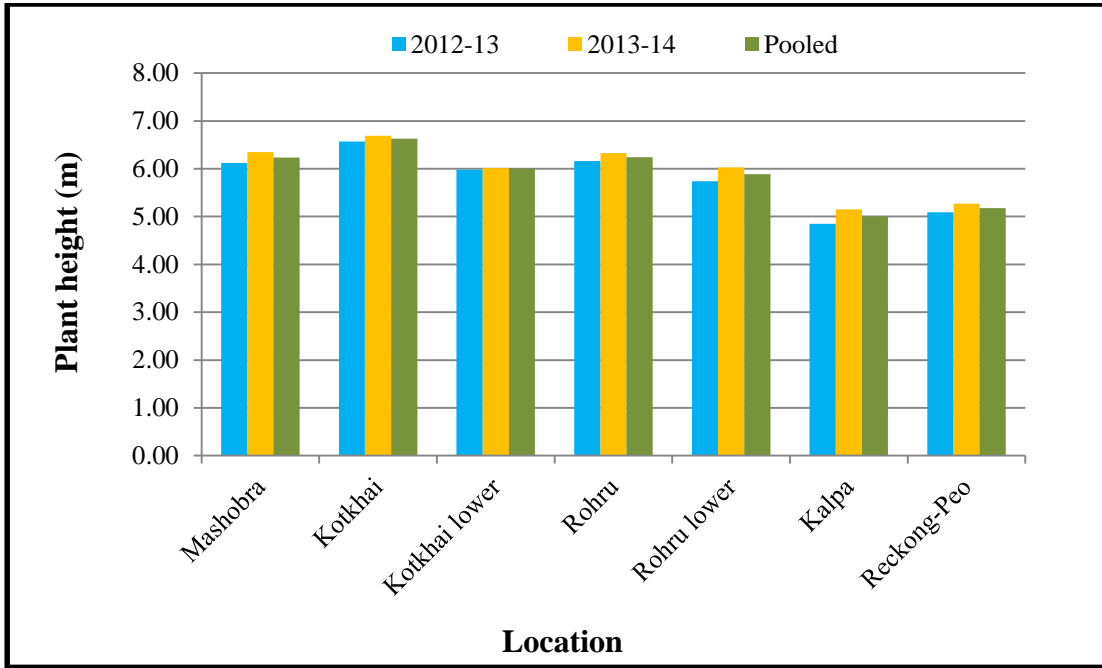


Figure 7 Tree height of apple cv. Starking Delicious at different locations of Shimla and Kinnaur districts

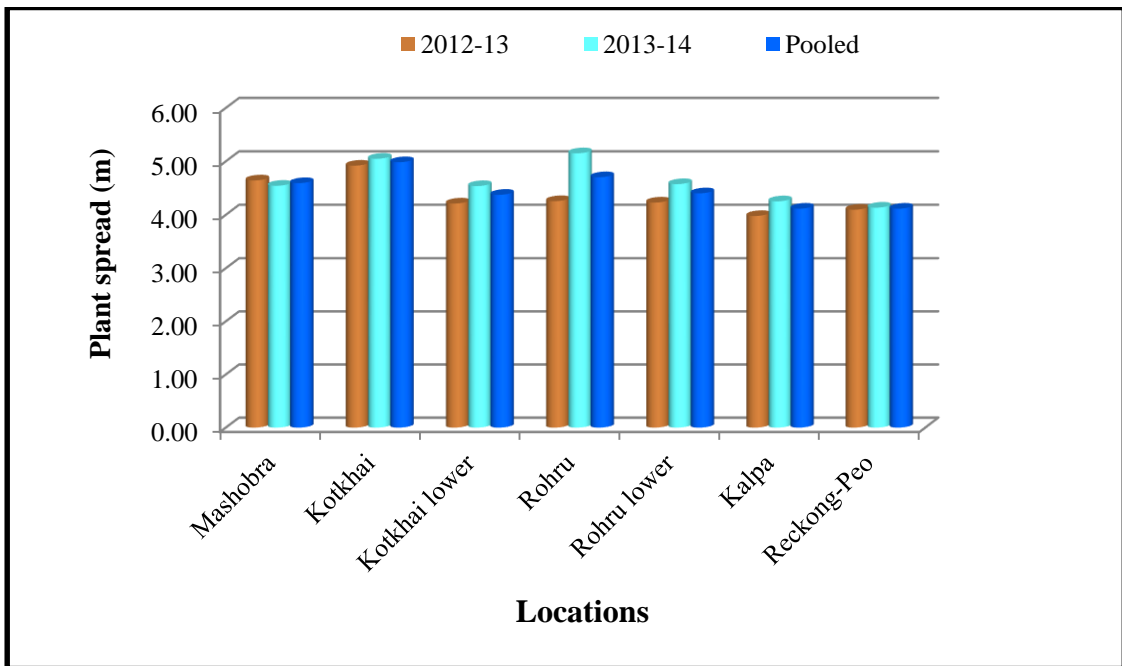


Figure 8 Tree spread of apple cv. Starking Delicious at different locations of Shimla and Kinnaur districts

2013, the average plant spread was recorded maximum (4.92 m) at higher altitude of Kotkhai, which was comparable with Mashobra (4.64 m). While, plant spread at higher altitude of Rohru, lower altitude of Rohru, Kotkhai and Kinnaur (Reckong Peo) and higher altitudes of Kinnaur (Kalpa) was recorded 4.26, 4.23, 4.21, 4.10 and 3.98 meters, respectively and these values were statistically at par with each other. However, during second year (2014), the maximum plant spread was recorded at higher altitude of Rohru (5.15 m) followed by higher altitude of Kotkhai (5.05 m). The plant spread was found to be least (4.13 m) at lower altitude of Kinnaur, which was however, statistically equal to all other locations except, higher altitudes of Kotkhai and Rohru.

Table 14 Tree height and spread of apple cv. Starking Delicious at different locations of Shimla and Kinnaur districts

Treatment	Location	Altitudes (m amsl)	2013		2014		Pooled	
			Height	Spread	Height	Spread	Height	Spread
T ₁	Mashobra-E1	2245	6.12	4.64	6.35	4.54	6.24	4.59
T ₂	Kotkhai-E1	1950	6.57	4.92	6.69	5.05	6.63	4.98
T ₃	Kotkhai-E2	1670	5.98	4.21	6.02	4.54	6.00	4.37
T ₄	Rohru- E1	2124	6.16	4.26	6.33	5.15	6.24	4.70
T ₅	Rohru-E2	1690	5.74	4.23	6.03	4.57	5.89	4.40
T ₆	Kalpa	2780	4.85	3.98	5.15	4.25	5.00	4.11
T ₇	Reckong Peo	2547	5.09	4.10	5.27	4.13	5.18	4.11
Mean			5.81	4.33	6.04	4.61	5.93	4.47
CD_{0.05}			0.66	0.61	0.79	0.71	0.53	0.49

The pooled data (Table 14 and Figure 7 & 8) revealed that the plant spread was significantly higher at higher altitude of Kotkhai (4.98 m) than all other locations except, higher altitude of Rohru (4.70 m) and Mashobra (4.59 m). It was found to be minimum (4.11 m) jointly at lower and higher altitude at Kinnaur, which was comparable to the lower altitudes of Rohru (4.40 m), and Kotkhai (4.37 m).

Lesser tree vigour at both the locations of Kinnaur can be attributed to shorter growing period as a result delayed phenological development (Table 15& 16). Further, tree growth at higher Kalpa and Reckong Peo might have lower down at lower air temperature (Table 5). Way and Oren (2010) found that increased temperature generally increases tree growth, except for tropical trees.

4.1.6 Effect of different locations on flowering parameters of apple cv. Starking Delicious

The data relating to flowering phenological stages (Plate 1 a & b) viz. bud swell, green tip, pink bud, anthesis, full bloom, petal fall and duration of flowering during 2013 at different locations are presented in (Table 15 and Table 16)

Table 15 Flowering phenological stages in apple cv. Starking Delicious at different locations of Shimla and Kinnaur districts, during 2013

Locations	Date of bud swell	Date of green tip	Date of pink bud	Date of anthesis	Date of full bloom	Date of petal fall	Duration of flowering
Mashobra-E1	10-03-2013	18-03-2013	24-03-2013	30-03-2013	06-04-2013	13-04-2013	20
Kotkhai-E1	10-03-2013	20-03-2013	23-03-2013	27-03-2013	31-03-2013	07-04-2013	17
Kotkhai-E2	26-02-2013	05-03-2013	09-03-2013	14-03-2013	18-03-2013	26-03-2013	16
Rohru-E1	13-03-2013	21-03-2013	26-03-2013	31-03-2013	07-04-2013	15-04-2013	18
Rohru-E2	12-03-2013	17-03-2013	23-03-2013	29-03-2013	02-04-2013	09-04-2013	17
Kalpa	05-04-2013	13-04-2013	21-04-2013	30-04-2013	04-05-2013	13-05-2013	25
Reckong Peo	18-03-2013	27-03-2013	04-04-2013	10-04-2013	15-04-2013	26-04-2013	23

Table 16 Flowering phenological stages in apple cv. Starking Delicious at different locations of Shimla and Kinnaur districts, during 2014

Locations	Date of bud swell	Date of green tip	Date of pink bud	Date of anthesis	Date of full bloom	Date of petal fall	Duration of flowering
Mashobra-E1	14-03-2014	21-03-2014	26-03-2014	02-04-2014	07-04-2014	14-04-2014	19
Kotkhai-E1	15-03-2014	22-03-2014	28-03-2014	01-04-2014	04-04-2014	10-04-2014	17
Kotkhai-E2	01-03-2014	10-03-2014	14-03-2014	17-03-2014	21-03-2014	28-03-2014	16
Rohru-E1	24-03-2014	31-03-2014	05-04-2014	11-04-2014	14-04-2014	22-04-2014	18
Rohru-E2	23-03-2014	26-03-2014	02-04-2014	08-04-2014	11-04-2014	17-04-2014	16
Kalpa	07-04-2014	17-04-2014	24-04-2014	30-04-2014	06-05-2014	13-05-2014	23
Reckong Peo	27-03-2014	04-04-2014	10-04-2014	18-04-2014	22-04-2014	30-04-2014	22

4.1.6.1 Bud swell stage

Bud swell stage was observed on different dates at different altitude ranges (Table 15 & 16). It ranged from 26th February to 5th April, during the year 2013 (Table 15), the earliest bud swell time pertained to lower altitude of Kotkhai and the latest to Kalpa. During 2014, it ranged from 1st March to 7th April. The earliest bud swell was recorded again at lower altitude of Kotkhai (1st March) followed by higher altitude of Kotkhai (15th March), however, it was much delayed at Kalpa (7th April).



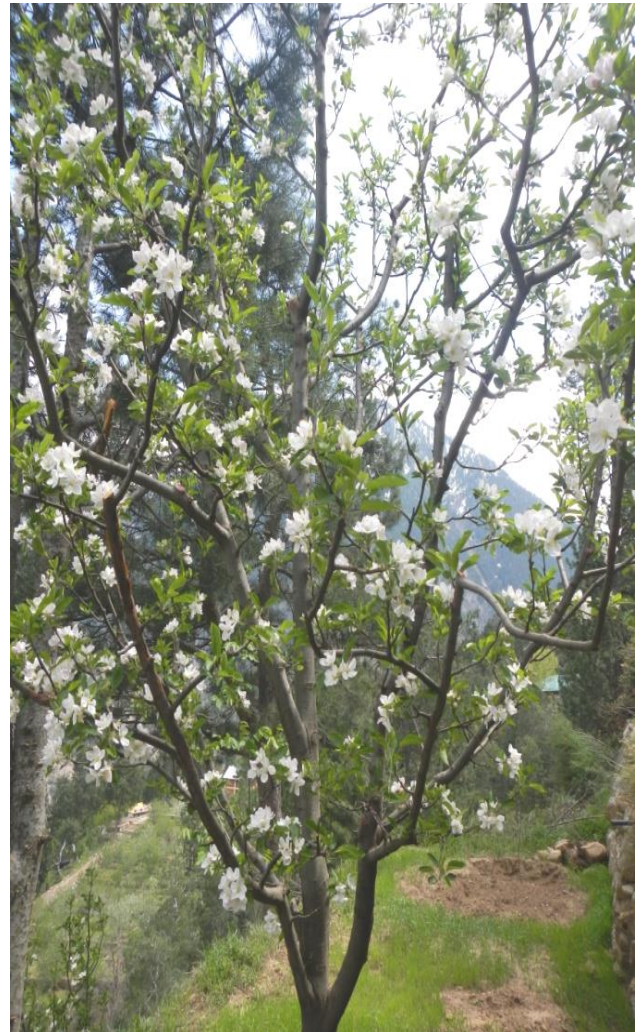
Green tip



Pink bud



Anthesis



Flowering stage



Petal fall

Plate 1 (a) Developing stages of apple fruit from green tip to fruit development



Fruit set



Walnut stage



Fruit development



Pre harvest

Plate 1 (b) Developing stages of apple fruit from green tip to pre harvest

4.1.6.2 Green tip stage

During the year 2013, green tip stage ranged from 5th March to 13th April at different locations (Table 15). Green tips appeared earliest at lower altitude of Kotkhai (5th March) however, this stage was seen much delayed at Kalpa (13th March). During 2014, green tip stage (Table 16) ranged from 10th March to 17th April. The appearance of green tips was noticed earliest (10th March) at lower altitude of Kotkhai, followed by higher altitude of Kotkhai (22th March) however, it got much delayed at Kalpa (17th April).

4.1.6.3 Pink bud stage

During year 2013, time of pink bud stage (Table 15) ranged from 9th March to 21st April at different locations. The appearance of pink buds was noticed earliest at lower altitude of Kotkhai (9th March) followed by higher altitude of Kotkhai (23rd March) whereas, at Reckong Peo and Kalpa pink buds appeared much later on 4th April and 21st April, respectively. During the year 2014, pink bud stage (Table 16) ranged from 14th March to 24th April, the earliest time pertained to lower altitude of Kotkhai and the furthest to Kalpa.

4.1.6.4 Time of anthesis

Time of anthesis was also greatly variable at different locations (Table 15 & 16). During 2014, it was first observed at lower altitude Kotkhai on 14th March followed by higher altitude of Kotkhai (27th March). It got much delayed at Reckong Peo (10th April) and Kalpa, (30th April). During 2014, (Table 16) it was observed first at lower altitude of Kotkhai on 17th March followed by higher altitude of Kotkhai (1st April). However, it got much delayed at Reckong Peo (18th April) and Kalpa (30th April).

4.1.6.5 Time of full bloom

During 2013, time of full bloom (Table 15) was observed earliest at lower altitude Kotkhai on 18th March followed by Kotkhai, higher altitude (31 March). Full bloom occurred very late at Reckong Peo on 15th April, and this stage further got delayed till 4th May at Kalpa. During 2014, it was first observed (Table 16) at

lower altitude of Kotkhai (21st March) followed by Kotkhai, higher altitude (4th April). Whereas, at Reckong Peo it was noticed on 22nd April and at Kalpa still later on 6th May.

4.1.6.6 Petal fall

During 2013, petal fall stage (Table 15) was first observed at lower altitude of Kotkhai on 26th March, followed by higher altitude of Kotkhai (7th April). At Reckong Peo it was noted quite later on 26th April and at Kalpa still much later on 13th May. During 2014, this stage (Table 16) was first observed at lower altitude of Kotkhai on 28th March, followed by higher altitude of Kotkhai (10th April). However, it got delayed till 30th April at Reckong Peo and till 13th May at Kalpa.

4.1.6.7 Duration of flowering

The data presented in Tables 15 and 16 revealed appreciable variation in the duration of apple flowering at different locations. In the year 2013, the shortest duration of flowering (Table 15) was observed at lower altitude of Kotkhai (16 days) followed by higher altitude of Kotkhai. It was however, observed much longer at Reckong Peo (23 days) and Kalpa (25 days). During 2014, the minimum duration of flowering (Table 16) was observed at lower altitudes of Kotkhai and Rohru (16 days) followed higher altitudes of Rohru and Kotkhai. Whereas, at Reckong Peo and Kalpa, it was recorded 22 days 23 days, respectively.

4.1.6.8 Flowering intensity

The perusal of data from Table 17 and Figure 9 revealed that the flowering intensity was significantly affected by different altitudes and locations during both the years of study. The maximum flowering intensity (28.40 %) was recorded at higher altitude of Kinnaur (Kalpa) which was however, statistically at par with lower altitude of Kinnaur (Reckong Peo). The minimum flowering intensity (15.80 %) was registered at lower altitude of Kotkhai, which was however, statistically at par with higher altitude of Kotkhai and lower as well as higher altitudes of Rohru. During 2014, the lowest flowering intensity (12.61%) was found at lower altitude of Kotkhai, which was statistically identical with higher altitude of Kotkhai (15.03

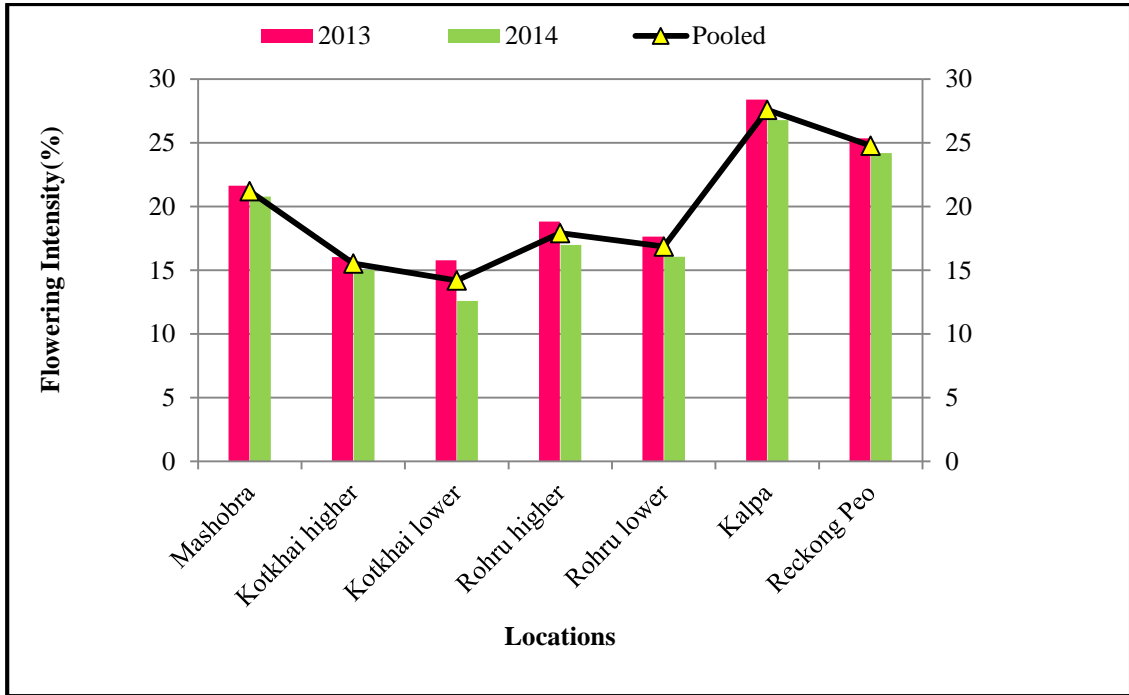


Figure 9 Flowering intensity of apple cv. Starking Delicious at different locations of Shimla and Kinnaur districts

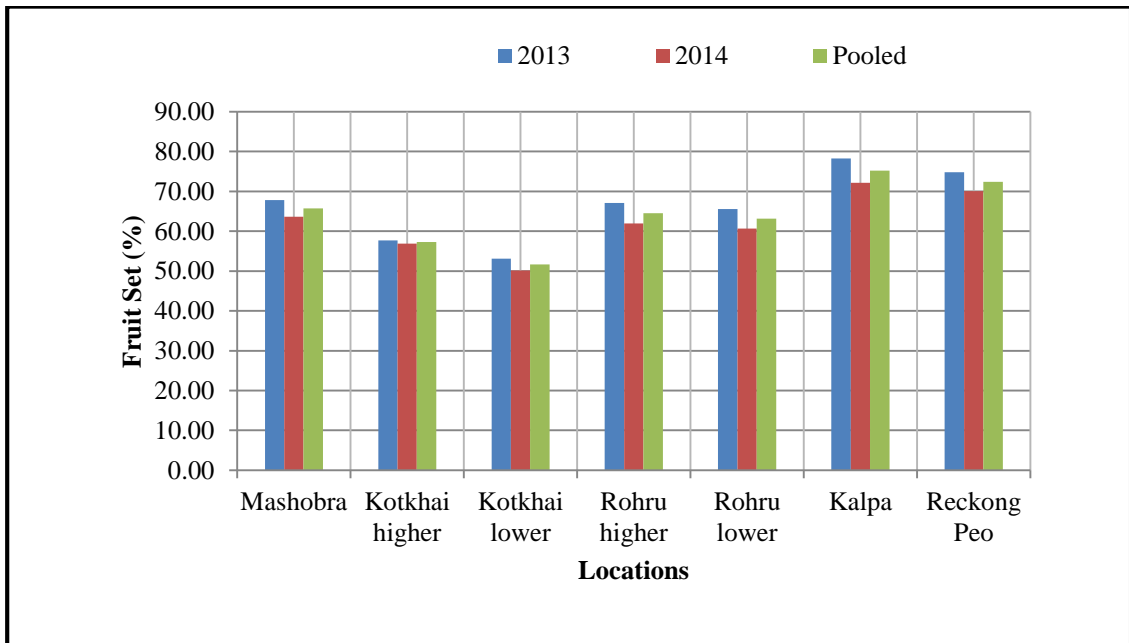


Figure 10 Fruit set of apple cv. Starking Delicious at different locations of Shimla and Kinnaur districts

%) and lower altitude of Rohru (16.06 %) whereas, the highest flowering intensity was recorded at Kalpa (26.78 %) which was however, statistical at par with Reckong Peo (24.20 %). The remaining locations *viz.*, Mashobra, and higher altitude of Rohru recorded 20.80 per cent and 17.00 per cent flowering intensity, respectively.

Table 17 Flowering intensity of apple cv. Starking Delicious at different locations of Shimla and Kinnaur districts

Treatment	Location	Altitudes (m amsl)	Flowering intensity (%)		
			2013	2014	Pooled
T ₁	Mashobra-E1	2245	21.63 (27.69)	20.80 (27.10)	21.21 (27.40)
T ₂	Kotkhai-E1	1950	16.05 (23.47)	15.03 (22.63)	15.54 (23.05)
T ₃	Kotkhai-E2	1670	15.80 (23.19)	12.61 (20.46)	14.20 (21.82)
T ₄	Rohru-E1	2124	18.84 (25.72)	17.00 (24.34)	17.92 (25.03)
T ₅	Rohru-E2	1690	17.66 (24.82)	16.06 (23.59)	16.86 (24.20)
T ₆	Kalpa	2780	28.40 (32.19)	26.78 (31.15)	27.59 (31.67)
T ₇	Reckong Peo	2547	25.37 (30.23)	24.20 (29.45)	24.78 (29.84)
Mean			20.53 (26.76)	18.92 (25.53)	19.73 (26.14)
CD_{0.05}			2.99	3.21	3.02

*Figures in parentheses are arcsine transformed values, while those outside are original values

The pooled analyzed data revealed that the flowering intensity was recorded highest (27.59 %) at higher altitude of Kinnaur (Kalpa) which was however, statistically at par with lower altitude of Kinnaur (Reckong Peo). The minimum flowering intensity was however, recorded at lower altitude of Kotkhai (14.20 %), which was found to be statistically at par with higher altitude of Kotkhai and higher altitudes of Rohru. In the present study, maximum temperature and minimum air temperature showed significant negative relationship (Table 36 and Table 37) with flowering intensity, which implied that higher flowering intensity at Kalpa and Reckong Peo was due to lower temperature.

4.1.7 Effect of different locations on fruit production and quality parameters of apple cv. Starking Delicious

4.1.7.1 Fruit set

The data presented in Table 18 revealed that per cent fruit set was significantly variable at different locations during the course of study. In the year 2013, the maximum fruit set (78.25 %) was recorded at higher altitude of Kinnaur (Kalpa) which was however, statistically at par with lower altitude of Kinnaur

(Reckong Peo) with 74.78 per cent fruit set. The fruit set was observed lowest at lower altitude of Kotkhai (53.09 %) which was however, statistically at par with higher altitudes of Kotkhai (57.70 %). The rest of locations viz., Mashobra, higher and lower altitudes of Rohru were intermediate in range (67.83-65.59 %). During the second year of study, the maximum fruit set (72.13 %) was recorded at higher altitude of Kinnaur (Kalpa) which was statistically at par with Reckong Peo (70.08 %). The minimum fruit set (50.70 %) was noted at lower altitude of Kotkhai which was however, statistically at par with higher altitude of Kotkhai (56.88 %). Rest of locations were ranged from 60.65 to 63.64 per cent fruit set, respectively.

Table 18 The fruit set of apple cv. Starking Delicious at different locations of Shimla and Kinnaur districts

Treatment	Location	Altitudes (m amsl)	Fruit set (%)		
			2013	2014	Pooled
T ₁	Mashobra-E1	2245	67.83 (55.48)	63.64 (52.93)	65.73 (54.19)
T ₂	Kotkhai-E1	1950	57.70 (49.45)	56.88 (48.95)	57.29 (49.20)
T ₃	Kotkhai E2	1670	53.09 (46.78)	50.17 (45.10)	51.63 (45.94)
T ₄	Rohru E1	2124	67.06 (55.06)	61.93 (51.95)	64.49 (53.49)
T ₅	Rohru E2	1690	65.59 (54.17)	60.65 (51.22)	63.12 (52.68)
T ₆	Kalpa	2780	78.25 (59.87)	72.13 (58.24)	75.19 (58.34)
T ₇	Reckong Peo	2547	74.78 (62.28)	70.08 (56.88)	72.43 (60.19)
Mean			66.33 (54.73)	62.21 (52.18)	64.27 (53.43)
CD_{0.05}			5.30	4.86	4.40

*Figures in parentheses are arcsine transformed values, while those outside are original values

The pooled data presented in Table 18 revealed that locations and altitudes had significant influence on the fruit set during the course of investigation. The maximum fruit set (75.19 %) was recorded at higher altitude of Kinnaur (Kalpa), which was however, statistically at par with lower altitude of Kinnaur (Reckong Peo) (72.43) whereas, the minimum fruit set (51.63 %) was recorded at lower altitude of Kotkhai. The rest of locations ranged between 57.29 to 65.73 per cent fruit set. Lu and Robersts (1952) also observed that better fruit set in ‘Delicious’ apples occurred under cooler than warm temperature conditions and opined that low night temperature and high day temperature was conducive to fruit set. During the study period, higher fruit set at Mashobra, Kalpa and Reckong Peo may be due to the prevalence of cooler night temperature conditions (Table 6) than lower altitudes of Kotkhai and Rohru. Singh (1987) reported that day time temperature of

18-22°C during flowering resulted in proper anthesis, cross pollination and fruit set in ‘Starking Delicious’ apples, while temperature above 25°C and below 15°C adversely affected the fruit set, which again supports the findings of the present study that higher fruit set at Kalpa and Reckong Peo may be attributed to near optimum day temperature conditions during flowering (Table 5). Kviklya and Robinson (2010) observed that high temperature (29/22.5°C) had more pronounced negative effect with on fruit set than cool temperatures (22/15°C) in ‘Empire’ apple.

4.1.7.2 Yield

The fruit yield was significantly affected by different locations and altitudes during the course of study (Table 19 & Figure 11). In the year 2013, the maximum fruit yield was recorded at higher altitude of Kinnaur (123.46 kg tree⁻¹) which was however, at par with lower altitude of Kinnaur (118.94 kg tree⁻¹) and Mashobra (115.91 kg tree⁻¹) whereas, the minimum yield was recorded at lower altitude of Kotkhai (107.42 kg tree⁻¹). The yield was recorded at remaining locations namely, higher and lower altitude of Rohru and higher altitude of Kotkhai were 112.98, 111.18 and 108.82 kg tree⁻¹, respectively. In the second year (2014), the maximum fruit yield was recorded again at Kalpa (115.73 kg tree⁻¹) which was statistically identical with Reckong Peo (111.43 kg tree⁻¹) and Mashobra (108.31 kg tree⁻¹). The minimum yield recorded at lower altitude of Kotkhai (99.31 kg tree⁻¹), which was however, statistically at par with higher altitude of Kotkhai and lower altitude of Rohru.

Table 19 Fruit yield of apple cv. Starking Delicious at different locations in Shimla and Kinnaur districts

Treatment	Location	Altitudes (m amsl)	Yield (kg tree ⁻¹)		
			2013	2014	Pooled
T ₁	Mashobra- E1	2245	115.91	108.31	112.11
T ₂	Kotkhai-E1	1950	108.82	103.09	105.96
T ₃	Kotkhai-E2	1670	107.42	99.31	103.37
T ₄	Rohru-E1	2124	112.98	107.17	110.08
T ₅	Rohru-E2	1690	111.18	105.01	108.10
T ₆	Kalpa	2780	123.46	115.73	119.60
T ₇	Reckong Peo	2547	118.94	111.43	115.19
Mean			114.10	107.15	110.63
CD_{0.05}			8.01	7.60	7.61

The pooled data presented in Table 19 clearly indicate that the higher altitude of Kinnaur (Kalpa) registered the maximum fruit yield (119.60 kg tree⁻¹) which was however, comparable with lower altitude of Reckong Peo (115.19 kg tree⁻¹) and Mashobra (112.11 kg tree⁻¹). The minimum average fruit yield was recorded at lower altitude of Kotkhai (103.37 kg tree⁻¹), which was however, statistically at par with higher altitude of Kotkhai and lower altitude of Rohru.

4.1.7.3 Productivity

The productivity (tonnes/ha) which is an important parameter was found to be significantly affected by different locations and altitudes during the course of study in 2013 and 2014 (Table 20 & Figure 12). In the first year of study, the maximum productivity was recorded at higher altitude of Kinnaur (Kalpa) (34.29 tonnes ha⁻¹) which was at par with lower altitude of Kinnaur (Reckong Peo) (33.04 tonnes ha⁻¹) whereas, the minimum productivity was recorded at lower altitude of Kotkhai (19.10 tonnes ha⁻¹). During 2014, the maximum productivity was recorded at Kalpa (32.15 tonnes ha⁻¹), which was identical with Reckong Peo (30.95 tonnes ha⁻¹). Whereas, the minimum productivity was recorded at lower altitude of Kotkhai (17.66 tonnes ha⁻¹).

The pooled data presented in Table 20 revealed that maximum productivity was recorded at Kalpa (33.22 tonnes ha⁻¹) which was comparable with Reckong Peo (32.00 tonnes ha⁻¹) whereas, the minimum productivity was recorded at lower altitude of Kotkhai (18.38 tonnes ha⁻¹).

Table 20 The productivity of apple cv. Starking Delicious at different locations of Shimla and Kinnaur districts of Himachal Pradesh

Treatment	Location	Altitudes (m amsl)	Productivity (tonnes ha ⁻¹)		
			2013	2014	Pooled
T ₁	Mashobra-E1	2245	20.61	19.26	19.93
T ₂	Kotkhai-E1	1950	19.35	18.33	18.84
T ₃	Kotkhai-E2	1670	19.10	17.66	18.38
T ₄	Rohru-E1	2124	20.09	19.05	19.57
T ₅	Rohru-E2	1690	19.77	18.67	19.22
T ₆	Kalpa	2780	34.29	32.15	33.22
T ₇	Reckong Peo	2547	33.04	30.95	32.00
Mean			23.75	22.30	23.02
CD_{0.05}			1.88	1.79	1.84

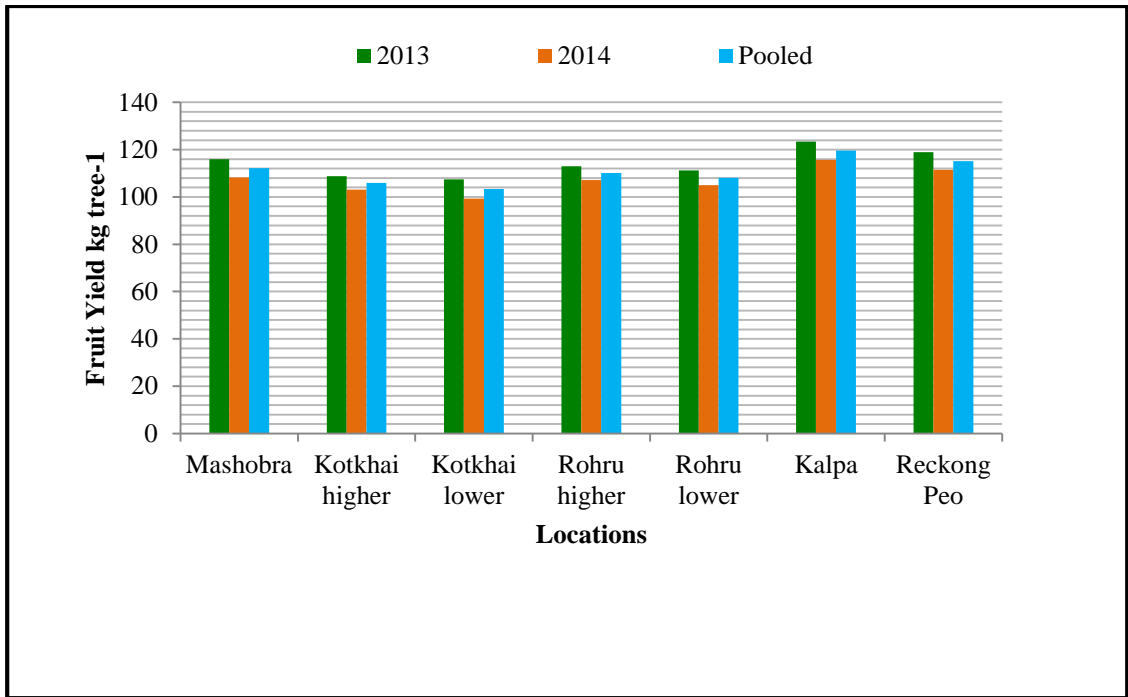


Figure 11 Fruit yield of apple cv. Starking Delicious at different locations in Shimla and Kinnaur districts

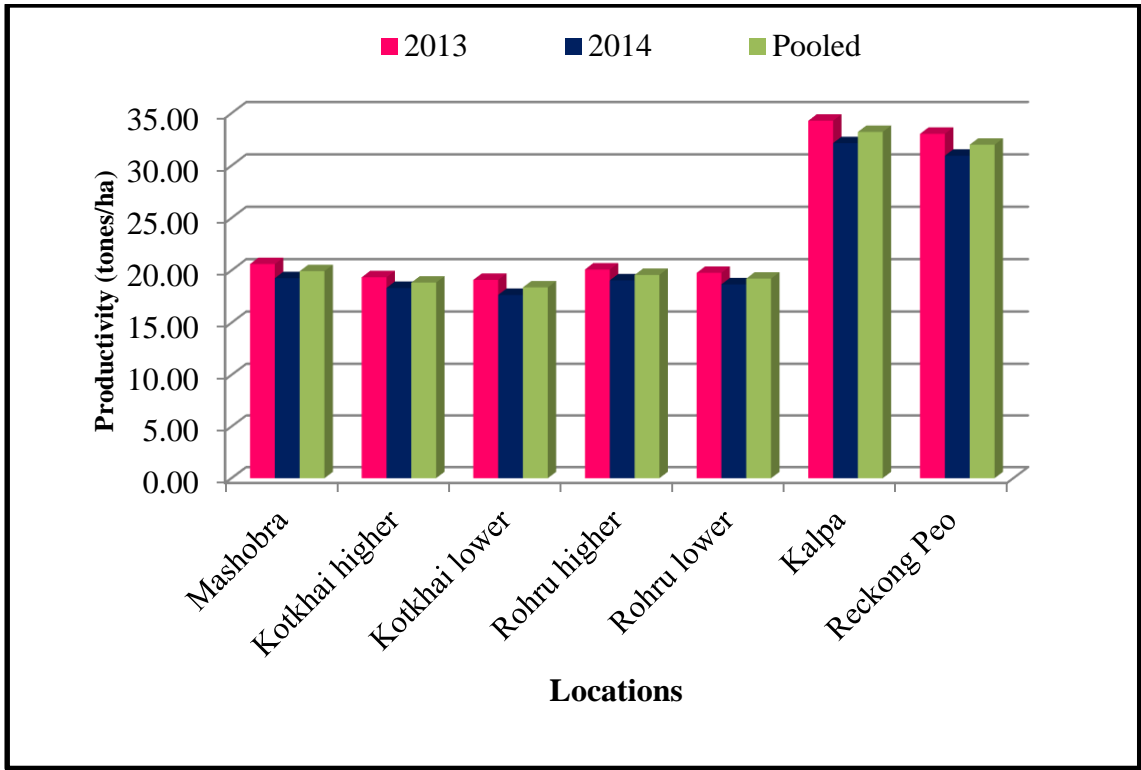


Figure 12 Productivity of apple cv. Starking Delicious at different locations of Shimla and Kinnaur districts of Himachal Pradesh

During the study, higher yield at Kalpa and Reckong Peo is clearly understandable due to higher flowering intensity (Table 17), fruit set (Table 18) and fruit weight (Table 24) at these location. Higher solar radiation (Figure 51 & 52) may have also led to increased fruit yield at these locations (Brar *et al.*, 2013). Jay and Lichou (2007) found that in apricot, yield had a positive correlation with low temperature in winter. In agreement with their finding, lower winter temperatures at Mashobra, Kalpa and Rockong Peo (Tables 5 & 6) might have led to higher flowering intensity and more yields. There are reports to suggest that the productivity of apple has a tendency to decline with an increase in the temperature (Sitompul *et al.*, 2013), thus it seems that the higher average air temperature recorded at lower altitudes of Kotkhai and Rohru (Table 5) during entire growing period in this study resulted in lower fruit yield compared to higher altitudes. Mattioli (1998) found that fluctuation in temperature at critical stages of fruit development was the main limiting factor affecting productivity in apple. Higher mean temperature from January to March shortened period of fruit development and decreased the fruit yield in 'Burlat and 'Germersdorfer' cultivars of sweet cherry (Usenik and Stamper, 2011).

4.1.7.4 Fruit length

It is evident from the data in Table 21 and Figure 13 that the fruit length was significantly affected by different locations and altitudes during both the years of study. During the year 2013, the average length was recorded significantly higher in fruits from higher altitude of Kinnaur i.e. Kalpa (77.23 mm) than those from all other locations except, lower altitude of Kinnaur (Reckong Peo). It was observed that fruit length was significantly shorter at lower altitude of Kotkhai (60.49 mm) which however, found to be at par with higher altitude of Kotkhai (61.86 mm), whereas, fruit length at Mashobra and both the locations of Rohru was in the intermediate range (65.44 - 66.71 mm). Likewise, during second year 2014, the fruit length was recorded significantly higher at Kalpa (73.81 mm) and followed by Reckong Peo. The fruit length was found to be significantly shorter at lower altitude of Kotkhai (62.03 mm) in comparison to both the locations of Kinnaur, however, it was significantly at par with the remaining locations.

Table 21 The fruit length of apple cv. Starking Delicious at different locations in Shimla and Kinnaur districts

Treatment	Location	Altitudes (m amsl)	Fruit length (mm)		
			2013	2014	Pooled
T ₁	Mashobra-E1	2245	65.83	65.82	65.83
T ₂	Kotkhai-E1	1950	61.86	63.45	62.65
T ₃	Kotkhai-E2	1670	60.49	62.03	61.26
T ₄	Rohru-E1	2124	66.71	65.09	65.90
T ₅	Rohru-E2	1690	65.44	64.51	64.97
T ₆	Kalpa	2780	77.23	73.81	75.52
T ₇	Reckong Peo	2547	73.62	68.89	71.26
Mean			67.31	66.23	66.77
CD_{0.05}			4.11	3.91	3.92

The pooled data revealed that the fruit length (Table 21) was significantly more (75.52 mm) at higher altitude of Kinnaur (Kalpa), followed by lower altitude of Kinnaur (Reckong Peo). It was found to be minimum at lower altitude at Kotkhai (61.26 mm) which was however, statistically at par with higher altitude of Kotkhai (62.65 mm) and lower altitude of Rohru (64.97 mm). The average fruit length at Mashobra and higher altitude of Rohru were in the intermediate range. The fruit length was found greater at higher altitudes in the study. Greater fruit expansion rates at higher altitudes can be attributed to extended period of cell division at cooler growing conditions (Warrington *et al.*, 1999).

4.1.7.5 Fruit diameter

Data presented in Table 22 and Figure 14 show that the fruit diameter was significantly variable at different locations during the course of investigation. During the year 2013, the fruit diameter was observed significantly higher at Kalpa (76.70 mm) than all other locations except, Reckong Peo (73.74 mm). Although, fruit diameter was found to be minimum (68.66 mm) at the lower altitude Rohru, it was however, statistically at par with all other locations except, Kalpa. Likewise, in the year 2014, the fruit diameter recorded significantly higher at Kalpa (76.70 mm) in comparison to all other locations except, Reckong Peo (74.23 mm). The fruit diameter was noted smallest (64.42 mm) at lower altitude of Kotkhai, which was however, statistically at par with higher altitude of Kotkhai, both the locations of Rohru and Mashobra.

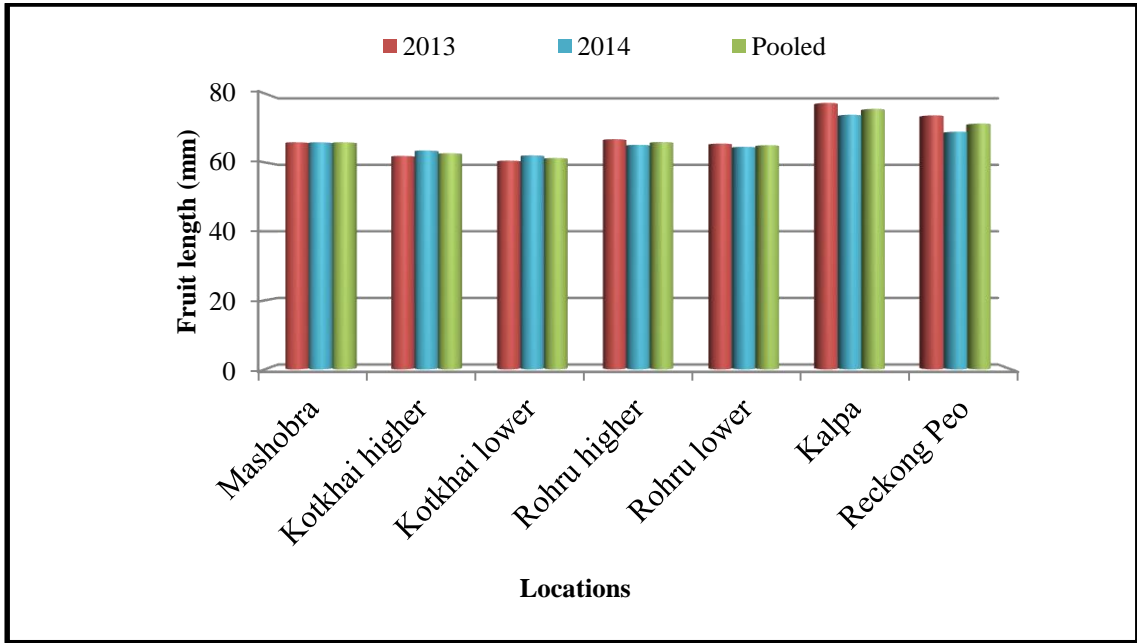


Figure 13 Fruit length of apple cv. Starking Delicious at different locations in Shimla and Kinnaur districts

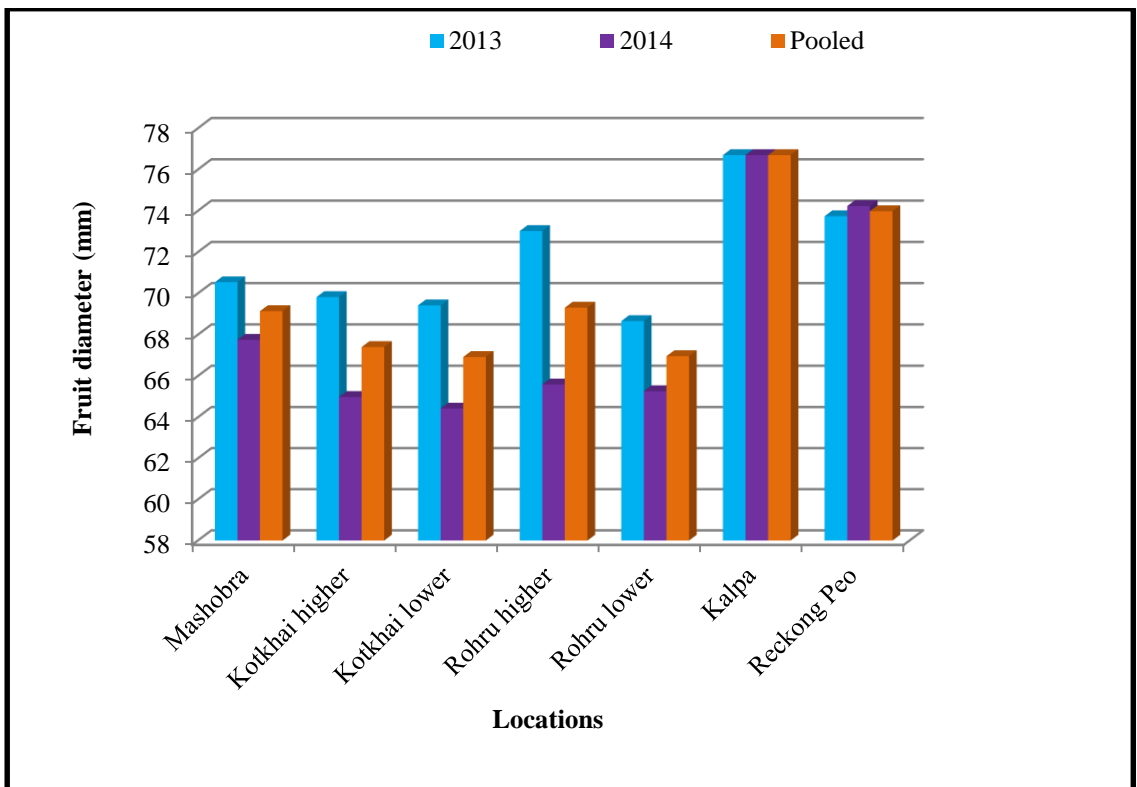


Figure 14 Fruit diameter of apple cv. Starking Delicious at different locations in Shimla and Kinnaur districts

Table 22 The fruit diameter of apple cv. Starking Delicious at different locations in Shimla and Kinnaur districts

Treatment	Location	Altitudes (m amsl)	Fruit diameter (mm)		
			2013	2014	Pooled
T ₁	Mashobra-E1	2245	70.54	67.75	69.14
T ₂	Kotkhai-E1	1950	69.82	64.98	67.40
T ₃	Kotkhai-E2	1670	69.42	64.42	66.92
T ₄	Rohru-E1	2124	73.02	65.59	69.31
T ₅	Rohru-E2	1690	68.66	65.26	66.96
T ₆	Kalpa	2780	76.70	76.70	76.70
T ₇	Reckong Peo	2547	73.74	74.23	73.98
Mean			71.70	68.42	70.06
CD_{0.05}			3.63	3.91	3.69

The pooled data presented in Table 22 revealed significantly higher fruit diameter was recorded at Kalpa (76.70 mm) in comparison to all other locations except, Reckong Peo (73.98 mm). Average fruit diameter was found to be minimum (66.92 mm) at lower altitude of Kotkhai, however, it was statistically at par with all other locations except, Kalpa and Reckong Peo. In the present study, smaller apple fruits at lower altitudes in Shimla can be attributed to higher air temperature during fruit development (Table 5). Higher temperature over 30°C for more than 15 days can reduce apple fruit size in comparison to those developed during the normal climate year, in apple cultivar Fuji (WongLiXin and FengShiHai, 2006). Furthermore, lower availability of water in the soil (Table 10 & 11) might have impeded fruit growth at lower altitudes.

4.1.7.6 Length/diameter ratio

The data on fruit length/diameter ratio of apple presented in Table 23 and Figure 15 revealed that during the year 2013, its maximum value (1.01%) was registered at Kalpa which was however, statistically at par with Reckong Peo (1.00 %). It was found to be minimum at lower altitude of Kotkhai (0.87 %) which was comparable with higher altitudes of Kotkhai (0.89 %) and Rohru. However, during the year 2014, the highest length/diameter ratio (0.99 %) was recorded jointly at higher and lower altitude of Rohru which was however, statistically at par with all other locations except, Reckong Peo (0.93 %).

Table 23 Fruit length/diameter ratio of apple cv. Starking Delicious at different locations in Shimla and Kinnaur districts

Treatment	Location	Altitudes (m amsl)	Length/diameter ratio (%)		
			2013	2014	Pooled
T ₁	Mashobra-E1	2245	0.93 (5.54)	0.97 (5.66)	0.95 (5.60)
T ₂	Kotkhai-E1	1950	0.89 (5.40)	0.98 (5.67)	0.93 (5.54)
T ₃	Kotkhai-E2	1670	0.87 (5.35)	0.96 (5.63)	0.92 (5.49)
T ₄	Rohru-E1	2124	0.91 (5.48)	0.99 (5.72)	0.95 (5.60)
T ₅	Rohru-E2	1690	0.95 (5.60)	0.99 (5.71)	0.97 (5.66)
T ₆	Kalpa	2780	1.01 (5.76)	0.96 (5.63)	0.98 (5.69)
T ₇	Reckong Peo	2547	1.00 (5.73)	0.93 (5.53)	0.96 (5.63)
Mean			0.94 (5.55)	0.97 (5.55)	0.95 (5.60)
CD_{0.05}			0.01	0.02	0.01

*Figures in parentheses are arcsine transformed values while those outside are original values

The pooled analyzed data show that the fruit length/diameter ratio was higher at Kalpa (0.99 %) which was however, statistically at par with all other locations except, lower altitude of Kotkhai (0.92 %). Higher fruit length/diameter ratio as noted at different higher altitude locations in the present study is similar to the findings of Kim Seungttevi *et al.* (2004), who found that the altitude of orchard has curvilinear correlation with fruit shape index, and that hilly apple orchards located at higher altitude had more chances for production of quality fruits.

4.1.7.7 Fruit weight

The data on fruit weight of apple presented in Table 24 and Figure 16 revealed that the fruit weight was significantly affected by different altitudes and locations during the course of study. In the year 2013, significantly higher fruit weight (223.86 g) was recorded at higher altitude of Kinnaur (Kalpa) in comparison to all other locations. Second higher value (204.94 g) pertained to lower altitude of Kinnaur (Reckong Peo), which was significantly superior to all the locations of district Shimla. However, the lower altitude of Kotkhai registered the minimum fruit weight (143.39 g), which was however, comparable with higher altitude of Kotkhai (145.82 g). Almost similar pattern was noted on this parameter in the year 2014. The higher altitude of Kinnaur (Kalpa) registered significantly more fruit weight (219.44 g) in comparison to all other locations. The next superior locations in this respect were Reckong Peo (191.06 g) and Mashobra (177.40 g).

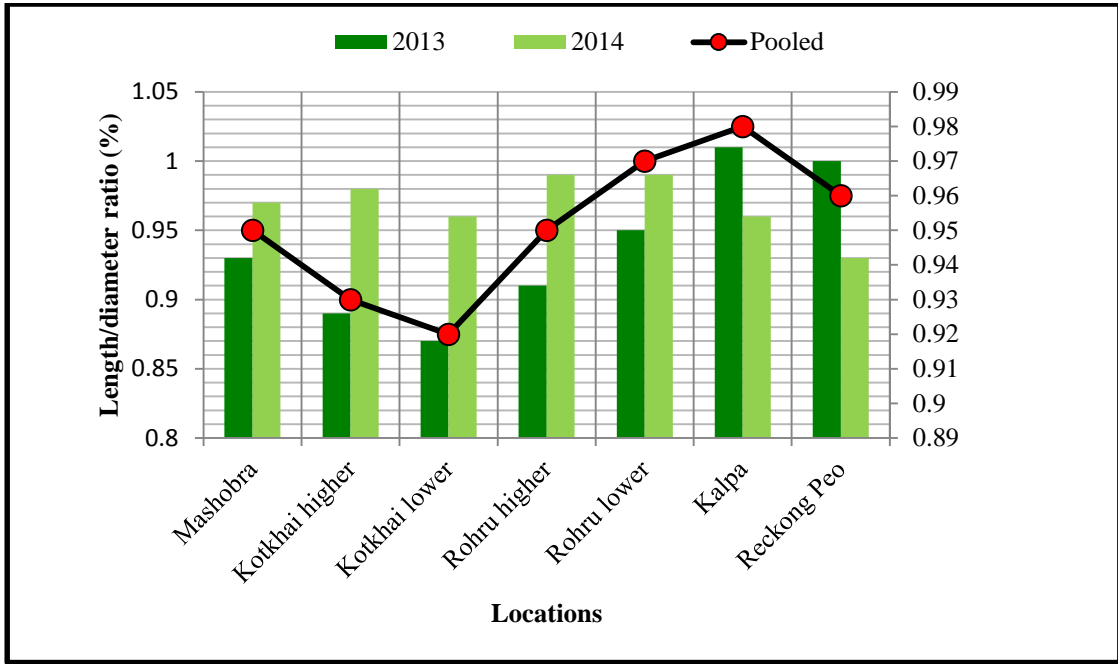


Figure 15 Fruit length/diameter ratio of apple cv. Starking Delicious at different locations in Shimla and Kinnaur districts

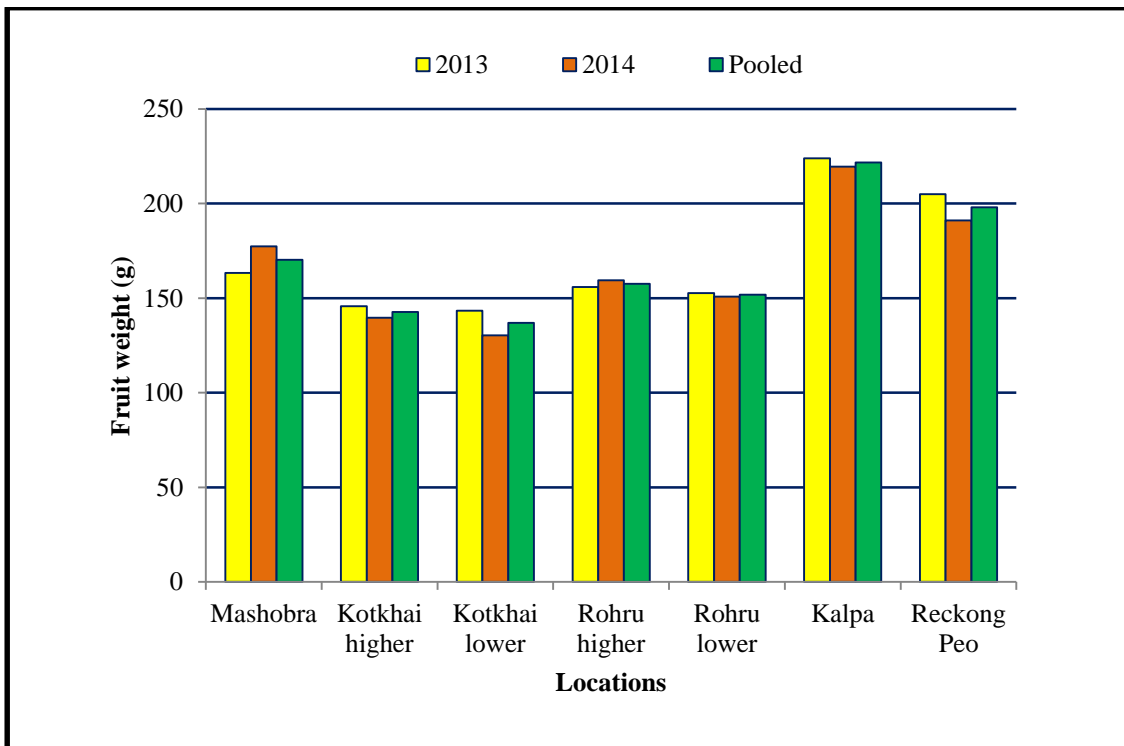


Figure 16 Fruit weight of apple cv. Starking Delicious at different locations in Shimla and Kinnaur districts

The average fruit weight was observed to be significantly lowest at lower altitude of Kotkhai (130.40 g).

Table 24 The fruit weight of apple cv. Starking Delicious at different locations in Shimla and Kinnaur districts

Treatment	Location	Altitudes (m amsl)	Weight (g)		
			2013	2014	Pooled
T ₁	Mashobra-E1	2245	163.30	177.40	170.35
T ₂	Kotkhai-E1	1950	145.82	139.73	142.77
T ₃	Kotkhai-E2	1670	143.39	130.40	136.89
T ₄	Rohru-E1	2124	155.93	159.39	157.66
T ₅	Rohru-E2	1690	152.73	150.90	151.82
T ₆	Kalpa	2780	223.86	219.44	221.65
T ₇	Reckong Peo	2547	204.94	191.06	198.00
Mean			170.00	166.90	168.45
CD_{0.05}			3.55	3.49	3.43

The pooled data present in Table 24 show that the fruit weight was significantly more at higher altitude of Kinnaur (221.65 g), which was followed by lower altitude of Kinnaur (198.00 g). The fruit weight was however, recorded significantly least (136.89 g) at lower altitude of Kotkhai. During the study, apple fruits from the higher altitude locations were greater in size and weight in comparison to those obtained from lower altitude locations, which can be attributable to lower air temperature (Tables 5 & 6) and higher solar radiation (Figure 51 & 52) as stated earlier and more availability of water (Table 10 & 11). As discussed above, increase in air temperature decreased the average fruit size and weight in apple than the fruits grown in cooler climates (Josuttis *et al.*, 2011) and regions receiving more solar radiations (Li JinQiang *et al.*, 2010).

4.1.7.8 Fruit colour

During 2013, observation on fruit colour development (Table 25 and Plate 2 & 3) revealed that greatly higher red colour (RED GROUP CARD 45 A) was observed on fruits at higher altitude of Kinnaur (Kalpa). However, the fruits of lower altitude of Kotkhai had lower color development over their surface (RED GROUP CARD 43 C). During 2014, fruits at higher altitude of Kinnaur (Kalpa) reported more intense red colour with RED GROUP CARD 45 A. While, lesser red color (RED GROUP CARD 47 D) was observed at lower altitude of Kotkhai.

Higher surface colour development in apple at Kalpa might be attributed to greater UV radiation (Figure 51 & 52). Liu XingJun *et al.*, (2000) found that apple cultivar Golden Delicious, exhibited red blush colour on the fruit at higher altitude due to more ultraviolet rays, more sunshine hours and larger daily temperature deviation. Solomakhin and Blanke (2010) observed that apple fruit colouration was dependent on photosynthetically active radiation (PAR) and UV radiations.

Table 25 The fruit colour of apple cv. Starking Delicious at different locations in Shimla and Kinnaur districts

Location	Colour of fruits	
	2013	2014
Mashobra-E1	Card 43 A	Card 45 C
Kotkhai-E1	Card 43 B	Card 47 C
Kotkhai-E2	Card 43 C	Card 47 D
Rohru-E1	Card 44 C	Card 44 D
Rohru-E2	Card 47 B	Card 44 C
Kalpa	Card 45 A	Card 45 A
Reckong Peo	Card 45 C	Card 45 C

4.1.7.9 Total Soluble Solid (TSS)

The data (Table 26 & Figure 17) revealed that the fruit TSS content was significantly affected by different altitudes and locations during both the years of study. During the year 2013, the highest TSS (15.99 °Brix) was found in fruits from higher altitude of Kinnaur (Kalpa) which was however, statistically at par with fruits of lower altitude of Kinnaur (Reckong Peo), Mashobra and higher altitude of Rohru. The minimum TSS content (14.39 °Brix) was observed in fruits from lower altitude of Kotkhai, which was statistically at par with fruits from all the locations of district Shimla. Likewise, during the year 2014, the maximum TSS (14.57 °Brix) was recorded in fruits from higher altitude of Kinnaur (Kalpa) which however, was statistically at par with lower altitude of Kinnaur (Reckong Peo), Mashobra and higher altitude of Rohru. The minimum fruit TSS (12.33 °Brix) was observed at lower altitude of Kotkhai which was however, statistically at par with higher altitude of Kotkhai and lower altitude of Rohru.

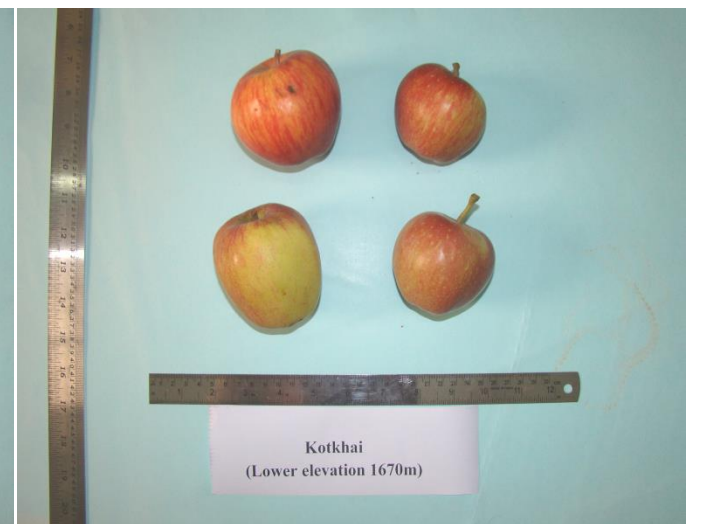


Plate 2—Colour of fruits at different locations in Shimla and Kinnaur Districts

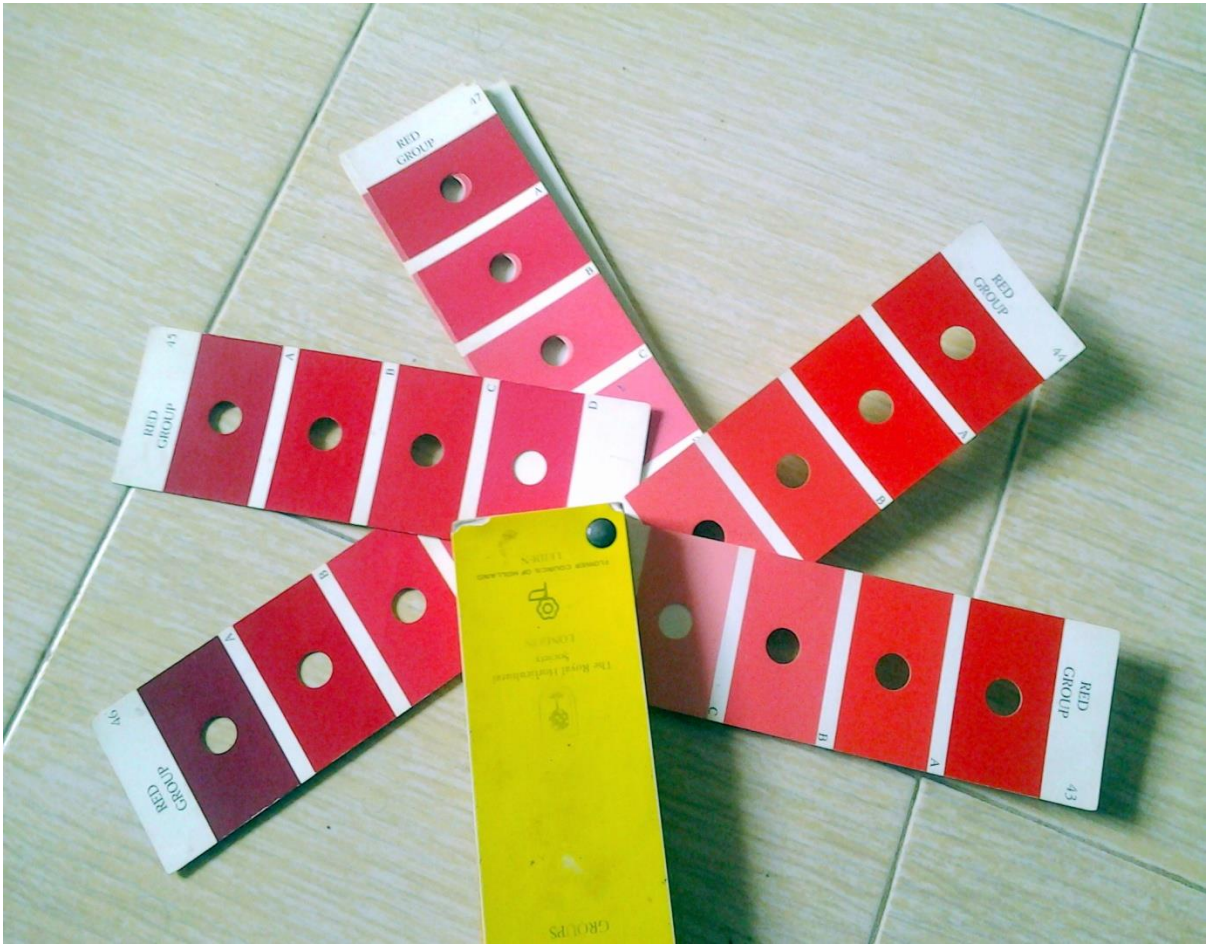


Plate 3- Colour chart used in colour of apple fruit of different locations

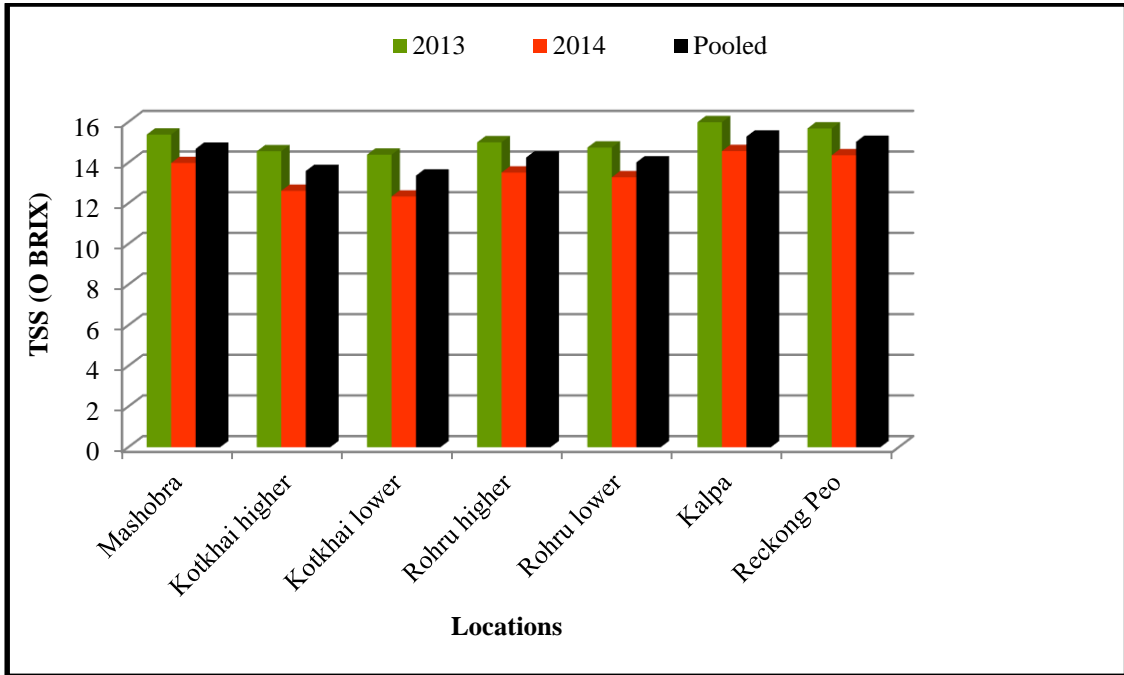


Figure 17 Fruit TSS contents of apple cv. Starking Delicious at different locations in Shimla and Kinnaur districts

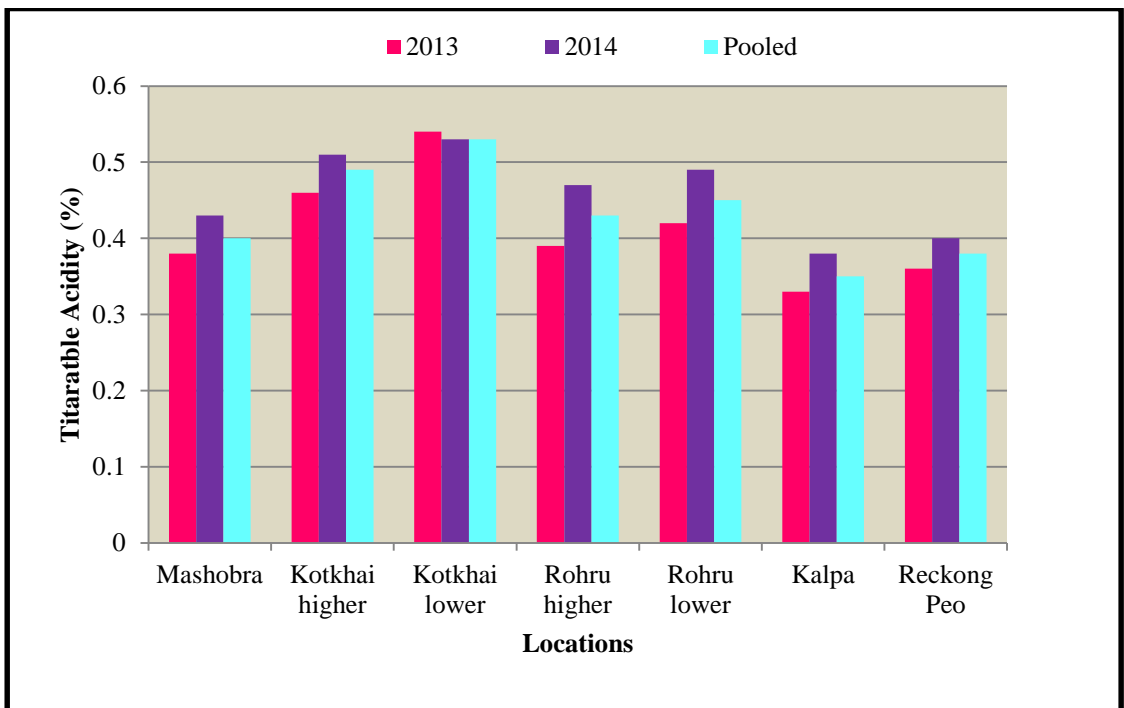


Figure 18 Titratable acidity of apple cv. Starking Delicious at different locations in Shimla and Kinnaur districts

Table 26 Fruit TSS contents of apple cv. Starking Delicious at different locations in Shimla and Kinnaur districts

Treatment	Location	Altitudes (m amsl)	TSS (°Brix)		
			2013	2014	Pooled
T ₁	Mashobra-E1	2245	15.38	13.98	14.68
T ₂	Kotkhai-E1	1950	14.56	12.61	13.59
T ₃	Kotkhai-E2	1670	14.39	12.33	13.36
T ₄	Rohru-E1	2124	15.00	13.51	14.25
T ₅	Rohru-E2	1690	14.74	13.28	14.01
T ₆	Kalpa	2780	15.99	14.57	15.28
T ₇	Reckong Peo	2547	15.68	14.36	15.02
Mean			15.11	13.52	14.31
CD_{0.05}			1.10	0.91	1.07

*Figures in parentheses are arcsine transformed values while those outside are original values

It is apparent from the pooled data (Table 26) that fruit TSS contents of apple cv. Starking Delicious ranged from 13.36 to 15.28 °Brix at different locations. The highest TSS value pertained to fruits from higher altitude of Kinnaur (Kalpa), which was significantly superior to fruits from both the locations of Kotkhai and lower altitude of Rohru. The minimum fruit TSS content was found at lower altitude of Kotkhai (13.36 °Brix) which was comparable with higher altitude of Kotkhai (13.59°Brix) and lower altitude of Rohru. The results are in agreement with the earlier findings that TSS contents were higher in apples from higher altitudes of Kinnaur (Verma and Chauhan, 2012) and Kotkhai (Attar, 2006) as compared to the respective lower altitudes. The higher TSS contents in apple fruits from Kalpa can be ascribed to more solar radiations (Figure 51 & 52) and lower respiration losses of sugars due to cooler night (Table 6). Soluble solids content increased with the increasing solar radiations (Li JinQiang *et al.*, 2010) and lower average daytime temperature (Li XianMing *et al.*, 2010).

4.1.7.10 Titratable acidity

The data on titratable acidity of apple presented in Table 27 and Figure 18 revealed that the fruit acidity expressed in terms of malic acid ranged from 0.33 to 0.54 per cent during the years 2013 and 0.38 to 0.53 per cent during 2014, at different locations. In the year 2013, the fruit acid content was recorded significantly higher at lower altitude of Kotkhai than all other locations, which was followed by higher altitude of Kotkhai and lower altitude of Rohru in the

decreasing order. The lowest percentage of acidity (0.33 %) was found in fruits of higher altitude of Kinnaur (Kalpa) which was however, statistically at par with lower altitude of Kinnaur (Reckong Peo). During the year 2014, the lowest acidity (0.38 %) was again recorded in fruits from higher altitude of Kinnaur (Kalpa) which was at par with Reckong Peo (0.40 %). Significantly higher acidity was recorded in fruits of lower altitude of Kotkhai (0.53 %) in comparison to all other locations except, higher altitude of Kotkhai.

Table 27 The titratable acidity of apple cv. Starking Delicious at different locations in Shimla and Kinnaur districts

Treatment	Location	Altitudes (m amsl)	Titratable acidity (%)		
			2013	2014	Pooled
T ₁	Mashobra-E1	2245	0.38 (3.50)	0.43 (3.76)	0.40 (3.63)
T ₂	Kotkhai-E1	1950	0.46 (3.89)	0.51 (4.09)	0.49 (3.99)
T ₃	Kotkhai-E2	1670	0.54 (4.20)	0.53 (4.18)	0.53 (4.19)
T ₄	Rohru-E1	2124	0.39 (3.56)	0.47 (3.94)	0.43 (3.75)
T ₅	Rohru-E2	1690	0.42 (3.69)	0.49 (4.02)	0.45 (3.86)
T ₆	Kalpa	2780	0.33 (3.27)	0.38 (3.54)	0.35 (3.41)
T ₇	Reckong Peo	2547	0.36 (3.42)	0.40 (3.64)	0.38 (3.53)
Mean			0.41 (3.65)	0.46 (3.88)	0.43 (3.76)
CD_{0.05}			0.03	0.03	0.03

*Figures in parentheses are arcsine transformed values while those outside are original values

It is clearly revealed from the pooled data (Table 27) that the lowest acidity was recorded at higher altitude of Kinnaur (Kalpa) (0.35 %) which was however, statistically at par with lower altitude of Kinnaur (Reckong Peo) but, significantly lower than the remaining locations. Fruit acidity was found to be significantly higher in fruits of lower altitude of Kotkhai (0.53 %) in comparison to those from all other locations. Vangdal *et al.* (2007) studied the correlation between climatic factors and fruit quality in plum cultivars in Norway and found that higher precipitation in rainy season led to higher acidity in fruits. These findings correlates well with present study, as higher acid content were observed at lower altitudes of Kotkhai and Rohru that comes under wet temperate zones and received more precipitation in rainy season (Table 9). Lower fruit acidity at Kalpa and Reckong Peo can also be attributed to lower average air temperature during day (Li XianMing *et al.*, 2010).

4.1.7.11 Total soluble solids / acid ratio

It is revealed from the perusal of data in Table 28 and Figure 19 that TSS/acid ratio in fruit was significantly variable at different locations during both the years of study. Fruit TSS/acid ratio ranged from 26.92 to 49.47 per cent and 23.20 to 38.34 per cent during the years 2013 and 2014, respectively. In the year 2013, fruit TSS/acid ratio was recorded significantly higher at higher altitude of Kinnaur (Kalpa) in comparison to all other locations except, lower altitude of Kinnaur (Reckong Peo). However, it was found to be significantly lowest at lower altitude of Kotkhai. During 2014, the highest TSS/acid ratio (38.34 %) was found at higher altitude of Kinnaur (Kalpa) which was however, statistically at par with lower altitude of Kinnaur (Reckong Peo) (35.84 %) and Mashobra (32.94 %). The lowest TSS/acid ratio was found at lower altitude of Kotkhai (23.20 %) which was however, on a par with higher altitude of Kotkhai (25.61 %) and lower altitude of Rohru (27.03 %).

Table 28 Fruit TSS/acid ratio in apple cv. Starking Delicious at different locations of Shimla and Kinnaur districts

Treatment	Location	Altitudes (m amsl)	TSS/acid ratio (%)		
			2013	2014	Pooled
T ₁	Mashobra-E1	2245	42.59 (40.69)	32.94 (34.97)	37.77 (37.83)
T ₂	Kotkhai-E1	1950	32.10 (34.45)	25.61 (30.28)	28.86 (32.37)
T ₃	Kotkhai-E2	1670	26.92 (31.24)	23.20 (28.78)	25.06 (30.01)
T ₄	Rohru-E1	2124	39.34 (38.81)	28.73 (32.38)	34.04 (35.59)
T ₅	Rohru-E2	1690	35.84 (36.74)	27.03 (31.31)	31.43 (34.03)
T ₆	Kalpa	2780	49.47 (44.70)	38.34 (38.24)	43.91 (41.47)
T ₇	Reckong Peo	2547	44.17 (41.65)	35.84 (36.76)	40.00 (39.20)
Mean			38.63 (38.33)	30.24 (33.25)	34.44 (35.79)
CD_{0.05}			4.47	3.27	3.83

*Figures in parentheses are arcsine transformed values while those outside are original values

The pooled data (Table 28) revealed that the TSS/ acid ratio in fruits of apple cv. Starking Delicious varied from 25.06 to 43.91 per cent. The maximum fruit TSS/ acid ratio was recorded at higher altitude of Kinnaur (Kalpa) which was however, at par with lower altitude of Kinnaur (Reckong Peo) (40.00 %) and Mashobra (37.77 %). The minimum TSS/ acid ratio was found at lower altitude of Kotkhai (25.06 %) which was on par with higher altitude of Kotkhai (28.86 %). Li JinQiang *et al.* (2010) noted that increasing solar radiations improved sugar/acid

ratio in cherry. In agreement with their findings, higher TSS/ acid ratio in fruits from Kalpa and Reckong Peo could be due to higher solar radiations (Figure 51 & 52) at these location. Gong *et al.* (2009) observed the relationship between ecological factors and sugar/acid ratio and found that the mean temperature in the period from fruit swelling to maturity was the main affecting factor governing this attribute. Zarifneshat *et al.*,(2010) observed greater sugar/acid ratio in ‘Fuji’ apples with temperature in between 25 to 27 °C during the growing season. During the present study, higher fruit TSS/acid ratio was obtained at the same air temperature range (Table 5) during day at Mashobra, Kalpa and Rockong Peo.

4.1.7.12 Total sugars

The data on total sugars of apple as affected by different altitudes and locations have been presented in Table 29 and Figure 20. It can be observed from the data that total sugars content of apple fruits varied from 9.04 % to 14.34 % and 8.51 % to 13.68 % during 2013 and 2014, respectively. In the year 2013, total sugars was found significantly heighest in fruits at higher altitude of Kinnaur (14.34 %) in comparison to all other locations. The next superior locations in this respect were Reckong Peo (13.42%) and Mashobra (12.52%) in the decreasing order. Whereas, total sugars was found to be significantly lowest at lower altitude of Kotkhai (9.04 %), followed by higher altitude of Kotkhai. However, fruit sugar level at both the locations of Rohru was in the intermediate range. During the year 2014, again significantly highest total sugars (13.68 %) was found at higher altitude of Kinnaur (Kalpa), followed by Reckong Peo (12.78%). However, fruit sugar level was noticed significantly lowest at lower altitude of Kotkhai (8.51 %).

Pooled data (Table 29) clearly indicate that fruit sugars content was significantly highest at Kalpa (14.01 %), followed by Reckong Peo (13.1%) and Mashobra (12.28%). However, it was observed to be significantly lower at both the locations of Kotkhai (8.78 & 9.76% at lower & higher altitude of Kotkhai, respectively) in comparison to all other locations.

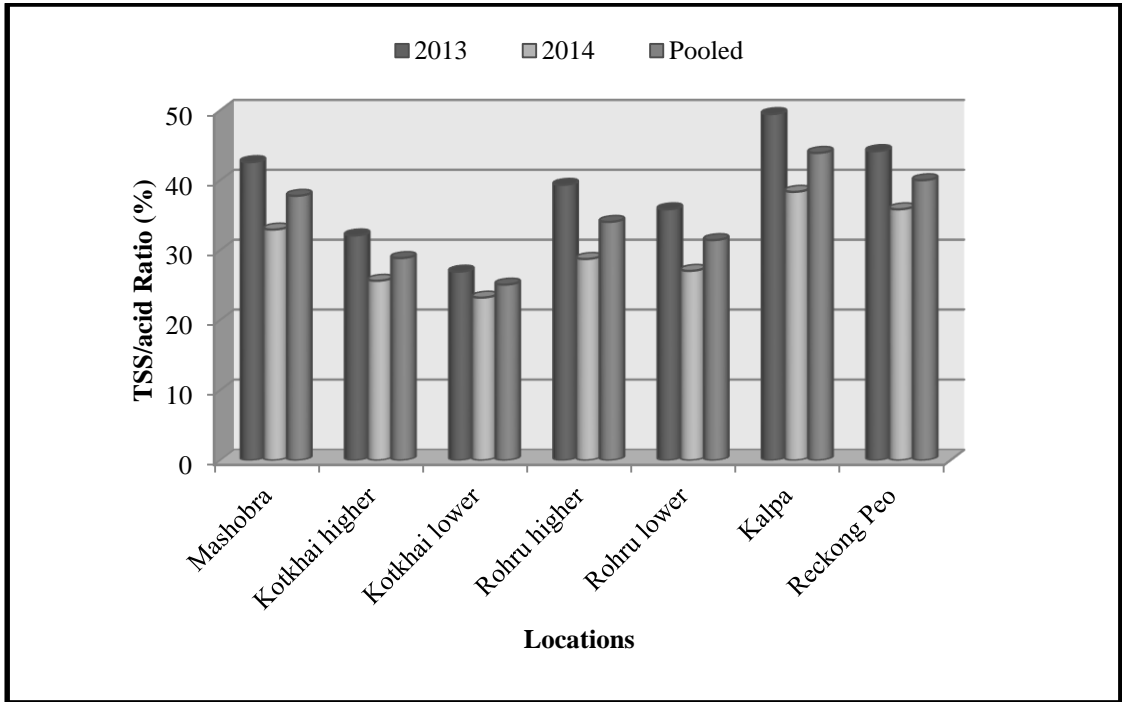


Figure 19 TSS/acid ratio in apple cv. Starking Delicious at different locations of Shimla and Kinnaur districts

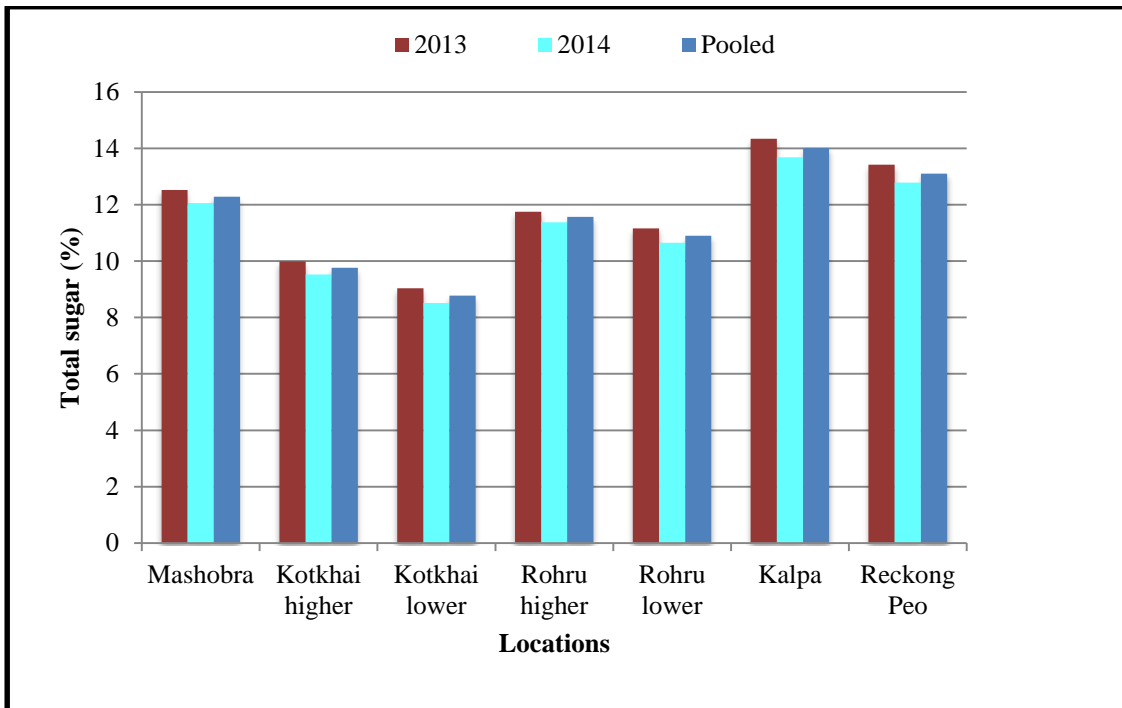


Figure 20 Total sugar content of fruits of apple cv. Starking Delicious at different locations of Shimla and Kinnaur districts

Table 29 Total sugar content of fruits of apple cv. Starking Delicious at different locations of Shimla and Kinnaur districts

Treatment	Location	Altitudes (m amsl)	Total sugar (%)		
			2013	2014	Pooled
T ₁	Mashobra-E1	2245	12.52 (20.71)	12.05 (20.30)	12.28 (20.51)
T ₂	Kotkhai-E1	1950	9.99 (18.41)	9.53 (17.96)	9.76 (18.18)
T ₃	Kotkhai-E2	1670	9.04 (17.49)	8.51 (16.96)	8.78 (17.23)
T ₄	Rohru-E1	2124	11.75 (20.04)	11.38 (19.71)	11.57 (19.88)
T ₅	Rohru-E2	1690	11.16 (19.51)	10.65 (19.04)	10.90 (19.27)
T ₆	Kalpa	2780	14.34 (22.25)	13.68 (21.71)	14.01 (21.98)
T ₇	Reckong Peo	2547	13.42 (21.48)	12.78 (20.93)	13.10 (21.21)
Mean			11.74(19.98)	11.23 (19.52)	11.49 (19.75)
CD_{0.05}			0.83	0.84	0.82

*Figures in parentheses are arcsine transformed values while those outside are original values

4.1.7.13 Reducing sugars

The data on reducing sugars contents of apples from different locations are presented in Table 30 and Figure 21. It is clear from the data that during the year 2013, the highest percentage of reducing sugars was recorded in fruits from Kalpa (8.03 %) which was however, statistically at par with fruits from Reckong Peo (7.61 %). Whereas, the reducing sugars content of fruits was noted significantly lower at lower altitude of Kotkhai (5.04%) than the remaining locations except, higher altitude of Kotkhai (5.51 %). During the year 2014, significantly higher fruit non-reducing sugars content was observed at Kalpa (7.09%) and Reckong Peo (7.05%) than all other locations. However, the reducing sugars level in fruits was recorded

Table 30 Fruit reducing sugar content in apple cv. Starking Delicious at different locations of Shimla and Kinnaur districts

Treatment	Location	Altitudes (m amsl)	Reducing sugar (%)		
			2013	2014	Pooled
T ₁	Mashobra-E1	2245	7.06 (15.38)	6.23 (14.43)	6.64 (14.91)
T ₂	Kotkhai-E1	1950	5.51 (13.57)	4.56 (12.31)	5.04 (12.94)
T ₃	Kotkhai-E2	1670	5.04 (12.97)	3.95 (11.46)	4.49 (12.21)
T ₄	Rohru-E1	2124	6.51 (14.78)	5.63 (13.72)	6.07 (14.25)
T ₅	Rohru-E2	1690	6.09 (14.28)	5.20 (13.17)	5.64 (13.73)
T ₆	Kalpa	2780	8.03 (16.46)	7.09 (15.44)	7.56 (15.95)
T ₇	Reckong Peo	2547	7.61 (16.00)	7.05 (15.37)	7.33 (15.68)
Mean			6.55 (14.78)	5.67 (13.70)	6.11 (14.24)
CD_{0.05}			0.81	0.87	0.82

*Figures in parentheses are arcsine transformed values while those outside are original values

lowest at lower altitude of Kotkhai (3.95 %) which was however, statistically at par with higher altitude of Kotkhai (4.56 %).

It can be observed from pooled analyzed data (Table 30) that the maximum percentage of reducing sugars in fruits was recorded at Kalpa (7.56%) which was however, statistically at par with Reckong Peo (7.33 %). The minimum reducing sugars were recorded in fruits from lower altitude of Kotkhai (4.49 %), which was comparable with higher altitude of Kotkhai (5.04 %). Fruit non-reducing sugars content at Mashobra and both the locations of Rohru were in the intermediate range.

4.1.7.14 Non-reducing sugars

The data on non-reducing sugars of apple presented in Table 31 and Figure 22 revealed that during the year 2013, significantly higher non-reducing sugars (6.27 %) in fruit was recorded at higher altitude of Kinnaur (Kalpa) in comparison to all other locations except, lower altitude of Kinnaur (Reckong Peo). The non-reducing sugars content of fruit was however, recorded significantly lower at lower altitude of Kotkhai (3.96 %) as compared to the remaining locations except, higher altitude of Kotkhai (4.49 %). Similarly, during the year 2014, the fruit non-reducing sugars level was found significantly higher at Kalpa (6.59%) than all other locations except, Reckong Peo (6.12 %). The lowest percentage of non-reducing sugars (4.56 %) was registered at lower altitude of Kotkhai, which was however, statistically at par with higher altitude of Kotkhai (4.97 %).

It is revealed from the pooled data (Table 31) that the values of non-reducing sugar in fruits ranged from 4.26 to 6.43 % at different location. The highest fruit non-reducing sugars level pertained to higher altitude of Kinnaur (Kalpa), which was significantly greater than all other locations except, Reckong Peo. Significantly lower non-reducing sugars was found in fruits from lower altitude of Kotkhai (4.26 %) than all other locations except, higher altitude of Kotkhai (4.73 %). The fruit non-reducing sugars levels at Mashobra and both the locations of Rohru were in the intermediate range.

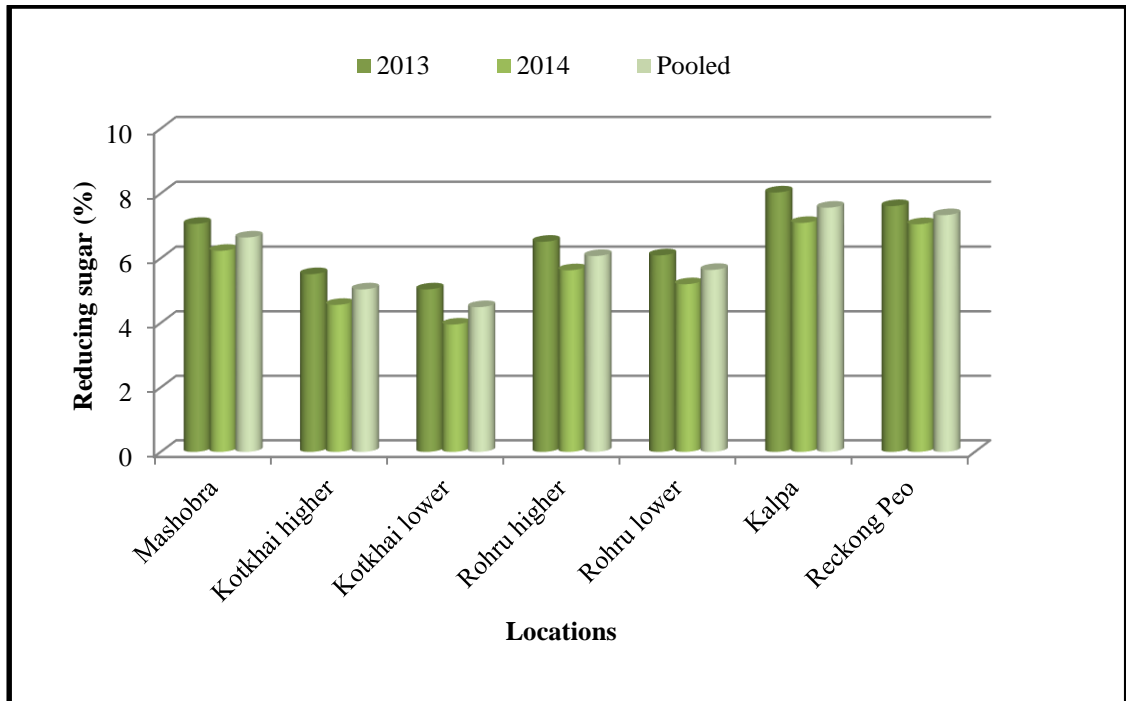


Figure 21 Fruit reducing sugar content in apple cv. Starking Delicious at different locations of Shimla and Kinnaur districts

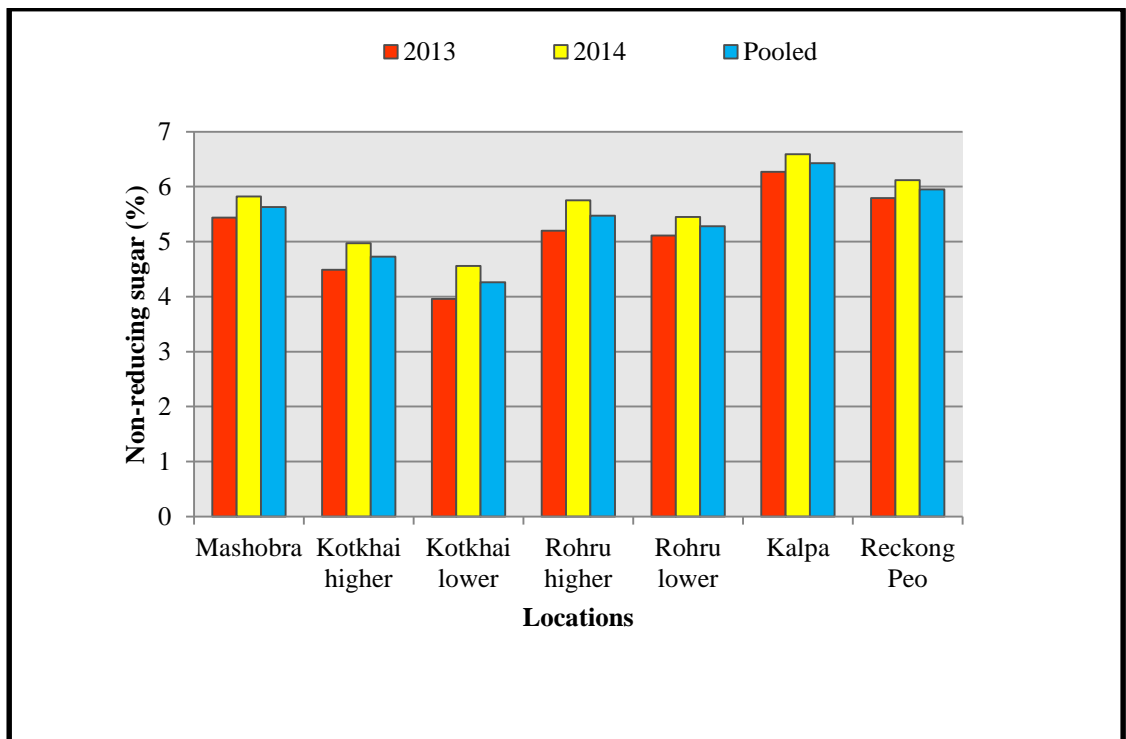


Figure 22 Fruit non-reducing sugar content in apple cv. Starking Delicious at different locations of Shimla and Kinnaur districts

Sugars accumulation in apple fruits is favoured by warm sunny days and cool night, the former affect photosynthesis and the later affect plant respiration. Higher

Table 31 Fruit non-reducing sugar content in apple cv. Starking Delicious at different locations of Shimla and Kinnaur districts

Treatment	Location	Altitudes (m amsl)	Non- reducing sugar (%)		
			2013	2014	Pooled
T ₁	Mashobra-E1	2245	5.44 (13.45)	5.82 (13.93)	5.63 (13.69)
T ₂	Kotkhai-E1	1950	4.49 (12.22)	4.97 (12.87)	4.73 (12.54)
T ₃	Kotkhai-E2	1670	3.96 (11.47)	4.56 (12.33)	4.26 (11.90)
T ₄	Rohru-E1	2124	5.20 (13.18)	5.75 (13.87)	5.47 (13.52)
T ₅	Rohru-E2	1690	5.11 (13.06)	5.45 (13.49)	5.28 (13.28)
T ₆	Kalpa	2780	6.27 (14.50)	6.59 (14.87)	6.43 (14.69)
T ₇	Reckong Peo	2547	5.79 (13.89)	6.12 (14.30)	5.95 (14.09)
Mean			5.18 (13.11)	5.61 (13.67)	5.39 (13.39)
CD_{0.05}			0.91	0.88	0.88

*Figures in parentheses are arcsine transformed values while those outside are original values

respiration rate due to warmer night consumes a larger portion of total photosynthates (Paembonan *et al.*, 1999). Lower sugars accumulation in apple fruits at Kotkhai and Rohru might be due to higher night temperature (Table 6) causing losses of sugars due to higher respiration (Mohammed and Tarpley, 2011). Besides, an increase in solar radiations at higher altitude may have improved the sugars content in fruits (Li JinQiang *et al.* 2010). Wang *et al.* (2009) found that higher annual average temperature had a negative influence on sugars in blueberries.

4.1.8 Relationship between chilling units, GDH accumulation and production of apple cv. Starking Delicious at different locations

4.1.8.1 Chilling unit accumulation (2012-13)

The correlation study (Table 32) revealed that there was significant positive correlation ($r=0.76$) between rest period and apple production; which indicated that the increase in duration of rest period resulted in a corresponding increase in apple production, in the year 2012-13 (Table 32). Significantly positive correlation ($r=0.82$) was also found between the chilling period and production, thus clearly indicating that the production of apple increased with the increase in chilling period.

Table 32: Correlation between rest period, chilling period, ECU and GDH and production of apple cv. Starking Delicious at different locations during 2012-13

Location	Elevation	Yield (kg/tree)	Rest period (Days)	Chilling period (Days)	ECU accumulation				GDH Accumulation		
					Chilling period		Peak period		Chilling initiation to rest completion	Peak winter	Rest completion to full bloom
					UTAH CU	NORTH CAROLINA CU	UTAH CU	NORTH CAROLINA CU			
Mashobra-E1	2245	115.91	115	151	1853	1941	1306	1358	15862	4521	8109
Kotkhai- E1	1950	108.82	129	176	1892	1964	964	1021	16084	4608	8114
Kotkhai- E2	1670	107.42	139	164	1795	1902	820	849	16584	5099	8194
Rohru - E1	2124	112.98	128	156	1874	2498.0	1234	1205	15742.5	5831	8102.5
Rohru - E2	1690	111.18	126	140	1898	1938	1139	1154	15612	5894	8219
Kalpa	2780	123.46	175	195	1526	1466	419	409	15107	2479	4951
ReckongPeo	2547	118.94	115	151	1853	1941	1306	1358	15862	4521	8109
Correlation			0.76	0.82*	-0.88*	-0.78*	-0.74	-0.70	-0.60	-0.97*	-0.86*

ECU- Effective chilling unit; GDH- Growing degree hours;* Significant at 0.5%

The production of apple have however, has shown significant negative correlation with chilling units ($r=-0.88$) weather computed according to Utah chill model or North Carolina chilling units model ($r= -0.78$), during the chilling period of 2012-13 (Table 32). Whereas, during peak winter, negative but non-significant correlation was found in between apple production and Utah chill model chilling units ($r=-0.74$) and North Carolina chilling units model ($r= -0.70$).

4.1.8.2 GDH°C accumulation (2012-13)

The correlation between apple production and GDH°C accumulation during chilling initiation to rest completion (Table 32) was found to be negative but non-significant ($r= -0.60$). However, the negative and significant correlation ($r= -0.97$) was observed between apple production and GDH°C accumulation during peak winter. Whereas, significantly negative correlation ($r= -0.86$) was found between apple production and GDH°C accumulation throughout the period of rest completion to full bloom.

4.1.8.3 Chilling unit accumulation (2013-14)

It is revealed from the data (Table 33) that during the year 2013-14, the ECU accumulation and GDH°C accumulation showed discrepancy from results of previous year (2012-13). The correlation between apple production and time for rest period was though found to be positive but non-significant ($r= 0.74$). The highly significant and positive correlation ($r=0.91$) was observed between apple production and time requirement for chilling period.

The production of apple had significant negative correlation ($r=-0.95$) with Utah Model chilling units while, negative but non-significant correlation ($r=-0.72$) was found in between apple production and North Carolina chilling unit model, during the chilling period. However, during peak winter, significantly negative correlation ($r=-0.76$) was found between apple production and Utah Model chilling units whereas, according to North Carolina model, apple production indicated negative but non-significant correlation ($r=-0.70$) with chilling units.

Table 33 Correlation between rest period, chilling period, ECU and GDH and production of apple cv. Starking Delicious at different locations during 2013-14

Location	Altitudes (m amsl)	Yield (kg/tree)	Rest period (Days)	Chilling period (Days)	ECU Accumulation				GDH Accumulation		
					Chilling period		Peak period		Chilling initiation to rest completion	Peak winter	Rest completion to full bloom
					UTAH CU	NORTH CAROLINA CU	UTAH CU	NORTH CAROLINA CU			
Mashora-E1	2245	108.31	114	153	1761	1892	1209	1277	15131	4371	7956.5
Kotkhai-E1	1950	103.09	115	144	1831.5	2507.5	1163.5	1122	15256.5	5951	7989
Kotkhai-E2	1670	99.31	126	140	1942	1922	1063	993	15331	5988	8362
Rohru-E1	2124	107.17	119	169	1806	1661	899.5	681	15792	4547	8170
Rohru-E2	1690	105.01	139	169	1876	2048	755	904	16032	5122	8263
Kalpa	2780	115.73	178	201	1414.5	1366.5	337	315	15019	2591	4892.5
Reckong Peo	2547	111.43	159	188	1561	1736	504	581	14982	2879	5127
Correlation			0.74	0.91*	-0.95*	-0.72	-0.76*	-0.70	-0.43	-0.96*	-0.85*

ECU- Effective chilling unit, GDH- Growing degree hours, * Significant at 0.5%

Mankotia (2005), observed significant negative correlation ($r = -0.716^{**}$) between duration of rest period and productivity at Mashobra near Shimla which indicated that the increase in the duration of rest period resulted in decrease in productivity. Further, significant positive correlation ($r = +0.642^{**}$) was observed between apple productivity and ECU accumulations during peak winters. However, consequent upon extending study area by covering various locations in different climatic zones in the present study, correlation of productivity with duration of rest period was found to be positive and with ECU it was recorded as negative.

4.1.8.4 GDH°C accumulation (2013-14)

In the year 2013-14, the negative and non-significant association ($r=-0.43$) was observed in between apple production and GDH°C accumulation during chilling initiation to rest completion, indicating that there was no effect of GDH°C accumulation during the period of chilling initiation to rest completion on the apple production (Table 33). During peak winter, negative and significant correlation (-0.96) was observed between apple production and GDH°C accumulation. The significantly negative correlation ($r= -0.85$) was found in between apple production and GDH°C accumulation throughout the period of rest completion to full bloom. Present findings are appropriate with those of Mankotia (2005), who observed significant negative correlation of apple productivity with 'r' values of -0.679^{**} and -0.771^{**} with GDH°C accumulation during rest period and peak winters, respectively.

4.1.9 Relationship between locations and different quality parameters

4.1.9.1 Correlations between locations and different quality parameters during 2013

The correlation coefficient between different locations and various quality parameters of apple was worked out and the results obtained for the year 2013 are presented in Table 34. A perusal of data revealed positive and significant association ($r = 0.84$) in between fruit yield and different range of altitudes. Likewise, significantly positive correlation ($r=0.87$) was observed between fruit

Table 34 Relationship between different quality parameters and altitudes in 2013

Location	Altitudes (m amsl)	Yield (kg/tree)	Fruit length (mm)	Fruit diameter (mm)	Fruit weight (g)	L/D ratio	TSS (°Brix)	Total sugar (%)	Reducing sugar (%)	Non-reducing sugar (%)	Acidity (%)	TSS/Acid Ratio
Mashobra-E1	2245	115.91	65.83	70.54	163.30	0.93	15.38	12.52	7.06	5.44	0.38	42.59
Kotkhai higher-E1	1950	108.82	61.86	69.82	145.82	0.89	14.56	9.99	5.51	4.49	0.46	32.10
Kotkhai lower-E2	1670	107.42	60.49	69.42	143.39	0.87	14.39	9.04	5.04	3.96	0.54	26.92
Rohru higher-E1	2124	112.98	66.71	73.02	155.93	0.91	15	11.75	6.51	5.20	0.39	39.34
Rohru lower-E2	1690	111.18	65.44	68.66	152.73	0.95	14.74	11.16	6.09	5.11	0.42	35.84
Kalpa	2780	123.46	77.23	76.70	223.86	1.01	15.99	14.34	8.03	6.27	0.33	49.47
Reckong Peo	2547	118.94	73.62	73.74	204.94	1.00	15.68	13.42	7.61	5.79	0.36	44.17
Correlation		0.84*	0.87*	0.61	0.80*	0.96*	0.81*	0.88*	0.85*	0.92*	-0.87*	0.86*

*Correlation significant at 0.05%

length and different altitudes. The fruit weight, L/D ratio (fruit index), TSS, total sugars, reducing sugars, non-reducing sugars and TSS/acid ratio have shown positive and significant association with the increasing altitudes (Table 34). Whereas, the increase in altitude have shown significantly negative correlation ($r=-0.87$) with fruit titratable acidity. However, the fruit diameter had positive but non-significant relationship ($r = 0.61$) with increasing altitudes.

These results implies that with the increase in the altitudes level, the yield, fruit length, length/diameter ratio, fruit weight, TSS, total sugars, reducing sugars, non-reducing sugars and TSS/acid ratio increased, and the acidity decreased in the apple fruit. The fruit diameter was however, found to have positive but non-significant association with different altitudes.

4.1.9.2 Correlations between locations and different quality parameters during 2014

In the year 2014, the fruit yield have shown significant and positive association ($r = 0.87$) with different range of altitudes (Table 35). While, significantly positive correlation ($r=0.84$) was observed between fruit length and different altitudes. The fruit diameter ($r=0.77$) and weight ($r=0.84$), fruit TSS ($r=0.86$), total sugars ($r=0.87$), reducing sugars ($r=0.85$) and non-reducing sugars ($r=0.88$) contents and fruit TSS/acid ratio ($r=0.82$) have indicated positive and significant correlation with different altitudes. Fruit acidity however, showed significantly negative correlation ($r=-0.82$) with different altitudes. The L/D ratio (fruit index) had positive association ($r = 0.64$) with different altitudes.

In the present study, significantly positive correlation was found between fruit length, diameter, and weight, fruit TSS and sugars contents with the increase in altitudes. These findings were exactly coincide with the study carried out by Lnglese *et al.* (2006), where in fruit weight, shape and total soluble solid content significantly increased with the increase in altitude in pear while titratable acidity did not.

Table 35 Relationship between different quality parameters and altitudes in 2014

Location	Altitudes (m a.m.s.l.)	Yield (kg/tree)	Fruit length (mm)	Fruit diameter (mm)	Fruit weight (g)	L/D ratio	TSS (°Brix)	Total sugar (%)	Reducing sugar (%)	Non - reducing sugar (%)	Acidity (%)	TSS/Acid ratio
Mashobra-E1	2245	108.31	65.82	67.75	177.40	0.96	13.98	12.05	6.23	5.82	0.43	32.94
Kotkhai higher-E1	1950	103.09	63.45	64.98	139.73	1.00	12.61	9.53	4.56	4.97	0.51	25.61
Kotkhai lower-E2	1670	99.31	62.03	64.42	130.40	0.97	12.33	8.51	3.95	4.56	0.53	23.20
Rohru higher-E1	2124	107.17	65.09	65.59	159.39	0.98	13.51	11.38	5.63	5.75	0.47	28.73
Rohru lower-E2	1690	105.01	64.51	65.26	150.90	0.92	13.28	10.65	5.20	5.45	0.49	27.03
Kalpa	2780	115.73	73.81	76.70	219.44	0.96	14.57	13.68	7.09	6.59	0.38	38.34
Reckong Peo	2547	111.43	68.89	74.23	191.90	0.94	14.36	12.78	7.05	6.12	0.40	35.84
Correlation		0.87*	0.84*	0.77*	0.84*	-0.64	0.86*	0.87*	0.85*	0.88*	-0.82*	0.82*

*Correlation significant at 5%

4.1.10 Correlation of flowering intensity, fruit set, fruit yield and productivity of apple with air temperature

The correlations between maximum and minimum air temperature with flowering intensity, fruit set, fruit yield and productivity at different locations of study are shown in Tables 36 and 37.

4.1.10.1 Relationship between air temperature and flowering intensity, fruit set, fruit yield and productivity of apple during 2012-13

The air temperature had significantly negative correlation with different flowering and fruiting parameters of apple during the year 2012-13 (Table 36). The maximum temperature showed significantly negative correlation with flowering intensity ($r = -0.90$), fruit set ($r = -0.81$), fruit yield ($r = -0.91$) and productivity ($r = -0.83$). The correlation studies revealed that the minimum temperature at different locations also had significantly negative correlation with flowering intensity ($r = -0.96$), fruit set ($r = -0.91$), fruit yield ($r = -0.96$) and productivity ($r = -0.89$), implying that increase the maximum and minimum temperature decreased the flowering intensity, fruit set, fruit yield and productivity.

Table 36 Correlation between temperature and flowering intensity, fruit set, fruit yield and productivity of apple cv. Starking Delicious 2012-13

Location	Max temperature (°C)	Min temperature (°C)	Flowering intensity (%)	Fruit set (%)	Fruit yield (kg/tree ⁻¹)	Productivity (tones ha ⁻¹)
Mashobra-E1	19.94	9.76	21.63	67.83	115.91	20.61
Kotkhai higher-E1	21.12	13.52	16.05	57.70	108.82	19.35
Kotkhai lower-E2	25.35	16.07	15.80	53.09	107.42	19.1
Rohru higher-E1	22.97	10.15	18.84	67.06	112.98	20.09
Rohru lower-E2	24.01	15.22	17.66	65.59	111.18	19.77
Kalpa	14.68	3.64	28.40	78.25	123.46	34.29
Reckong Peo	19.01	5.8	25.37	74.78	118.94	33.04
Max Temp correlation			-0.90	-0.81	-0.91	-0.83
Min Temp correlation			-0.96	0.91	-0.96	-0.89

4.1.10.2. Relationship between air temperature and flowering intensity, fruit set, fruit yield and productivity of apple during 2013-14

During the year 2013-14, the same trend with respect to correlations of air temperature with flowering intensity, fruit set, fruit yield and productivity of apple at different locations of study was observed (Table 37). The maximum temperature showed significantly negative relationship ($r = -0.89$) with flowering intensity.

Likewise, fruit set, fruit yield and productivity, with r values of -0.76, -0.84 and -0.87, respectively had significantly negative in relation with maximum temperature. The flowering intensity showed significantly negative association ($r = -0.96$) with minimum temperature. Fruit set, fruit yield and productivity showed significantly negative association with minimum temperature with r values of -0.97, -0.98 and -0.92, respectively.

Table 37 Correlation between temperature and flowering intensity, fruit set, fruit yield and productivity of apple cv. Starking Delicious during 2013-14

Location	Max temperature (°C)	Min temperature (°C)	Flowering intensity (%)	Fruit set (%)	Fruit yield (kg/tree ⁻¹)	Productivity (tones ha ⁻¹)
Mashobra-E1	20.31	10.56	20.80	63.64	108.31	19.26
Kotkhai higher-E1	22.18	14.59	15.03	56.88	103.09	18.33
Kotkhai lower-E1	23.17	15.66	12.61	50.17	99.31	17.66
Rohru higher-E1	23.58	10.43	17.00	61.93	107.17	19.05
Rohru lower-E2	24.43	11.49	16.06	60.65	105.01	18.67
Kalpa	13.99	3.81	26.78	72.13	115.73	32.15
Reckong Peo	19.13	5.91	24.20	70.08	111.43	30.95
Max Temp Correlation			-0.89	-0.76	-0.84	-0.87
Min Temp Correlation			-0.96	-0.97	-0.98	-0.92

4.1.11 Soil pH

The data presented in Table 38 revealed significant variations in soil pH at different locations during the course of study. The soil pH was recorded significantly higher at Kalpa (7.11) than all other locations except, Reckong Peo (6.75). This value was observed lowest in soil at lower altitude of Kotkhai (5.52) which was however, statistically at par with lower altitude of Rohru (5.67).

Table 38 The soil pH and texture at different location of Shimla and Kinnaur districts

Treatment	Location	Altitudes (m amsl)	Soil pH	Soil texture
T1	Mashobra-E1	2245	6.20	Sandy clay loam
T2	Kotkhai-E1	1950	5.90	Sandy loam
T3	Kotkhai-E2	1670	5.52	Sandy loam
T4	Rohru-E1	2124	6.13	Sandy loam
T5	Rohru-E2	1690	5.67	Sandy loam
T6	Kalpa	2780	7.11	Sandy loam
T7	Reckong-Peo	2547	6.75	Sandy loam
Mean			6.18	
CD _{0.05}			0.35	

4.1.12 Soil texture

The observations on soil texture at different location (Table 38 and Appendix I) revealed that soil at Mashobra was sandy clay loam however, soils at other locations namely, Kotkhai, Rohru, Reckong Peo and Kalpa were identified as sandy loam in texture.

4.2 EXPERIMENT II - GIS BASED ASSESSMENT OF LOCATION SUITABILITY FOR APPLE PRODUCTION

In the study, the area mapped for suitable locations for apple cultivation covered Shimla and Kinnaur districts. District Shimla constitutes nine blocks *viz.*, Shimla Urban, Theog, Chopal, Basantpur, Kumarsain, Jubbal-Kotkhai, Rohru, Rampur and Chirgaon and district Kinnaur have just three blocks *viz.*, Nichar, Kalpa and Pooh. On the basis of GIS assessment, Shimla and Kinnaur districts had 37630.54 ha and 10452 ha of area under apple cultivation, respectively during the years 2012-14 (Appendix II). The location suitability analysis was done by acquiring the elevation data from spatial radar topographic mission (SRTM) to form geo referenced digital elevation model (DEM). The results were then compiled in the form of thematic maps, charts and tables.

4.2.1 Geological parameters

4.2.1.1 Elevation

The thematic map (Figure 3) depicts the altitude range of the blocks in the selected study area. Blocks in district Shimla constituting Shimla urban, Theog, Chopal, Basantpur, Rampur, Kumarsain, Jubbal-Kotkhai, Rohru, Chopal and Chirgaon fall in the altitude range from 1350 to 2708 m. In the district Kinnaur, the three blocks Nichar, Kalpa and Pooh fall in the altitude range of 2086 m to 2780 m.

4.2.2 Temperature conditions at different altitudes of study area

4.2.2.1 Maximum temperature

The thematic layer (Figure 23 & 24) indicates that there was a direct relationship between the air temperature and different altitudes in Shimla and Kinnaur districts, i.e temperature decreased with the increase in altitude. Therefore, the two respective districts experienced a wide range of maximum temperature variations. In year 2012-13, it has been depicted that the altitudes of Theog, Jubbal, Chirgaon and Nichar having annual average maximum temperature range of 19.93-21.11°C while, this value has been shown in the map between 21.11-24.00°C at Rohru, 24.00-25.35°C at Basantpur and Rampur, 19.01-19.36°C at Shimla, 14.68°C at Kumarsain and Kalpa and 14.68-19.01°C at Pooh. In 2013-14, Rohru, Chirgaon and Nichar shows highest annual average temperature of 23.57°C followed by Basantpur and Rampur (Figure 24). In case of Kalpa and Phooh, thematic layer shows least average annual temperatures (13.99°C).

4.2.2.2 Minimum temperature

The thematic layer (Figure 25 & 26) indicates that there was direct relationship between different altitudes in Shimla and Kinnaur districts with the minimum temperature. i.e temperature decreased with increase in altitude. Therefore, the two respective districts experienced a wide range of minimum temperature variations. In the year 2012-13, it depicted 13.52°C annual average minimum temperature for Theog, Jubbal, Chirgaon and Nichar, 10.15°C for Rohru 16.07°C for Basantpur and Rampur. The minimum value of 3.81°C is shown jointly at Kalpa and Pooh. In the year 2013-14, it has shown minimum temperature range of 9.76°C, 3.64°C and 5.80°C for Shimla, Kumarsain, Pooh and Kalpa and Chopal, respectively.

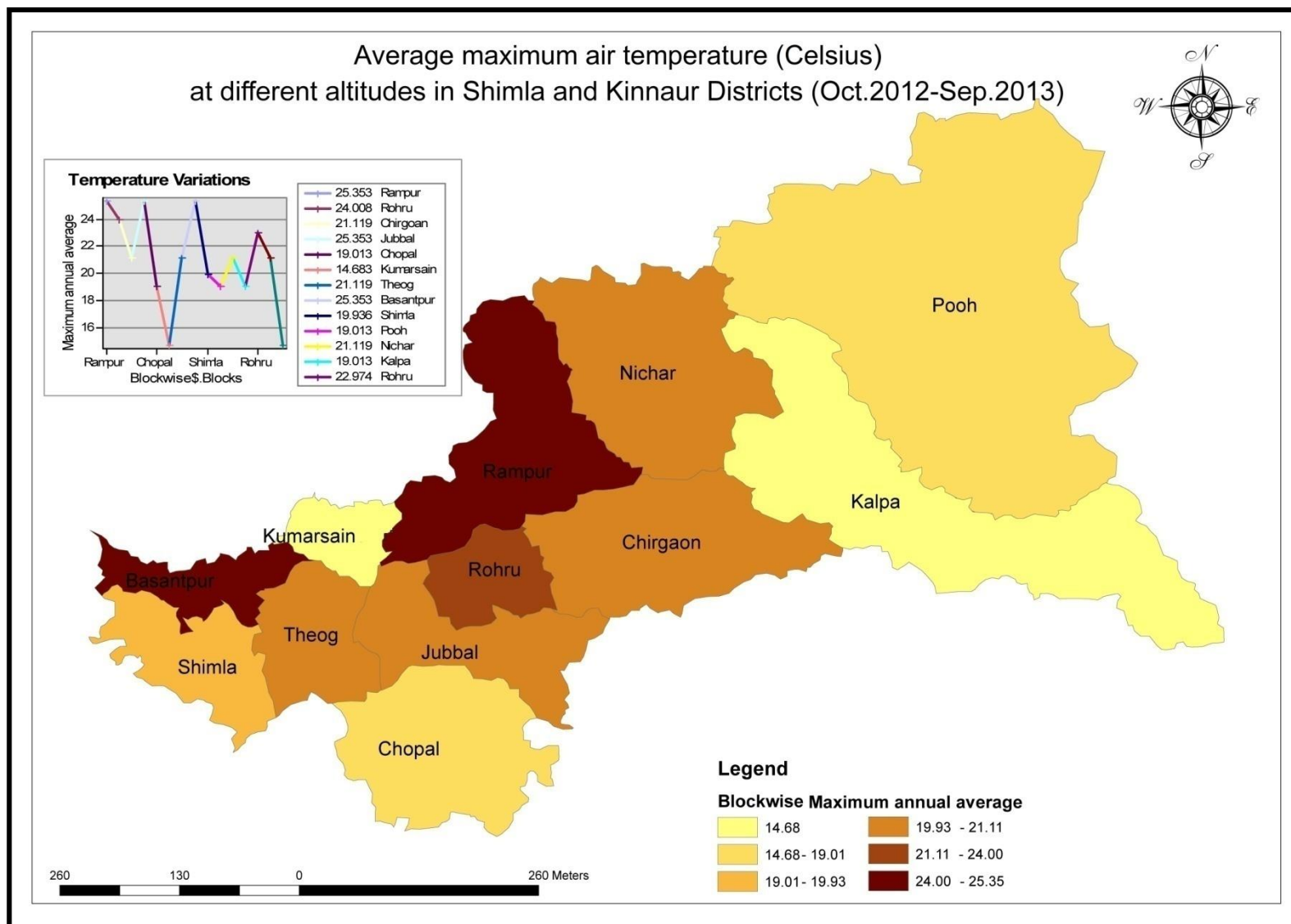


Figure 23

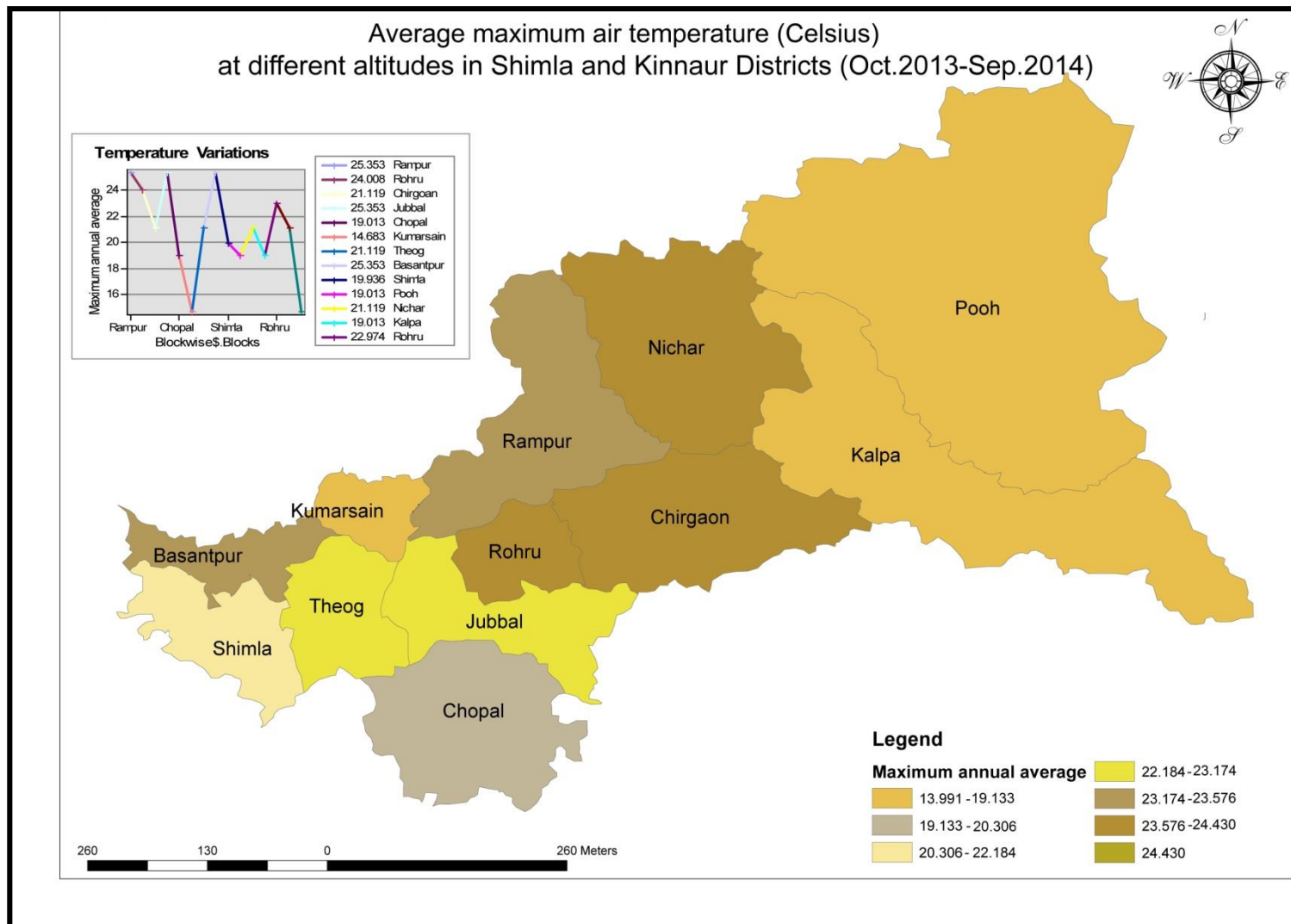


Figure 24

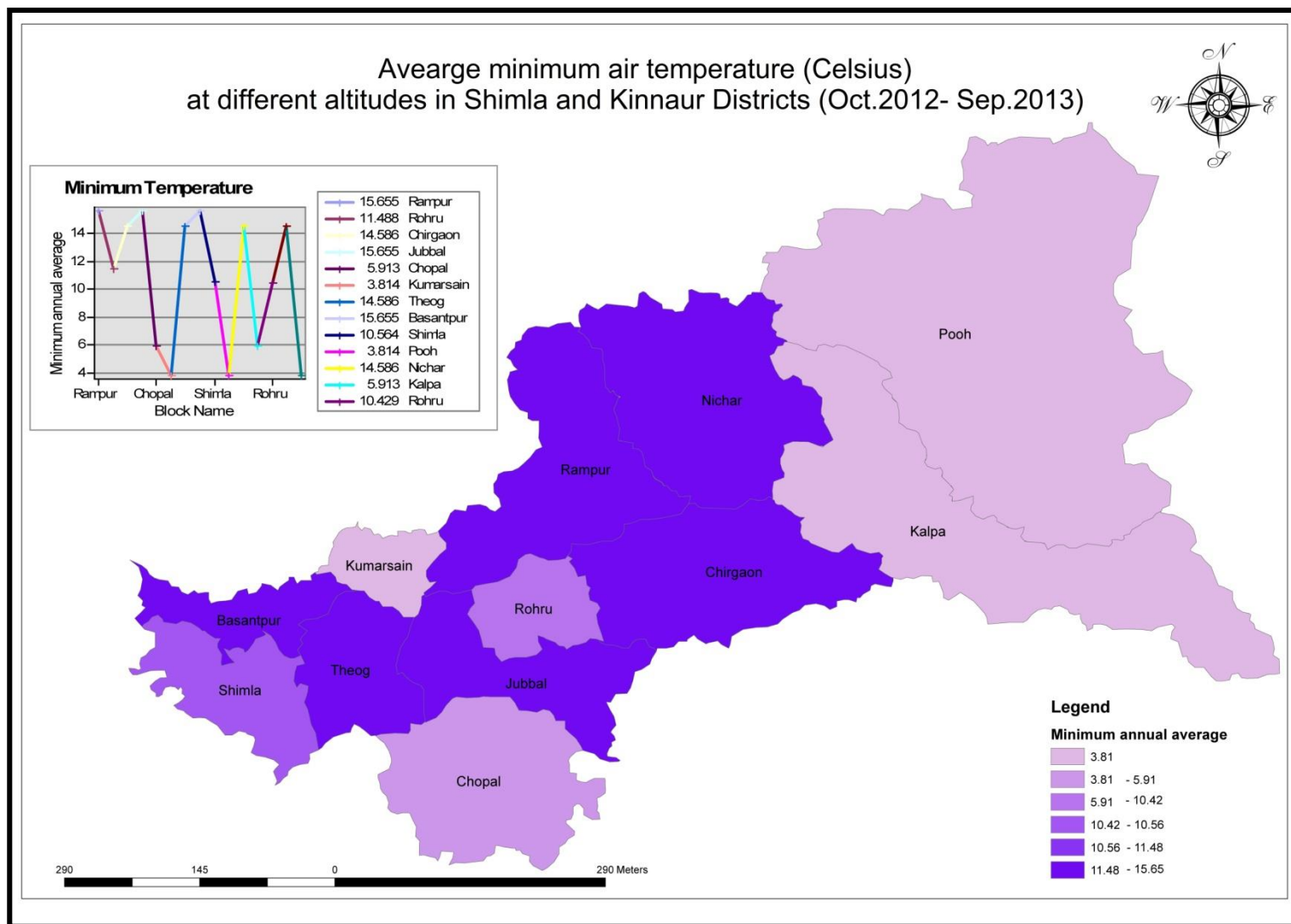


Figure 25

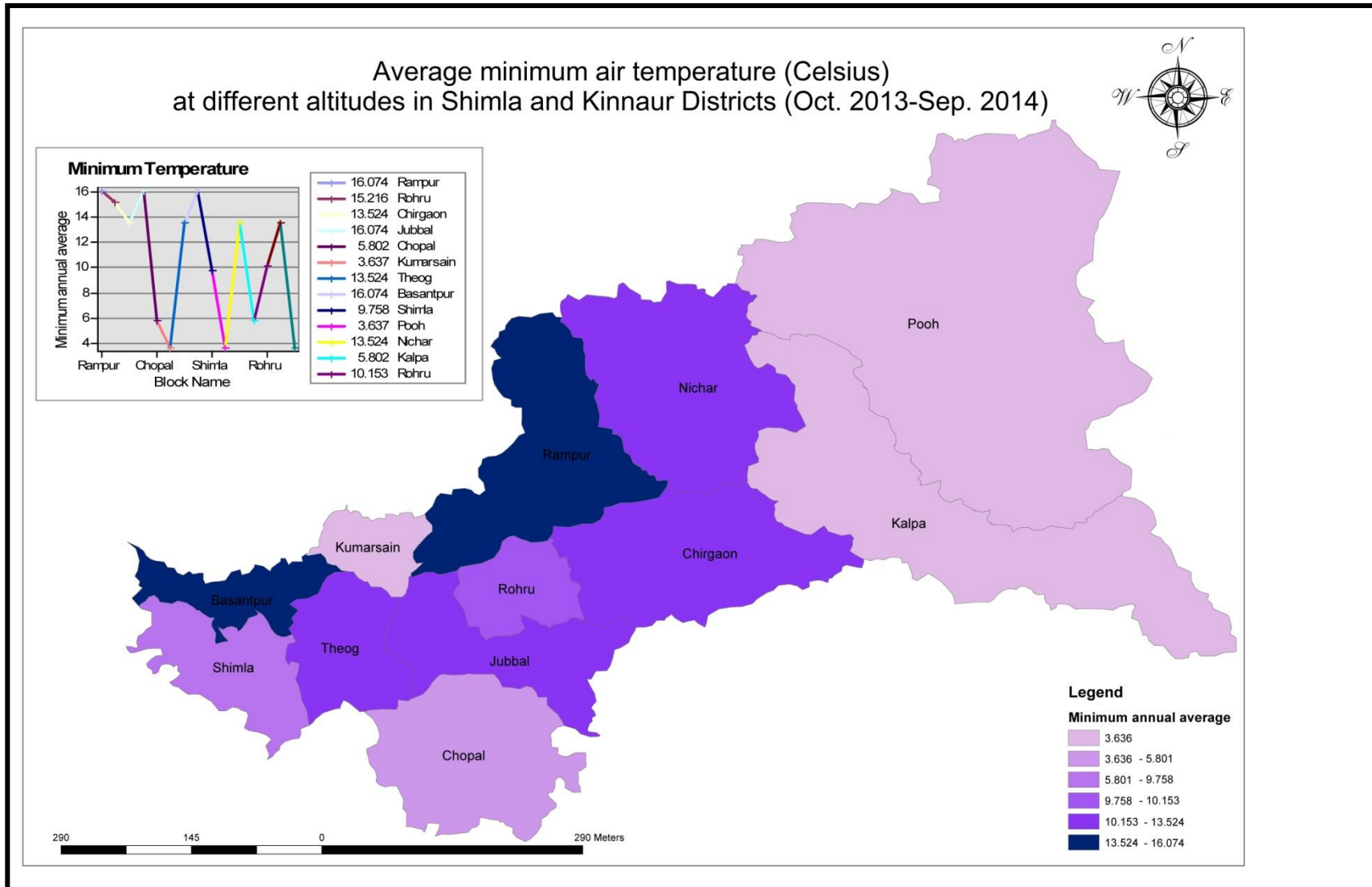


Figure 26

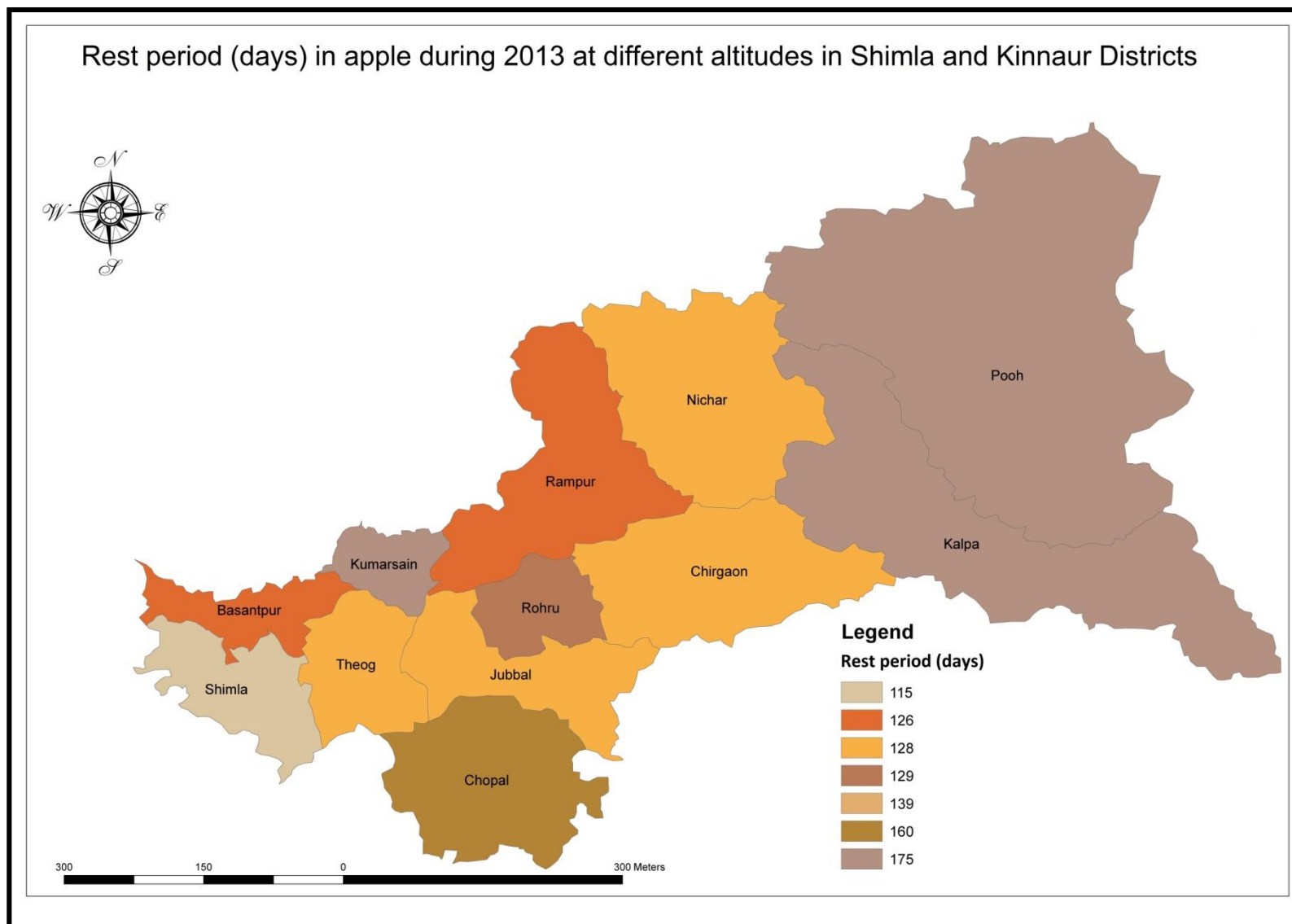


Figure 27

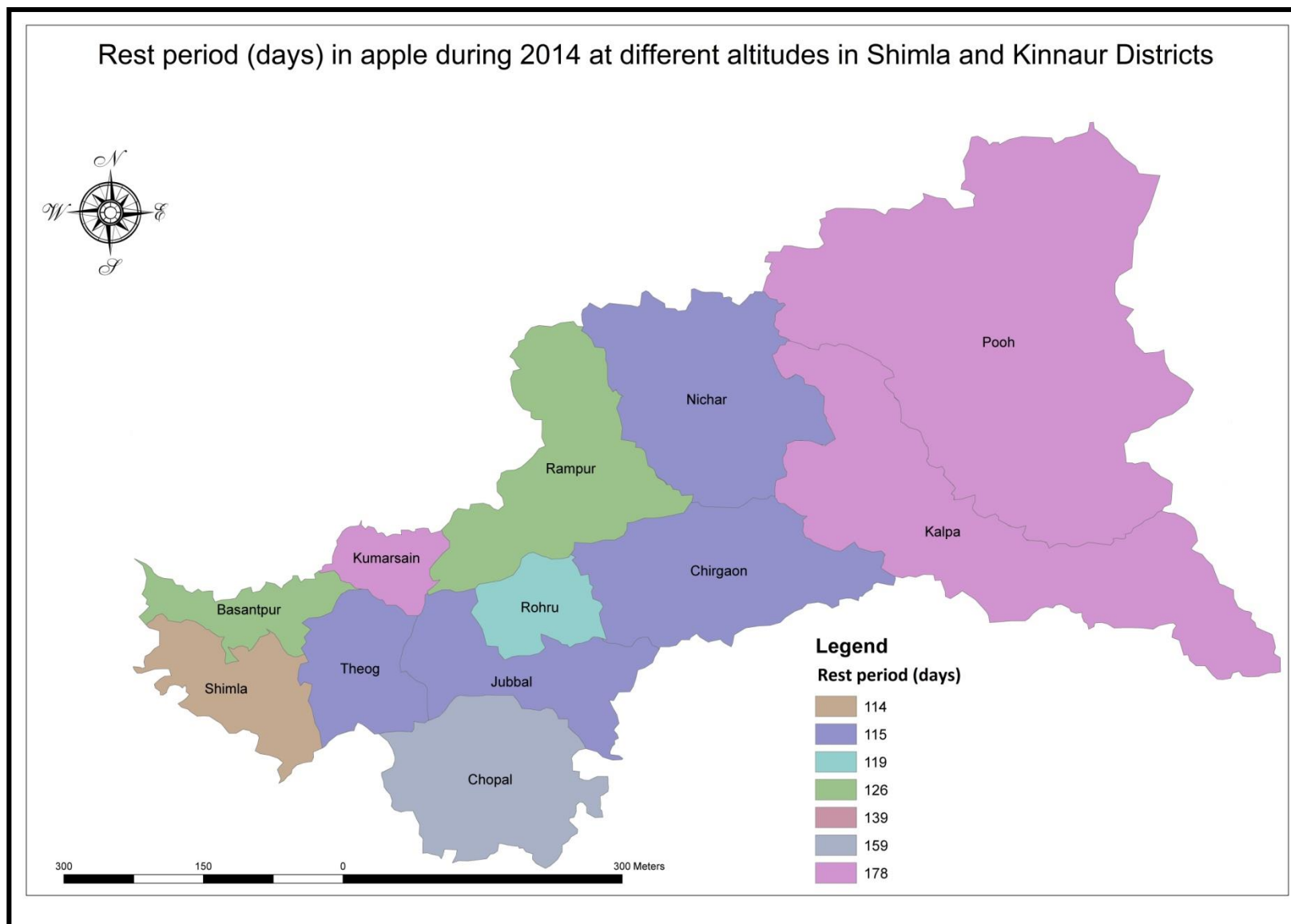


Figure 28

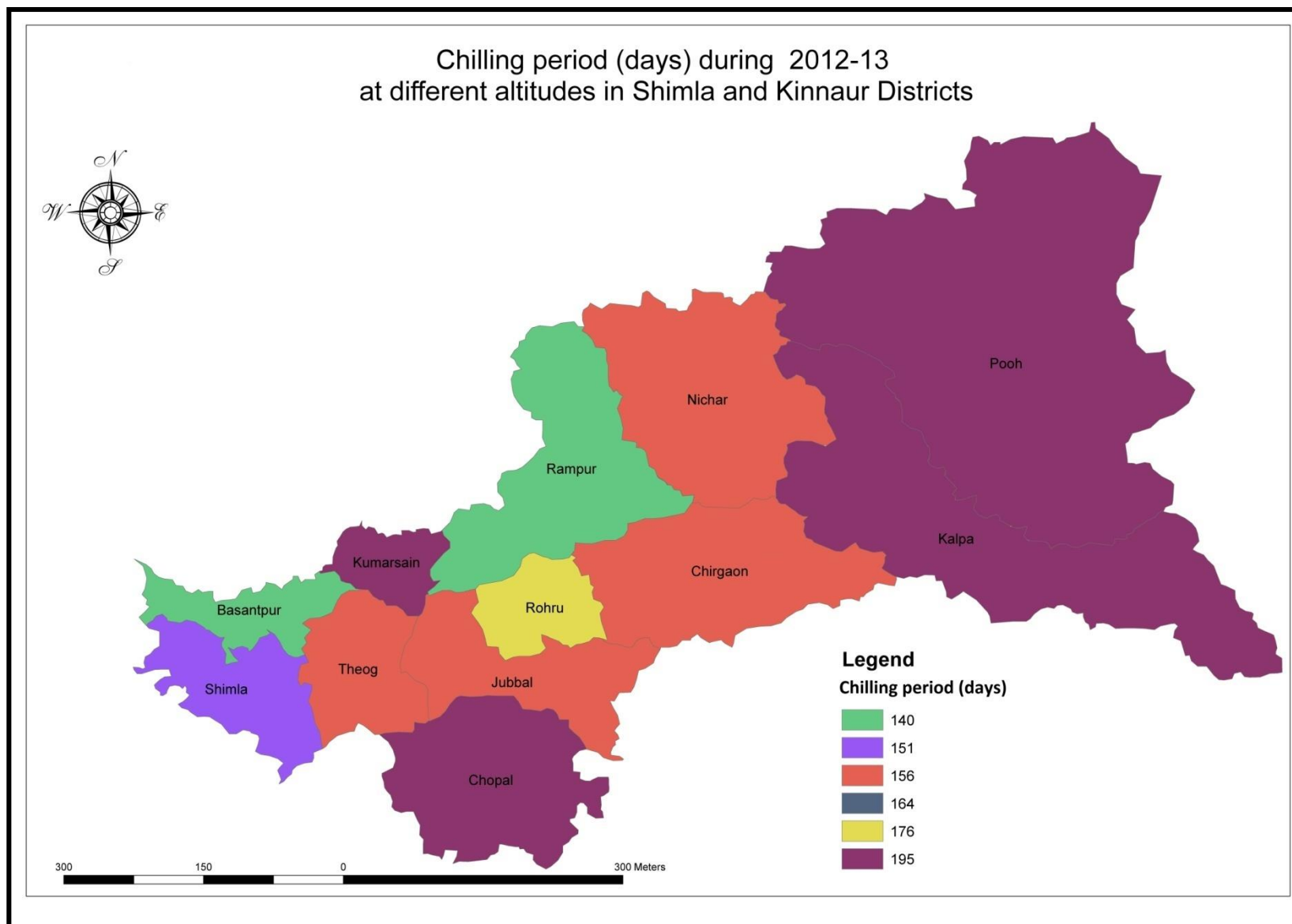


Figure 29

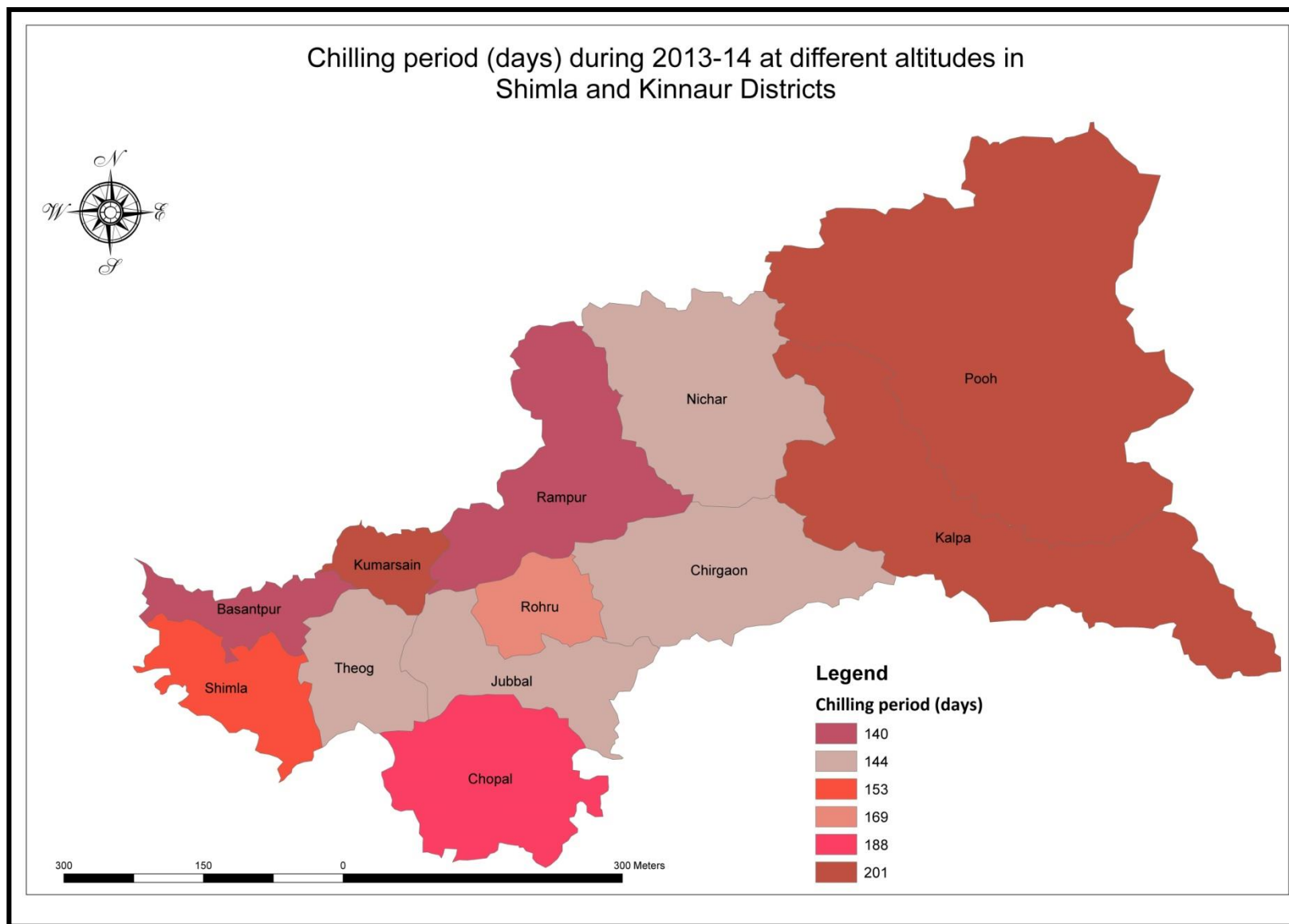


Figure 30

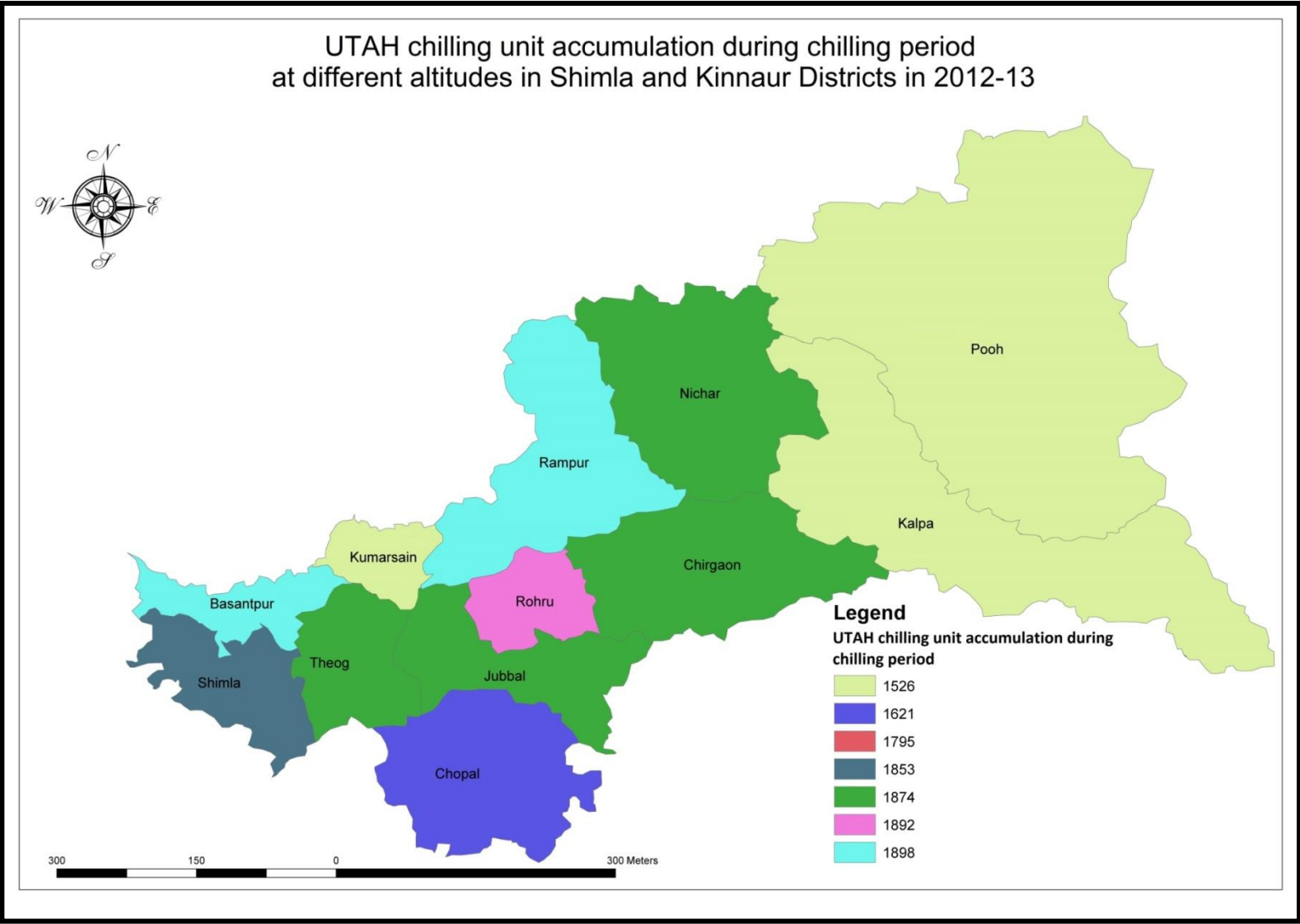


Figure 31

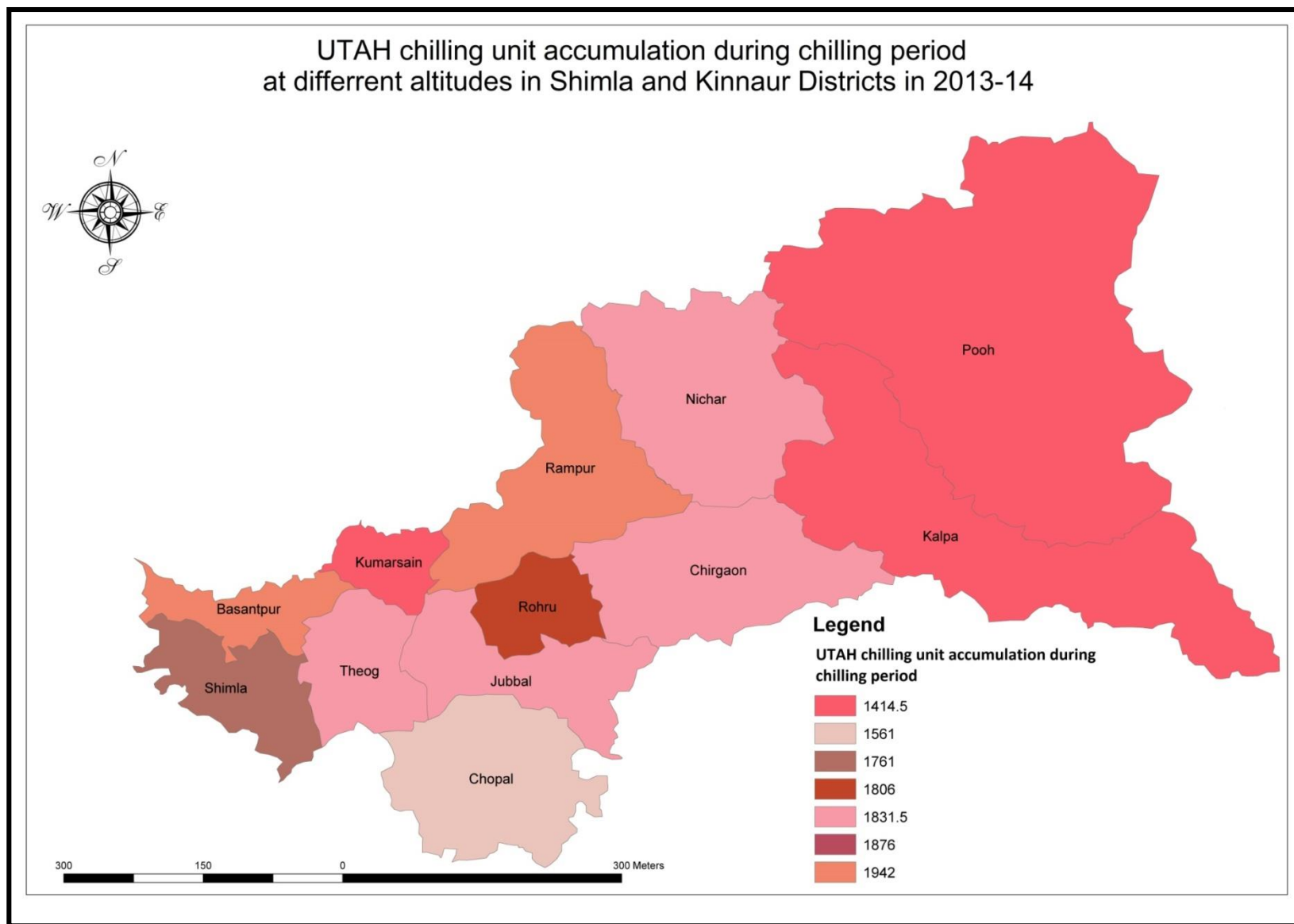


Figure 32

4.2.3 Effect of altitudes on different parameters of ECU and GDH in apple cultivar Starking Delicious

4.2.3.1 Effect of chilling units and ‘Growing Degree Hours (GDH)’ on apple production

4.2.3.1.1 Rest period (days)

The thematic map (Figure 27 & 28) has depicted the rest period (days) in apple for the districts of Shimla and Kinnaur during study period. During 2012-13, the maximum rest period (175 days) in apple has been shown in respect of Kalpa, Pooh and Kumarsain, followed by Chopal (160 days), however, it is shown least (115 days) at Shimla. During 2013-14, the same trend was observed with maximum rest period days (178) shown at Kalpa, Pooh and Kumarsain followed by Chopal (159 days). Whereas, thematic map depicts the minimum rest period (114) at Shimla jointly followed Nichar, Chirgaon, Jubbal and Theog (115).

4.2.3.1.2 Chilling period (days)

The thematic map (Figure 29 & 30) shows the availability of chilling period in Shimla and Kinnaur districts during the study period. In 2012-13, the maximum chilling period (195 days) has been depicted at Kalpa, Pooh, Chopal and Kumarsain followed by Rohru (176 days) whereas, the minimum chilling period with 140 days is shown at Rampur and Basantpur. During 2013-14, the maximum chilling period (201 days) is depicted at Kalpa, Pooh and Kumarsain followed by Chopal (188 days). Whereas, the minimum chilling period (140days) has been marked at Basantpur and Rampur.

4.2.3.1.3 UTAH chilling unit accumulation during chilling period

The thematic layers (Figure 31 & 32) shows the UTAH chilling unit accumulation during chilling period in the entire Shimla and Kinnaur blocks during study years. In 2012-13, maximum chilling units (1898) has been depicted at Rampur and Basantpur followed by Rohru (1892) whereas, minimum chilling units (1526) are shown at Kalpa, Pooh, and Kumarsain. During the year 2013-14, maximum chilling units (1942) during chilling period are projected at Basantpur and Rampur and minimum (1414.5) at Kalpa, Pooh and Kumarsain.

4.2.3.1.4 North Carolina chilling unit accumulation during chilling period

Chilling unit during chilling period of 2012-13 computed according to NORTH CAROLINA chilling model (Figure 33) revealed the maximum value (2498) at Nichar, Chirgaon, Jubbal and Theog followed by Rohru (1964). During this period, the minimum chilling units (1466) are shown at Kalpa, Pooh and Kumarsain. During 2013-14, the maximum chilling units (2507.5) is shown (Figure 34) at Nichar, Chirgaon, Jubbal and Theog followed by Basantpur and Rampur (1922) whereas, the minimum value (1366.5) has been indicated in respect of Kalpa, Pooh and Kumarsain blocks.

4.2.3.1.5 UTAH chilling unit accumulation during peak winter

The thematic map (Figure 35) in year 2012-13, indicates the maximum chilling units (1234) during peak winter at Nichar, Chirgaon, Jubbal and Theog jointly followed by Rampur and Basantpur (1139). Whereas, minimum chilling units (419) at peak winter has been depicted at Kalpa, Pooh and Kumarsain. During 2013-14, (Figure 36) the maximum chilling units (1209) at peak winter is depicted at Shimla followed by Nichar, Chirgaon, Jubbal and Theog (1163.5). Whereas, minimum chilling units during peak winter (337) is depicted at Kalpa, Pooh and Kumarsain.

4.2.3.1.6 North Carolina chilling unit accumulation during peak winter

The thematic map on chilling unit during peak winter in 2012-13 presented according to NORTH CAROLINA chilling model in Figure 37 revealed the maximum value (13581) at Shimla followed by Nichar, Chirgaon, Jubbal and Theog (1205). The minimum chilling units (409) are however, shown at Kalpa, Pooh and Kumarsain. During 2013-14, (Figure 38) the maximum chilling units has been shown to be accumulated during this period at Shimla (1277). The next higher corresponding value has been depicted at Nichar, Chirgaon, Jubbal and Theog. The lowest chilling units (315) during this period have been shown at Kalpa, Pooh and Kumarsain.

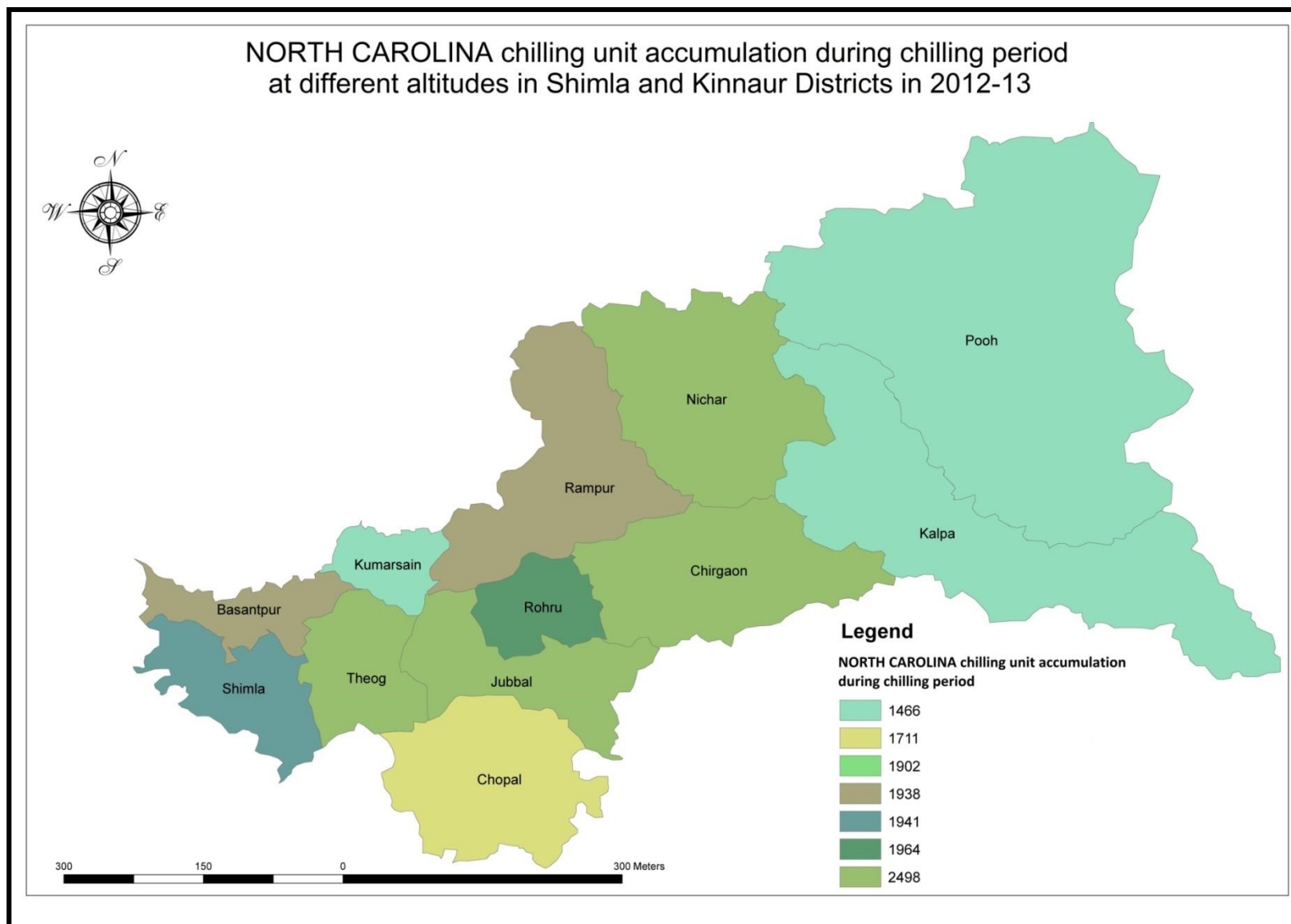


Figure 33

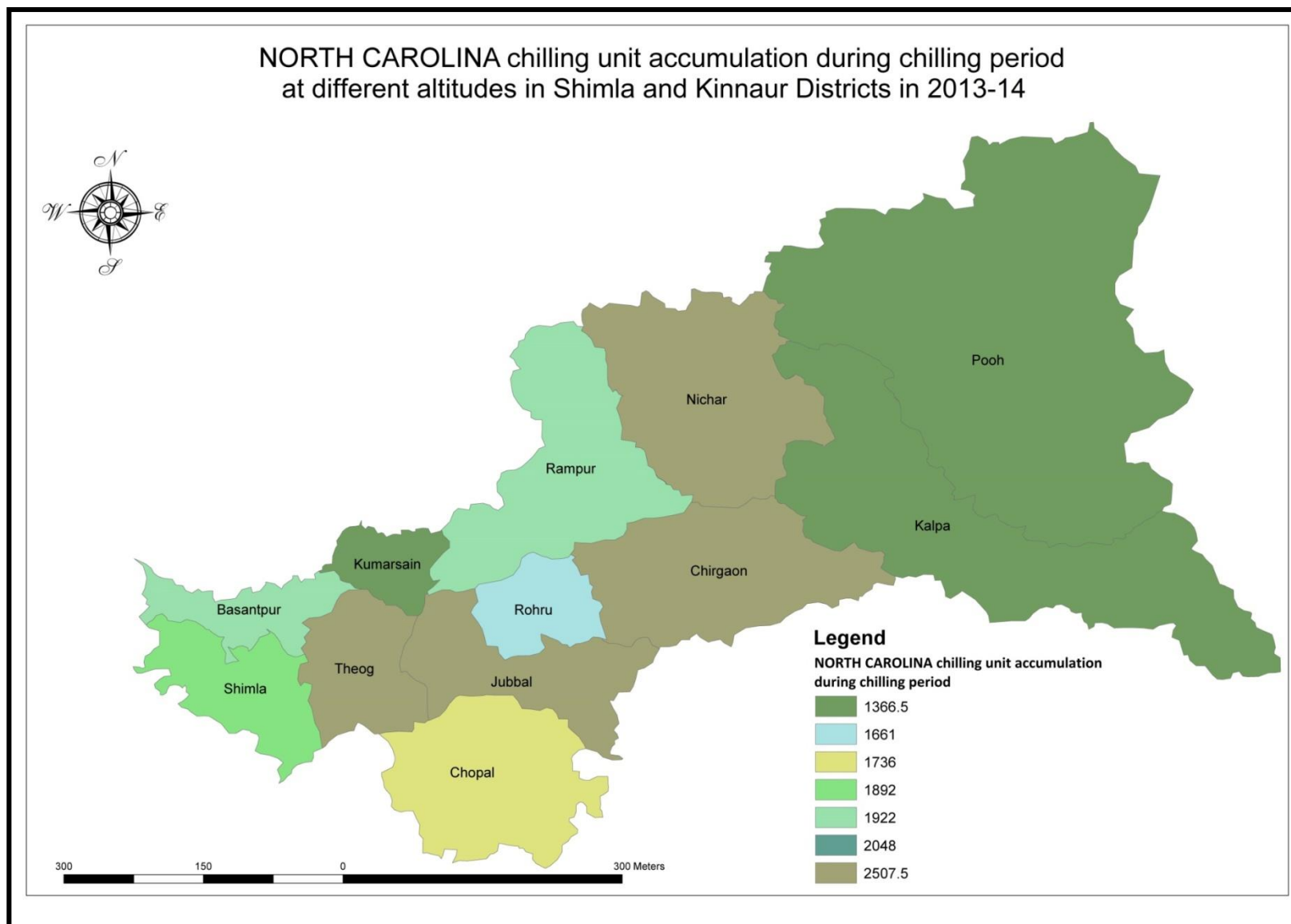


Figure 34

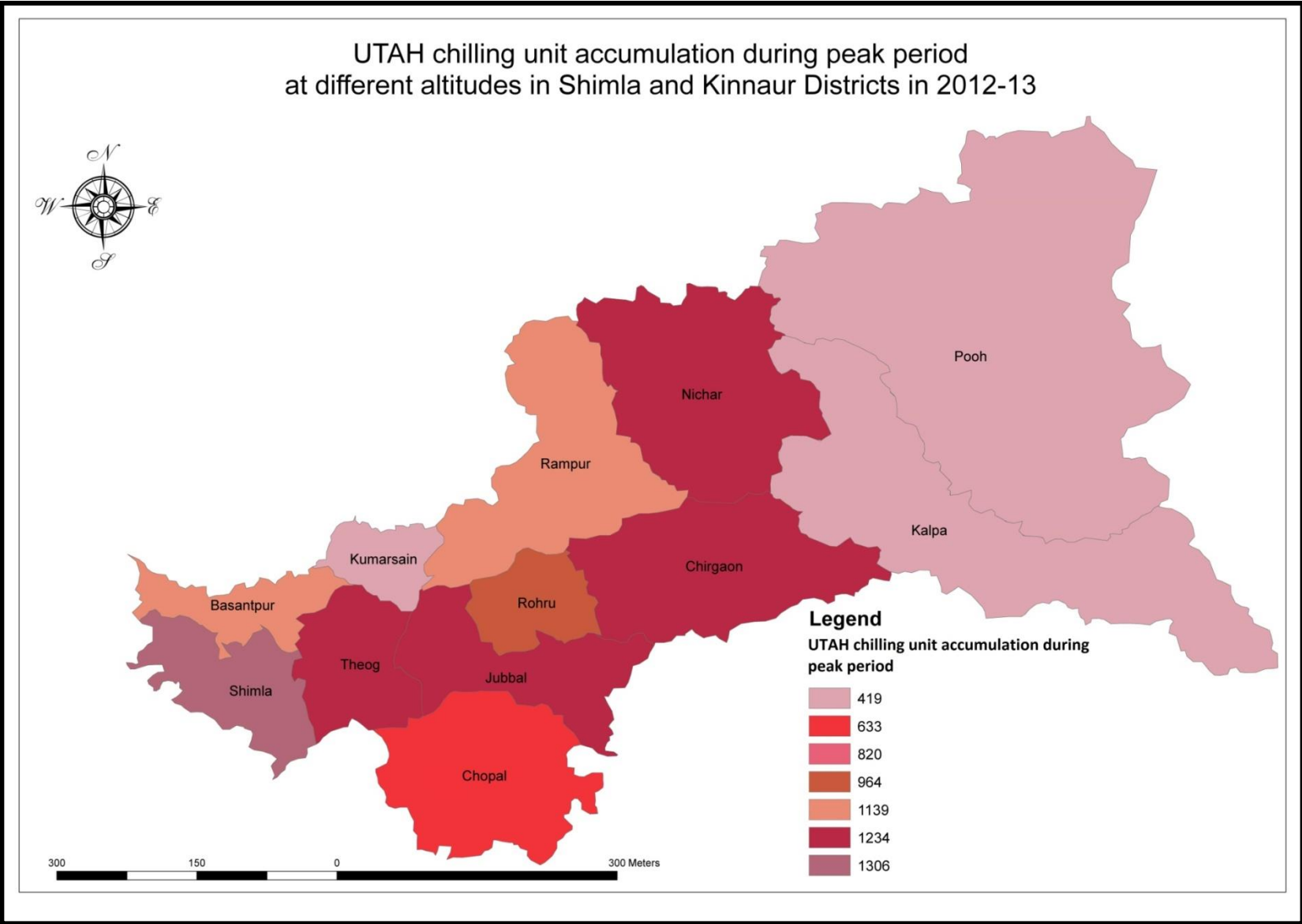


Figure 35

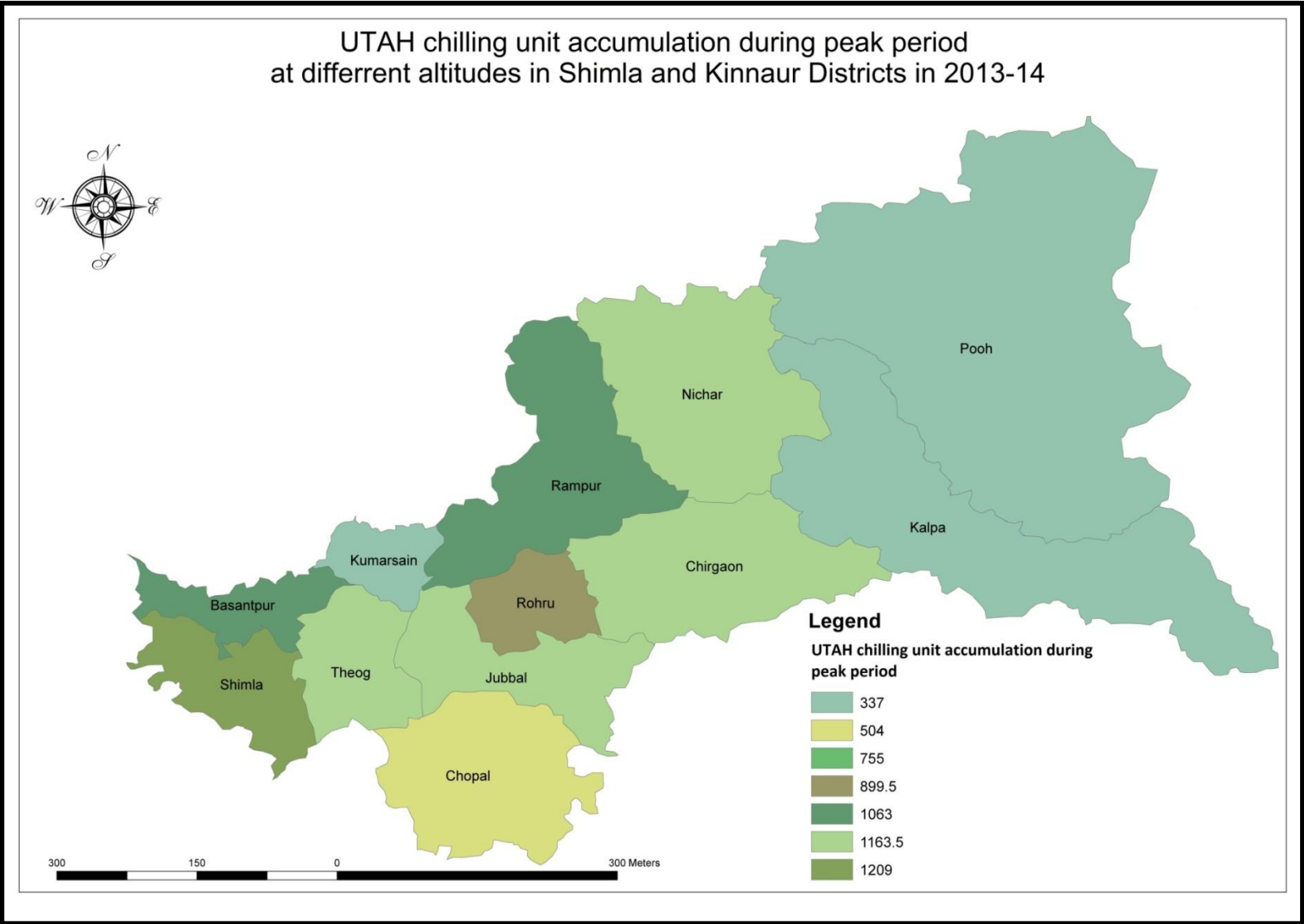


Figure 36

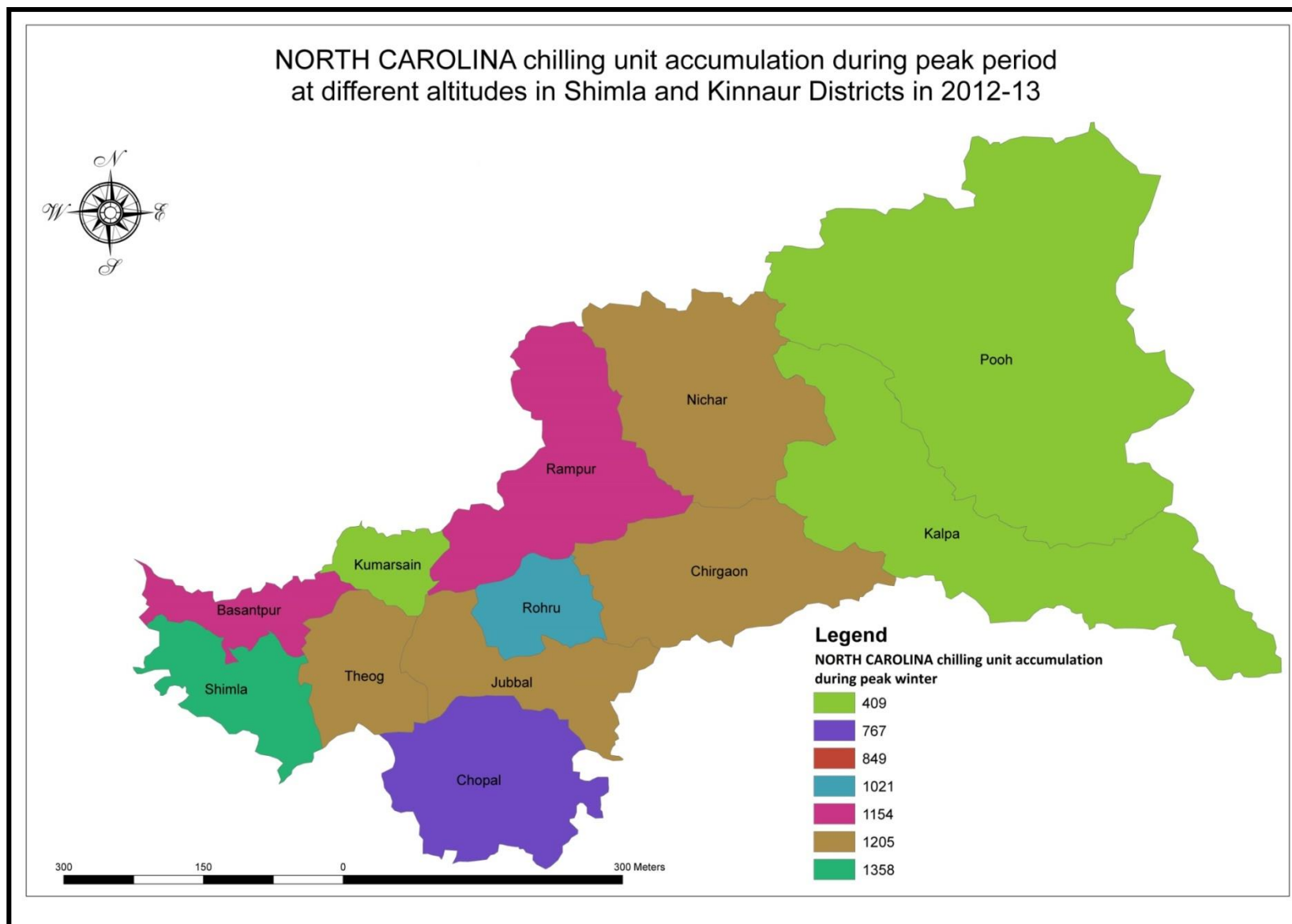


Figure 37

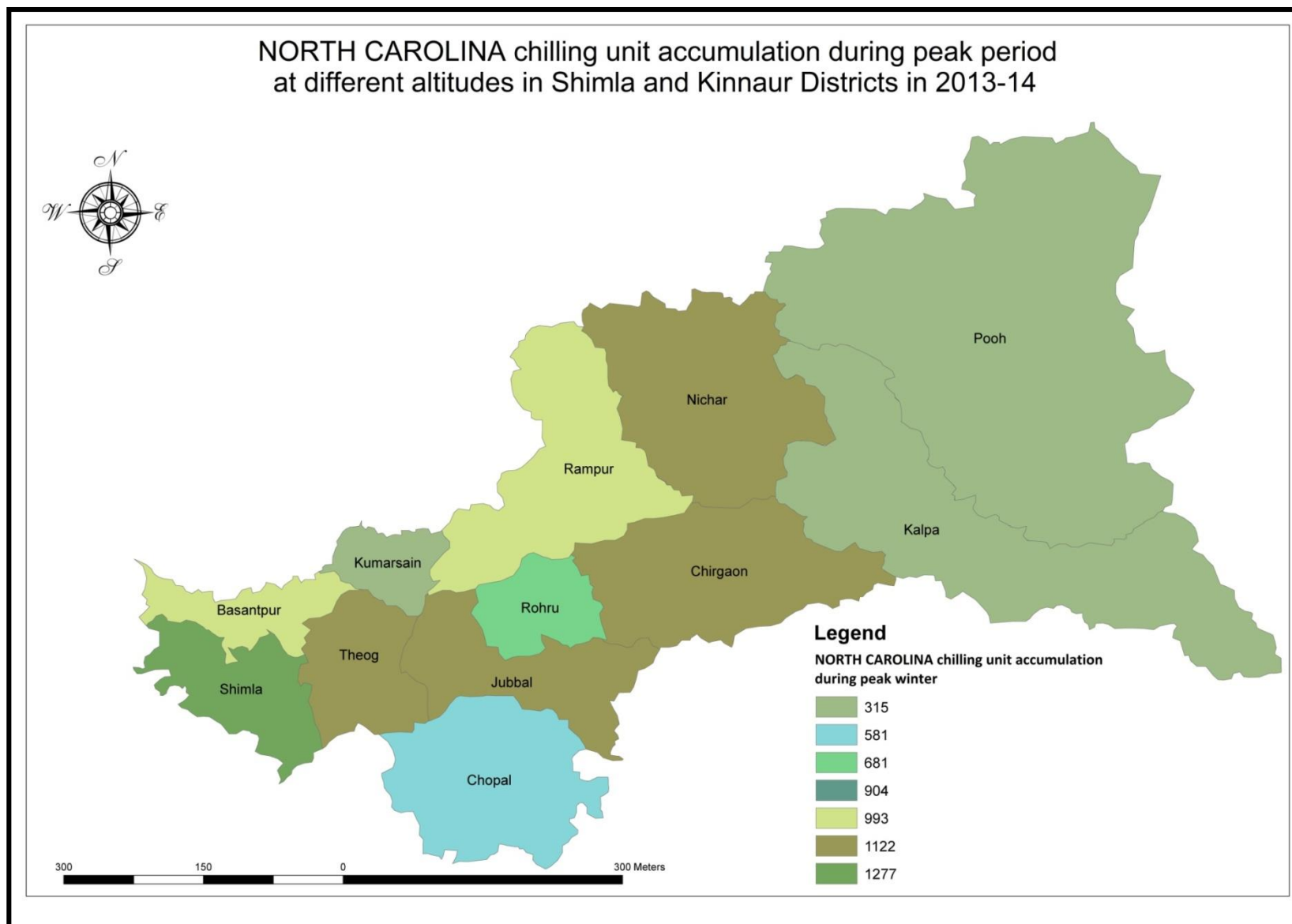


Figure 38

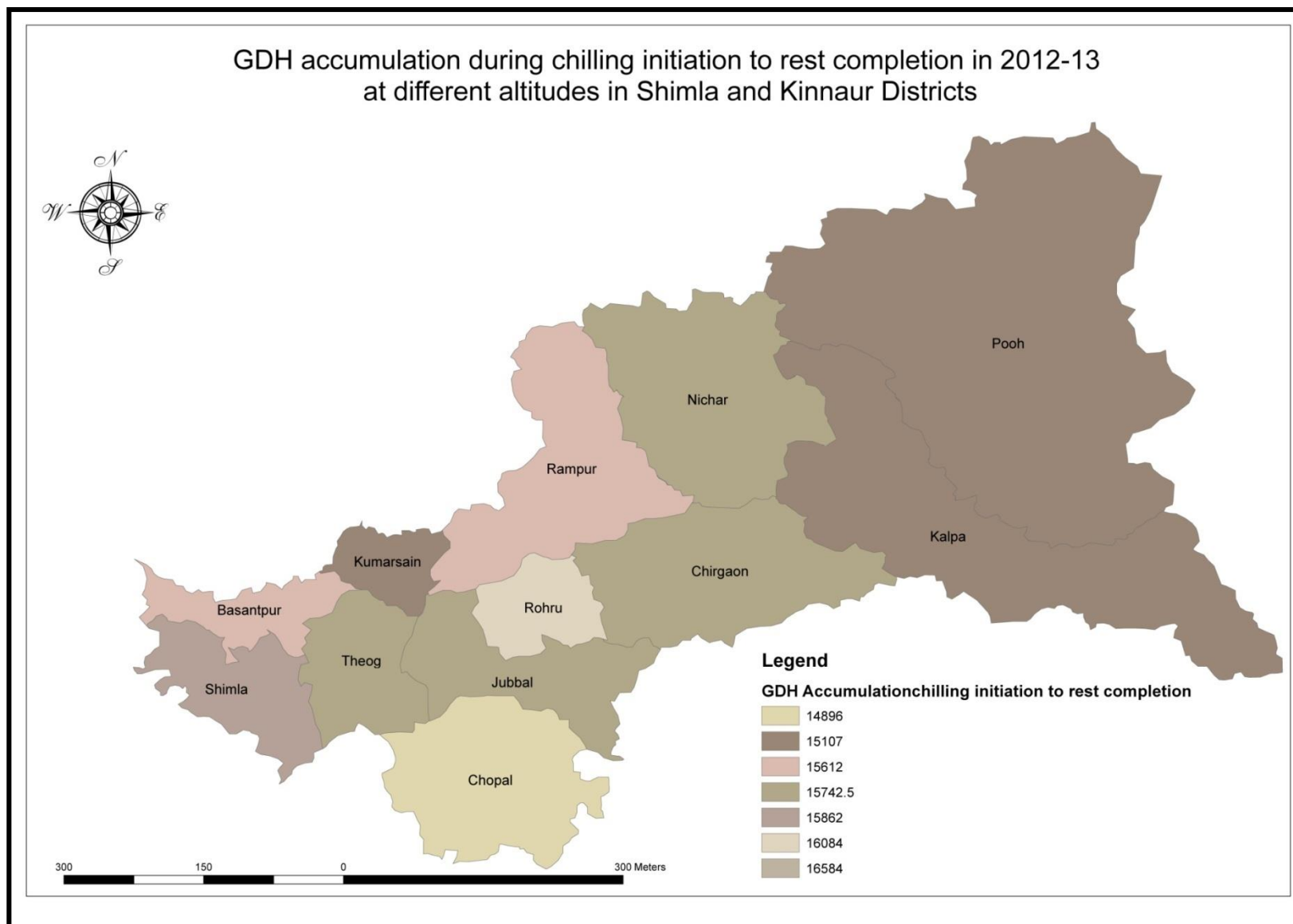


Figure 39

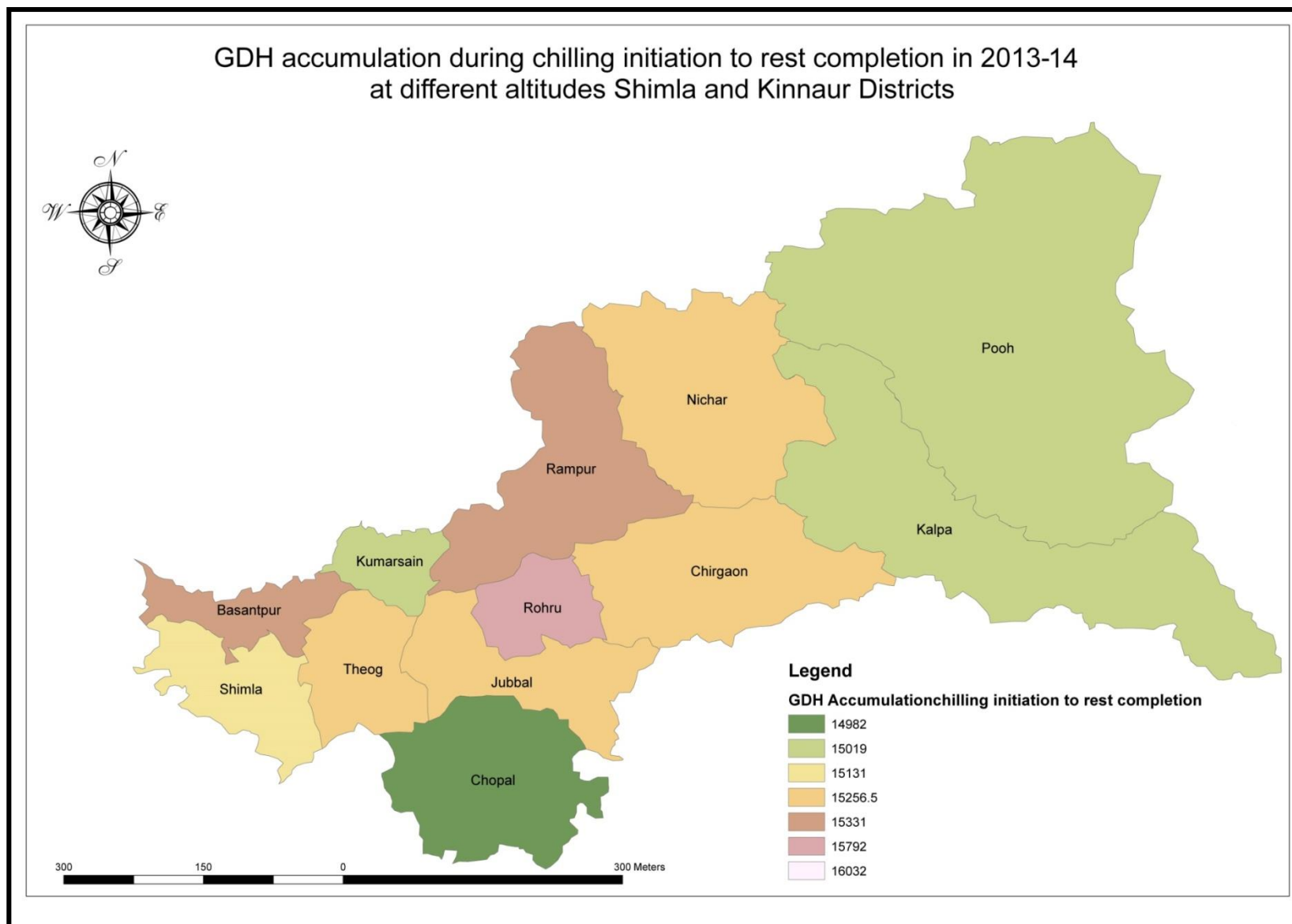


Figure 40

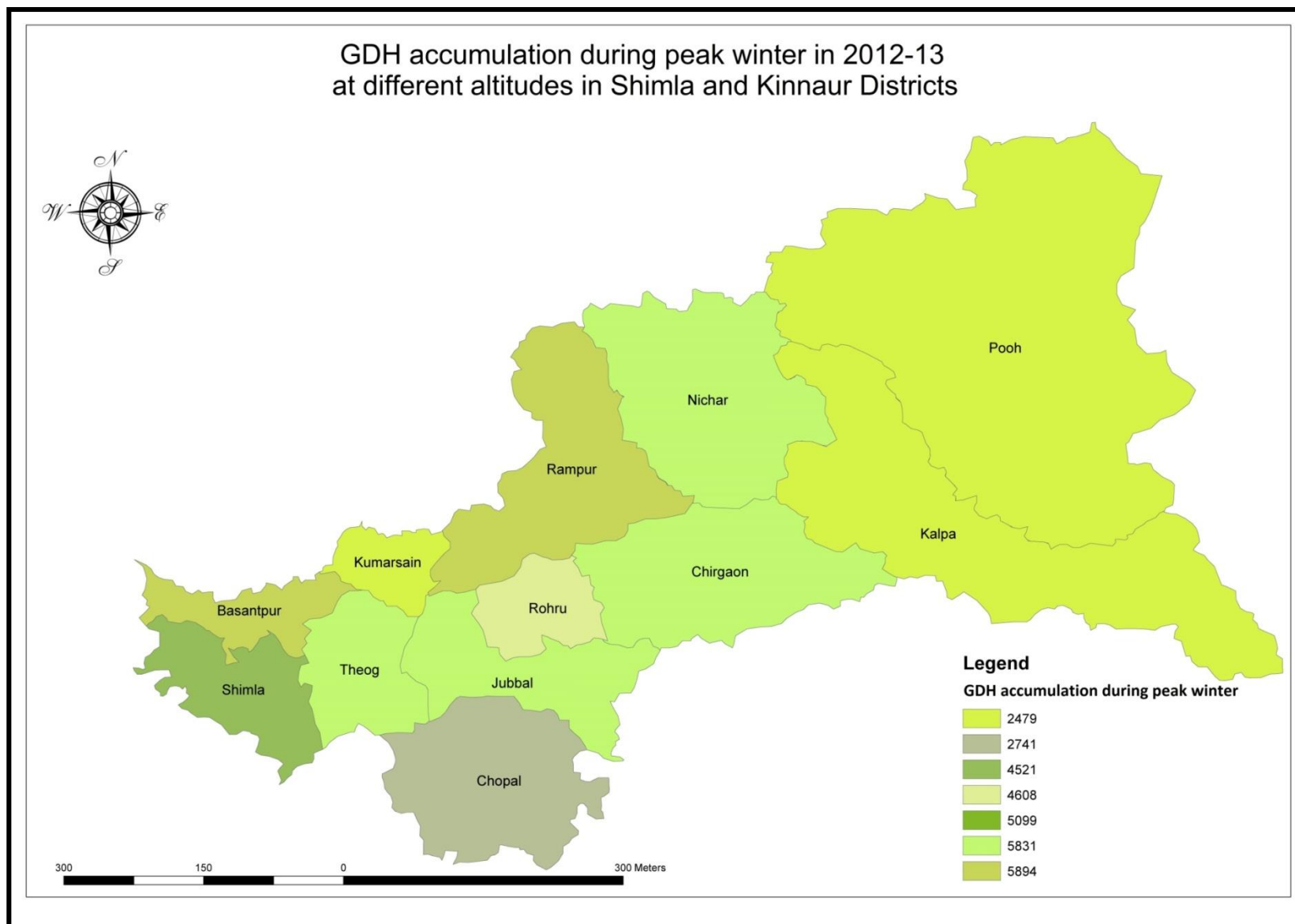


Figure 41

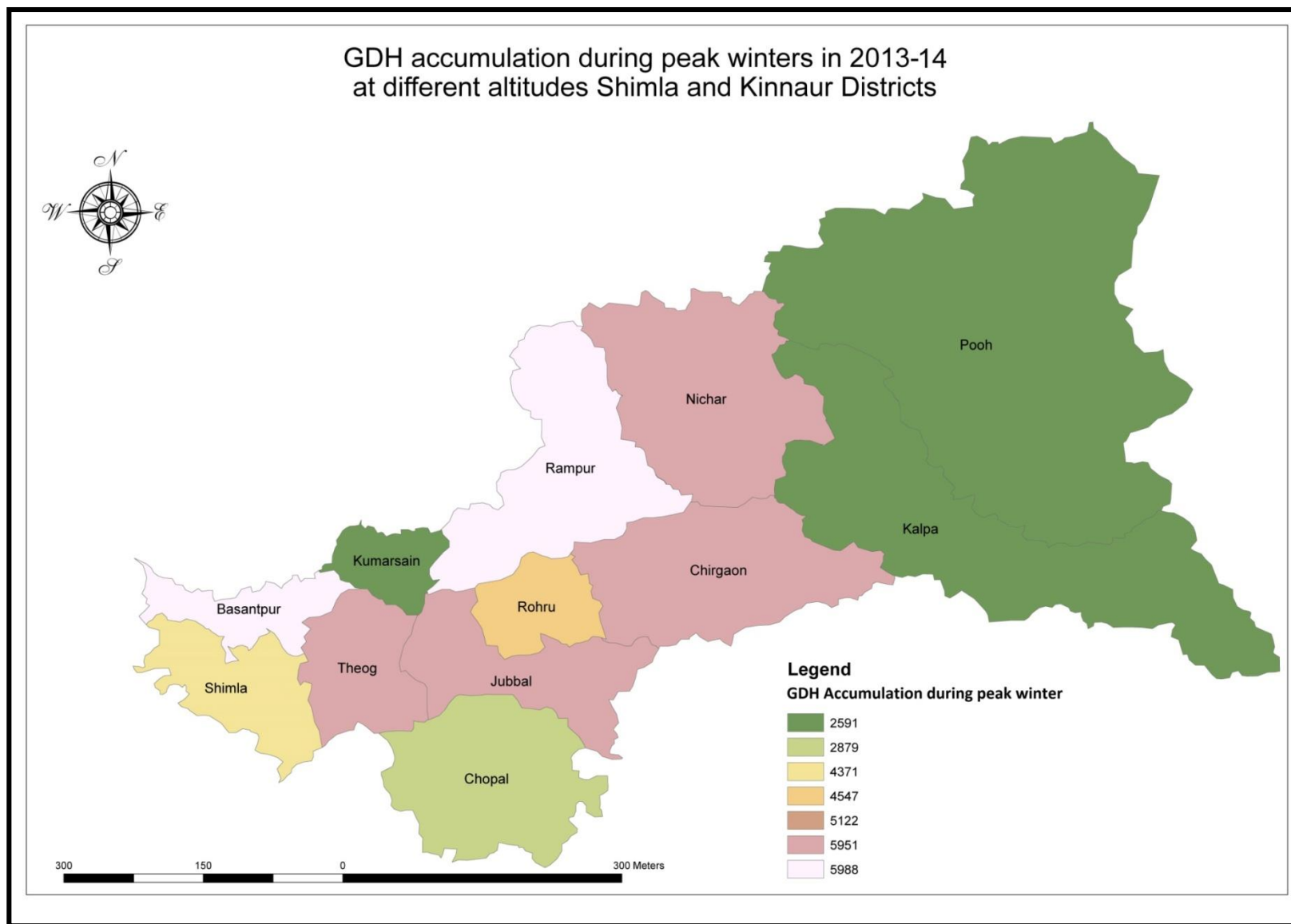


Figure 42

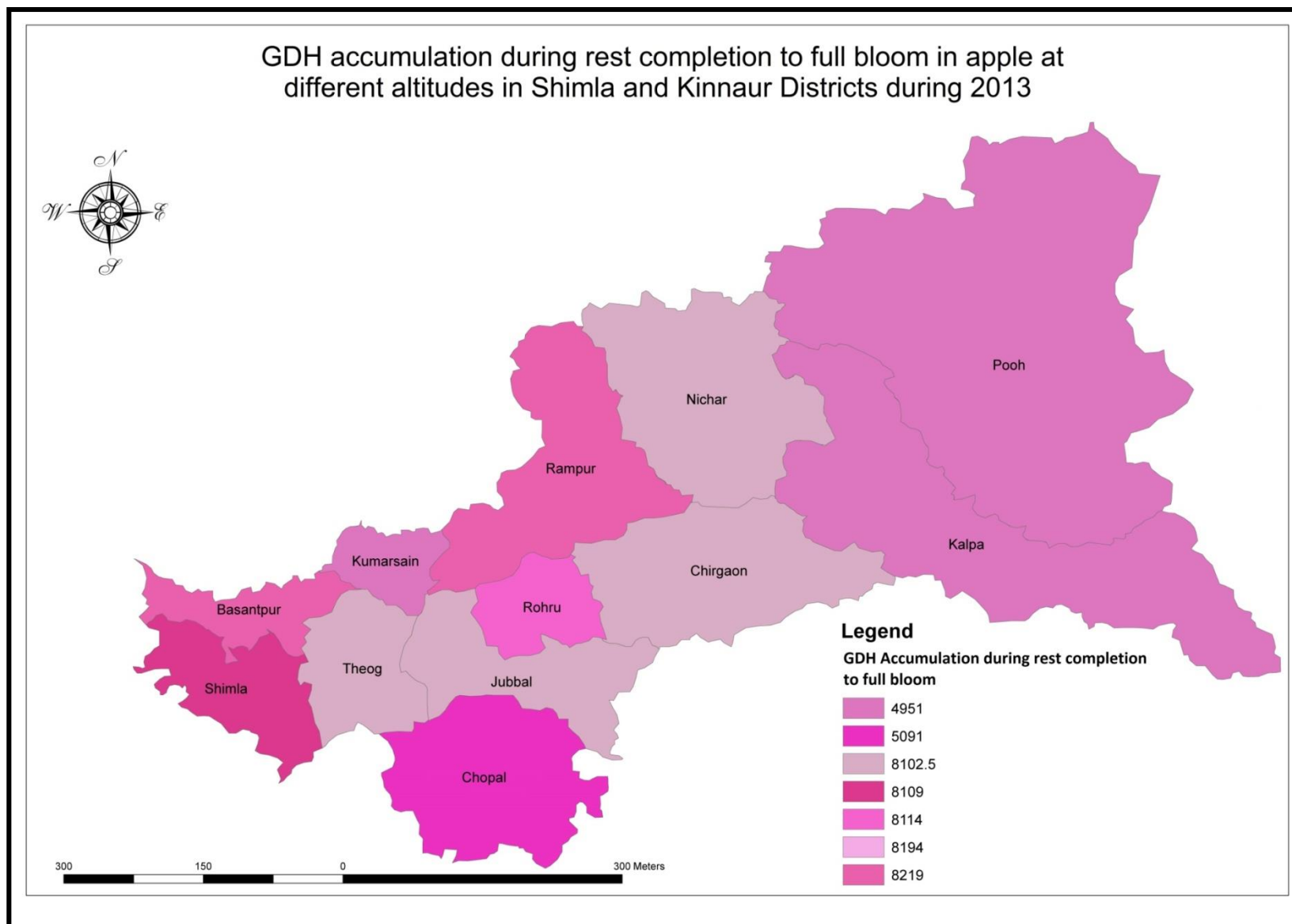


Figure 43

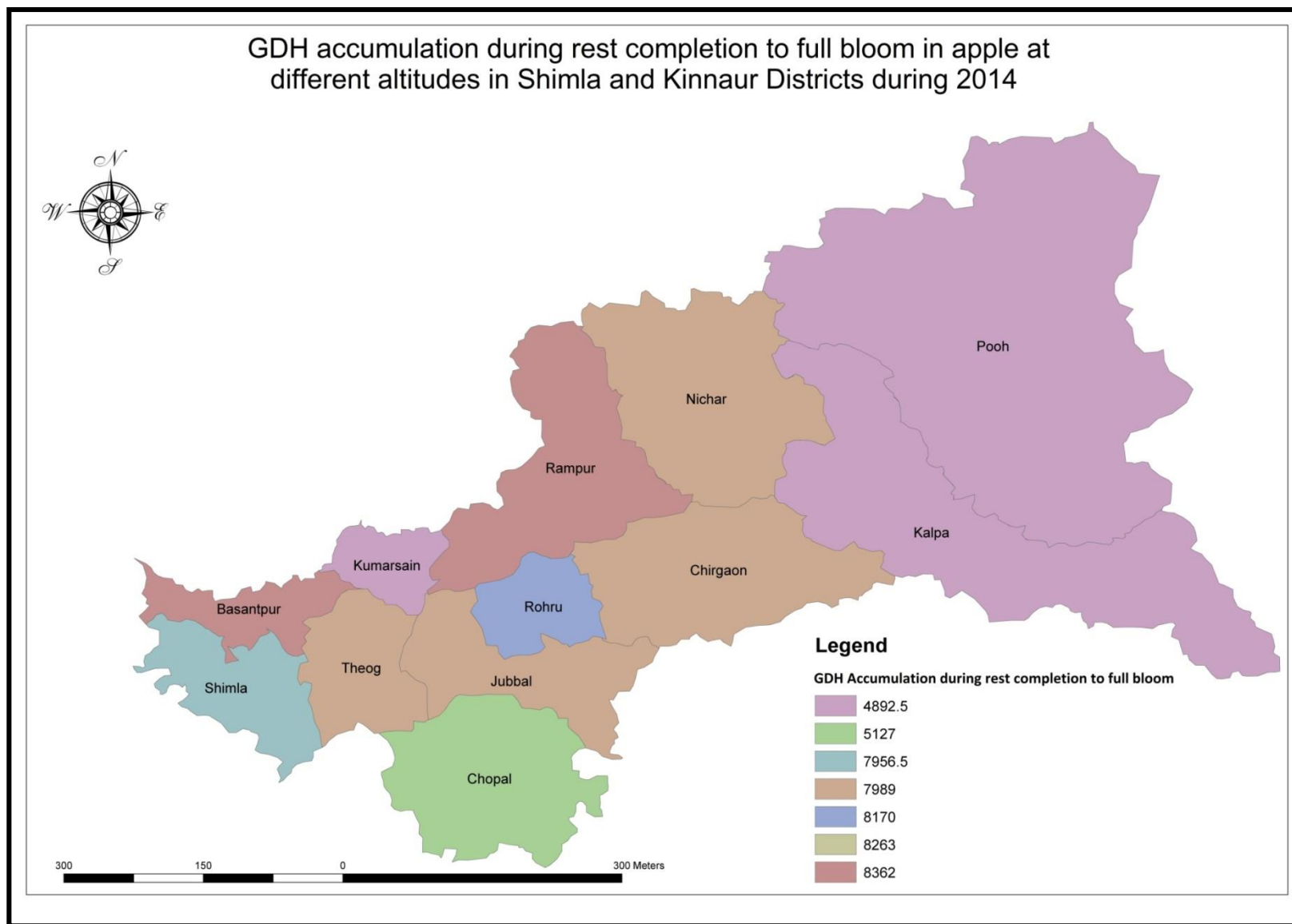


Figure 44

In the present study, thematic maps of chilling hours during chilling period and peak winters were made according to Utah and North Carolina chilling models. Similar thematic maps showing the availability of chilling hours for apple at different locations in Uttarakhand have been attempted quite recently (Dhami *et al.*, 2012).

4.2.3.1.7 GDH accumulation during chilling initiation to rest completion

The maximum GDH units accumulation (16584) from chilling initiation to rest completion in 2012-13 is shown (Figure 39) at Theog, Jubbal, Chirgaon and Nichar followed by Rohru (16084). However, the minimum accumulation of GDH unit (14896) during this period has been depicted at Chopal. In 2013-14, the maximum GDH unit (15792) were recorded at Rohru, followed by Basantpur and Rampur (15331). However, Chopal block registered the minimum GDH unit accumulation (14982) during this period (Figure 40).

4.2.3.1.8 GDH accumulation during peak winter

The thematic map (Figure 41 & 42) indicates great variation in GDH unit accumulation during peak winter of study period at different locations in Shimla and Kinnaur districts. During 2012-13, the maximum GDH accumulation (5894) during peak winter is shown at Basantpur and Rampur followed by Theog, Jubbal, Chirgaon and Nichar, whereas, the minimum GDH accumulation (2479) has been indicated at Kalpa, Pooh and Kumarsain. In 2013-14, the maximum GDH unit accumulation (5988) has been depicted at Basantpur and Rampur jointly followed by Theog, Jubbal, Chirgaon and Nichar. The minimum GDH unit accumulation (2591) is however, shown at Kalpa, Pooh and Kumarsain.

4.2.3.1.9 GDH unit accumulation during rest completion to full bloom

In the year 2013, the maximum GDH unit accumulations (8219) between rest completion to full bloom is depicted (Figure 43) at Basantpur followed by Rampur (8114). Whereas, the minimum GDH unit accumulation (4951) is indicated at Kalpa, Pooh and Kumarsain. In 2014, (Figure 44) GDH unit accumulations during rest completion to full bloom was depicted highest (8362) at Basantpur and

Rampur followed by Rohru (8170) whereas, lowest GDH unit accumulation (4892.5) is shown at Kalpa, Pooh and Kumarsain.

At higher altitudes, during chilling initiation to rest completion period temperature mostly remained extremely low (Appendix II). As per UTAH and North Carolina models used during the study for counting chill units, the number of hours below 4.5°C do not accounts for GDH, hence summation of GDH during this period were less at Kalpa, Pooh and Kumarsain.

4.2.4 Rainfall

The thematic layer (Figure 45 & 46) indicates that different altitudes in Shimla and Kinnaur districts had variable annual rainfall pattern. In year 2012-13, annual average rainfall of 106.08 mm has been indicated for Theog, Jubbal, Chirgaon and Nichar, 114.67 mm for Rohru, 113 mm in respect of Basantpur and Rampur, 126.25 mm for Shimla and 72.25 mm for Kalpa, Kumarsain and Pooh. In 2013-14, annual average rainfall of 112.45 mm has been shown for Rohru, 104.15 mm for Jubbal, Theog, Chirgaon and Nichar, 110.86 mm for Basantpur and Rampur and 123.75 mm in respect of Shimla. However, corresponding values has been indicated lowest (64.85 mm) for Chopal, followed by 69.79 mm rainfall at Kalpa, Pooh and Kumarsain. Therefore, all the blocks of Shimla and Nichar block of Kinnaur fall under medium rainfall zone, whereas, Kalpa and Pooh in Kinnaur experienced scanty rainfall during the course of study.

4.2.5 Solar elevation angle

The thematic map of the elevation angle for the year 2013 and 2014 (Figure 47 & 48) depicts that the maximum solar elevation angle is observed in month of May, June and July at all the locations.

4.2.6 Azimuth angle

The thematic map depicts that the azimuth angle in the year 2013 (Figure 49 & 50) at Kalpa, Pooh, Chopal and Kumarsain ranged between 106.9 to 107.5. It was between 107 to 121.3 at Shimla and 106.1 to 106.9 at Theog, Jubbal-Kotkhai,

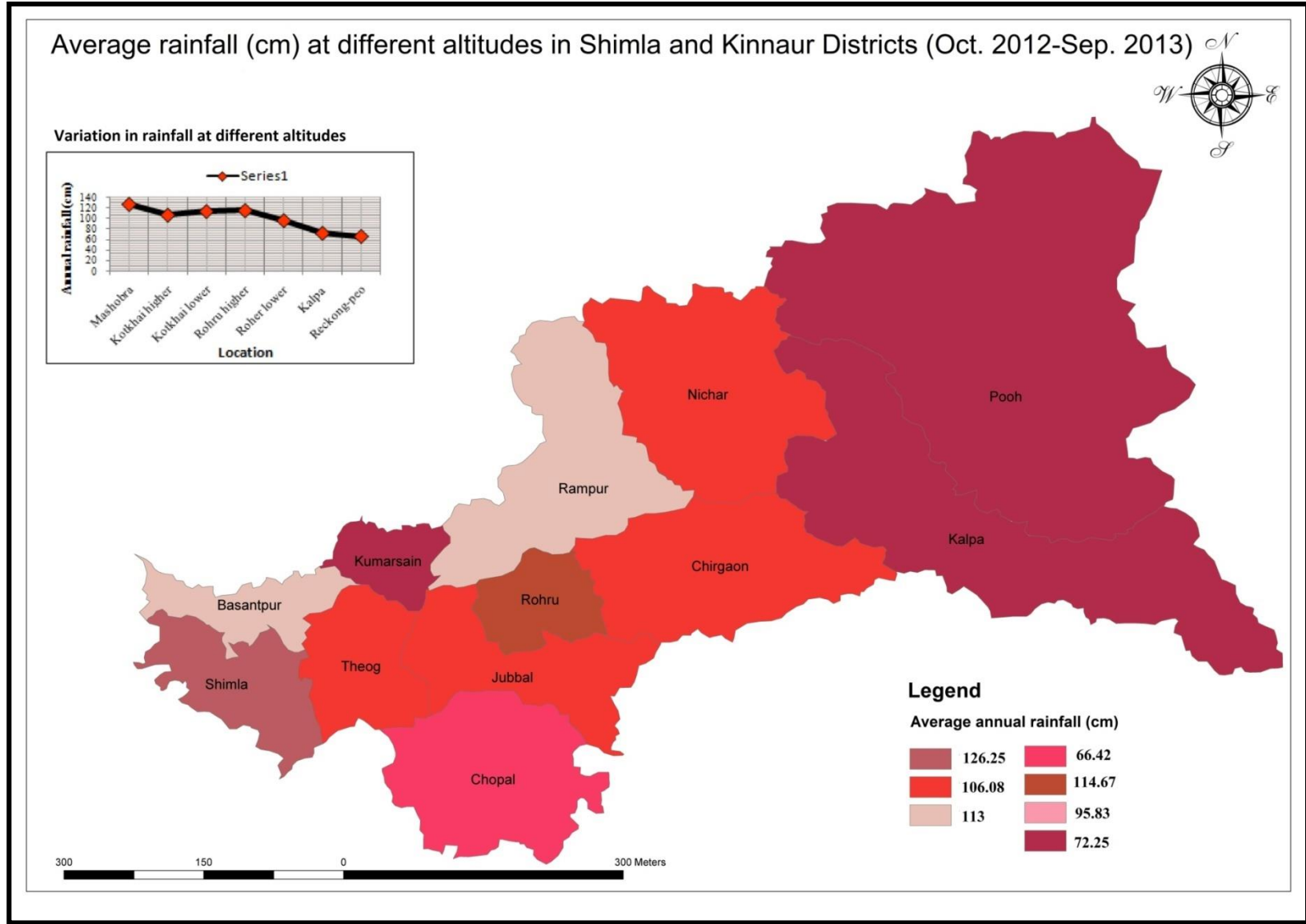


Figure 45

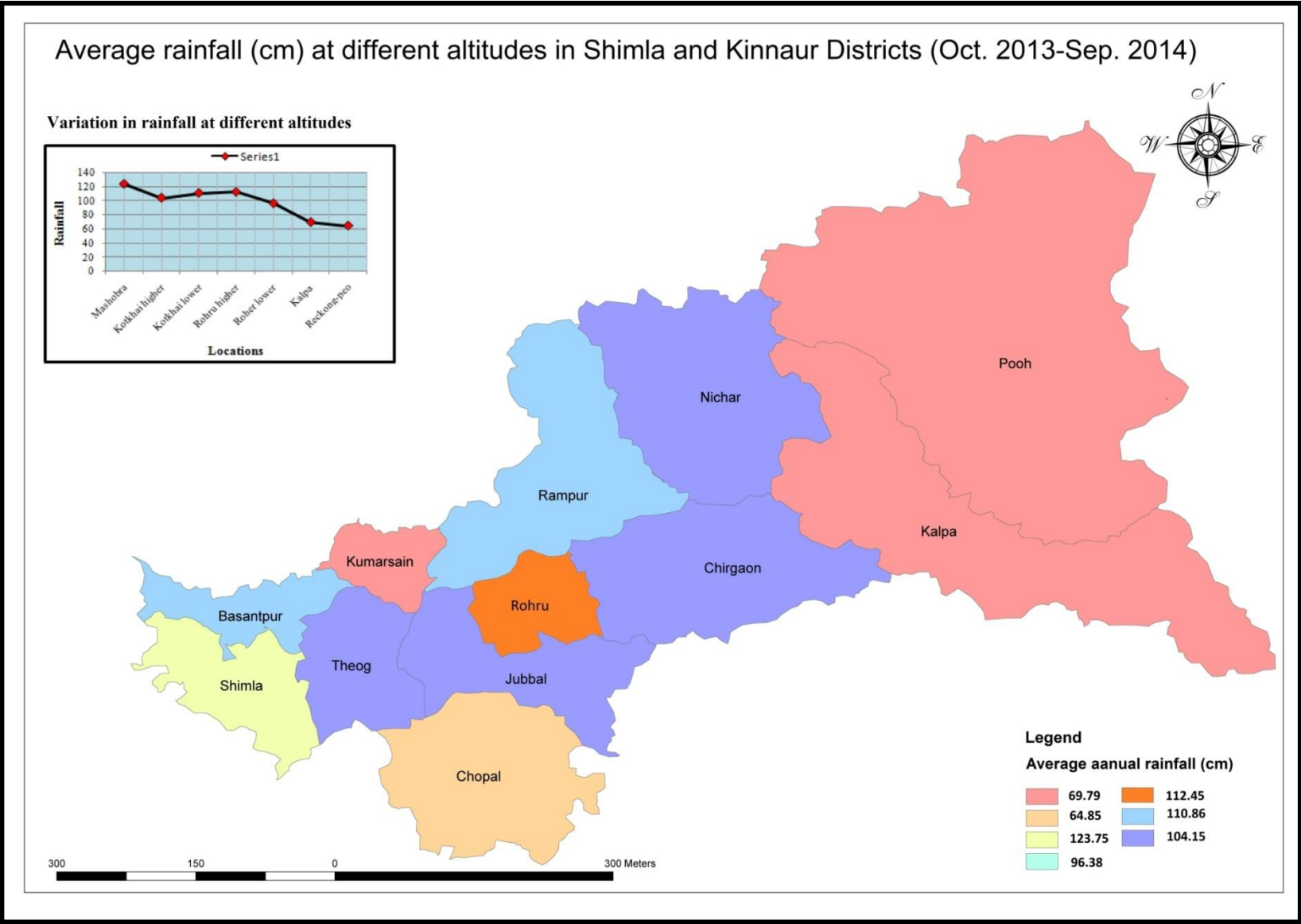


Figure 46

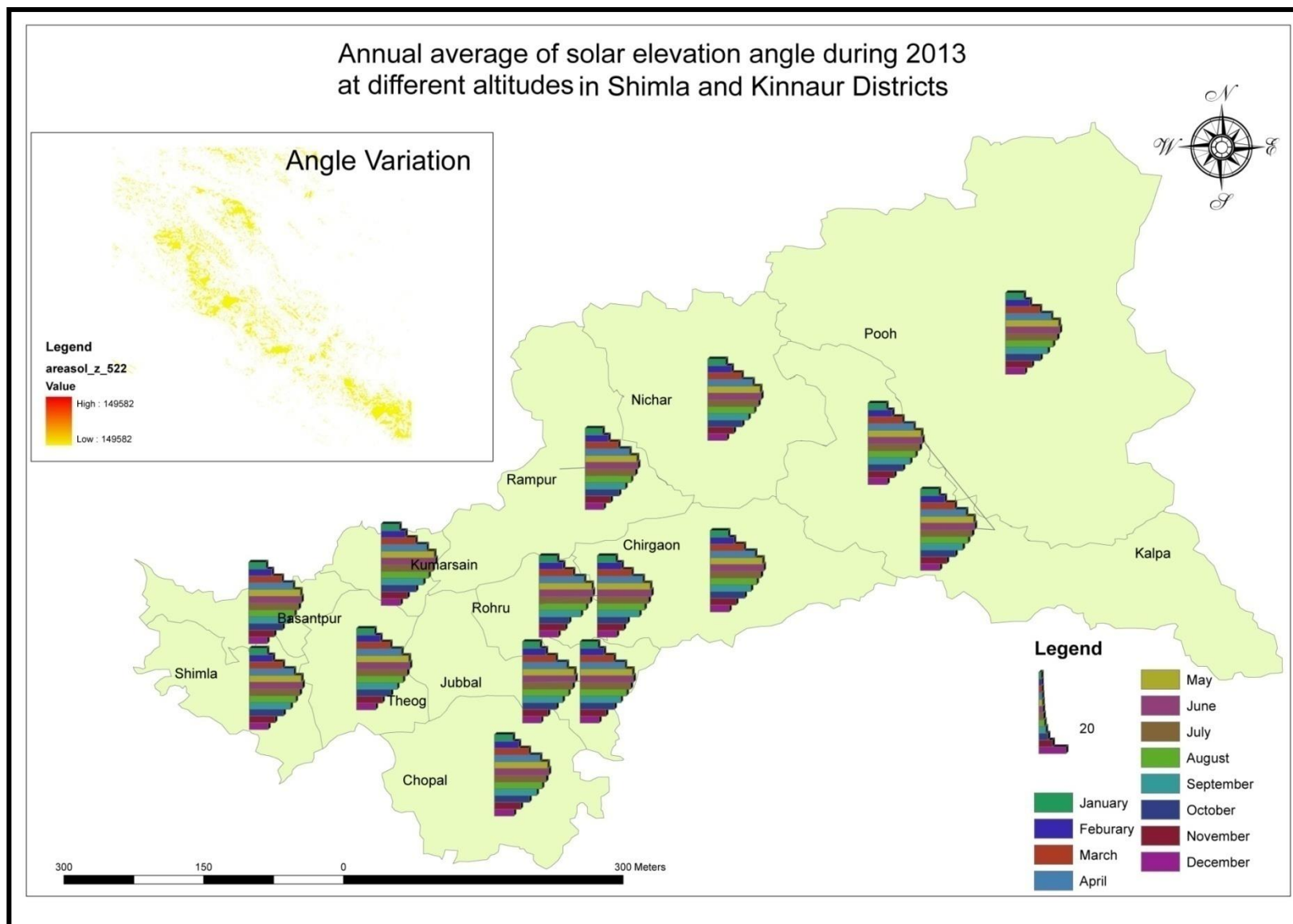


Figure 47

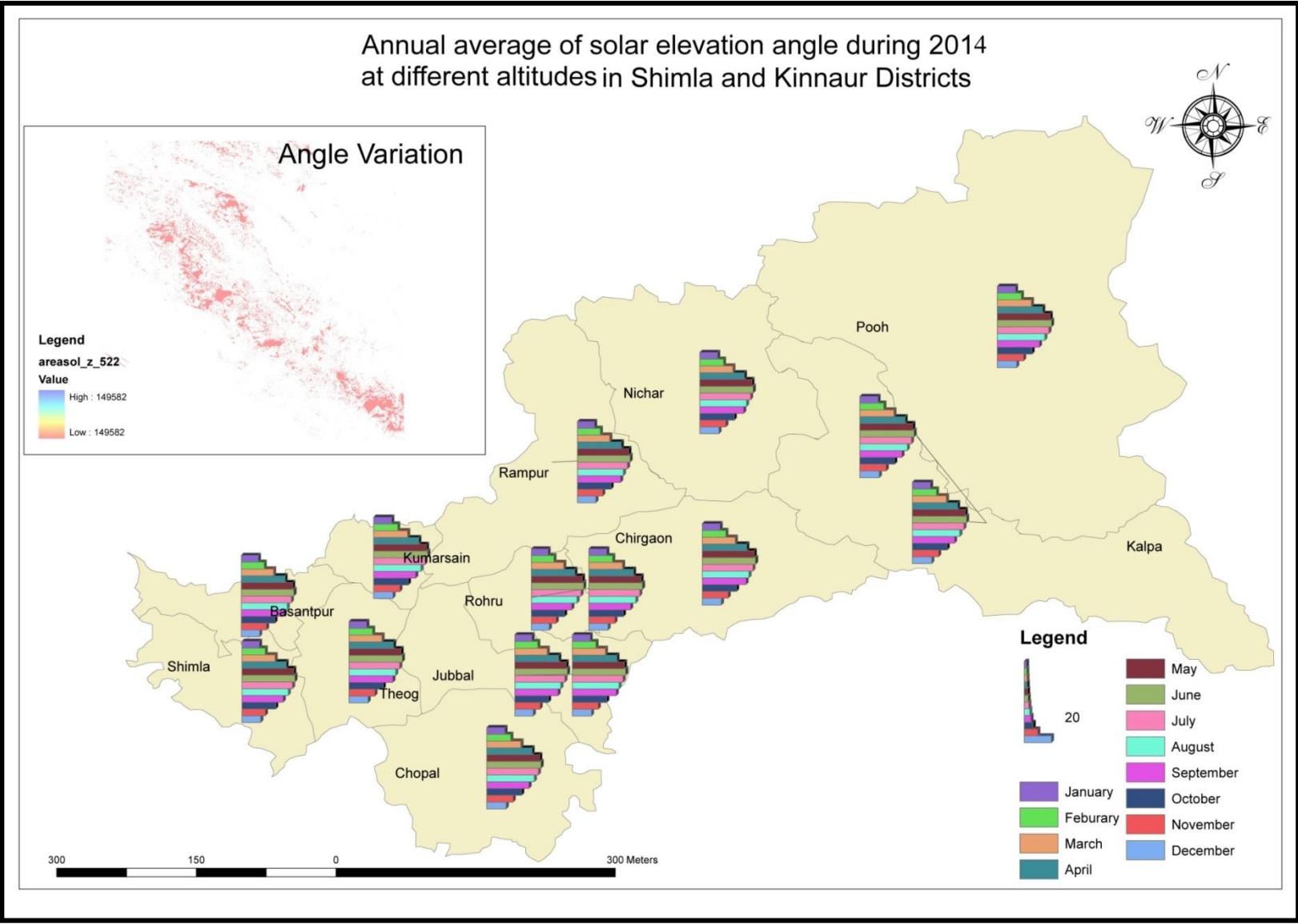


Figure 48

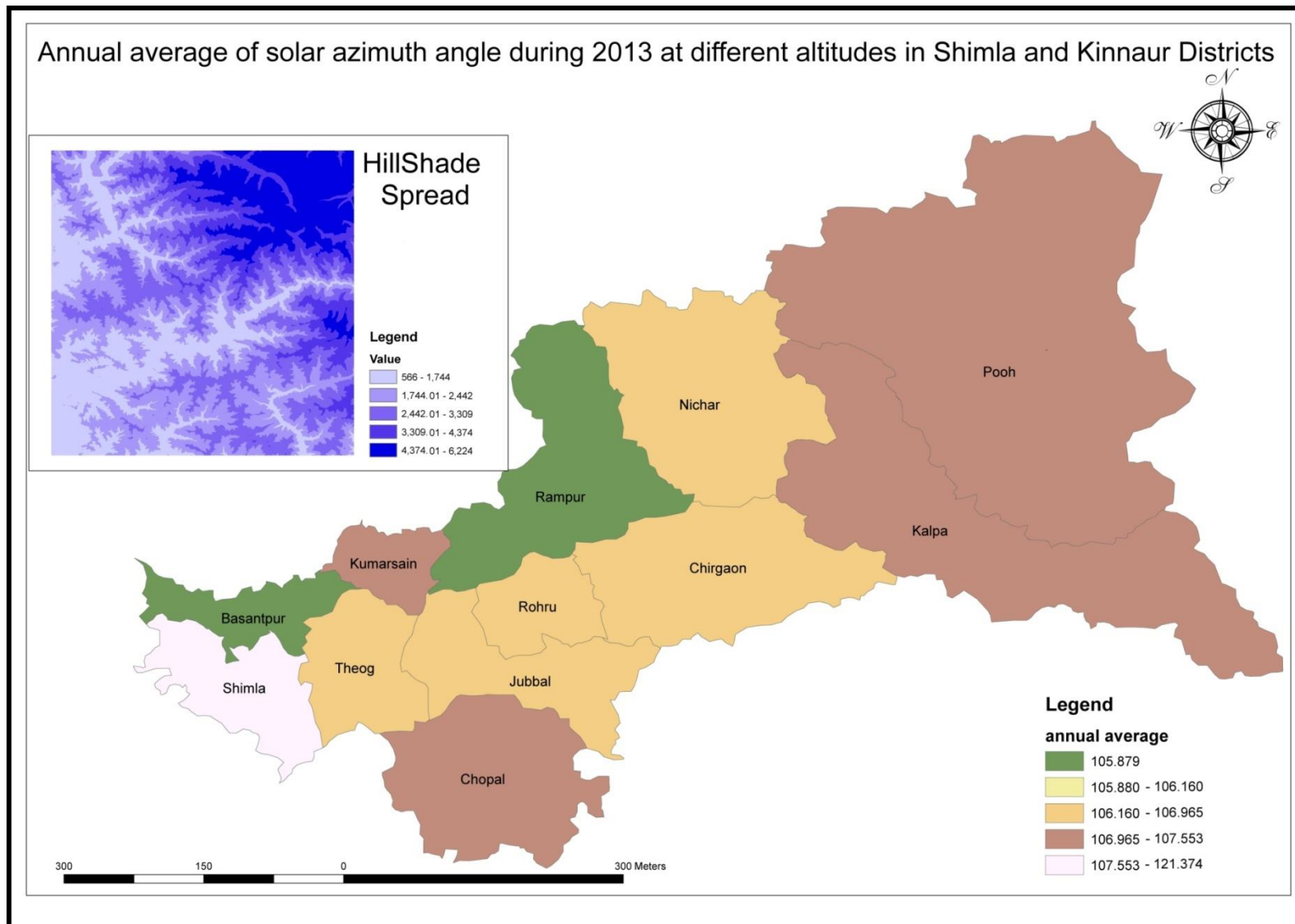


Figure 49

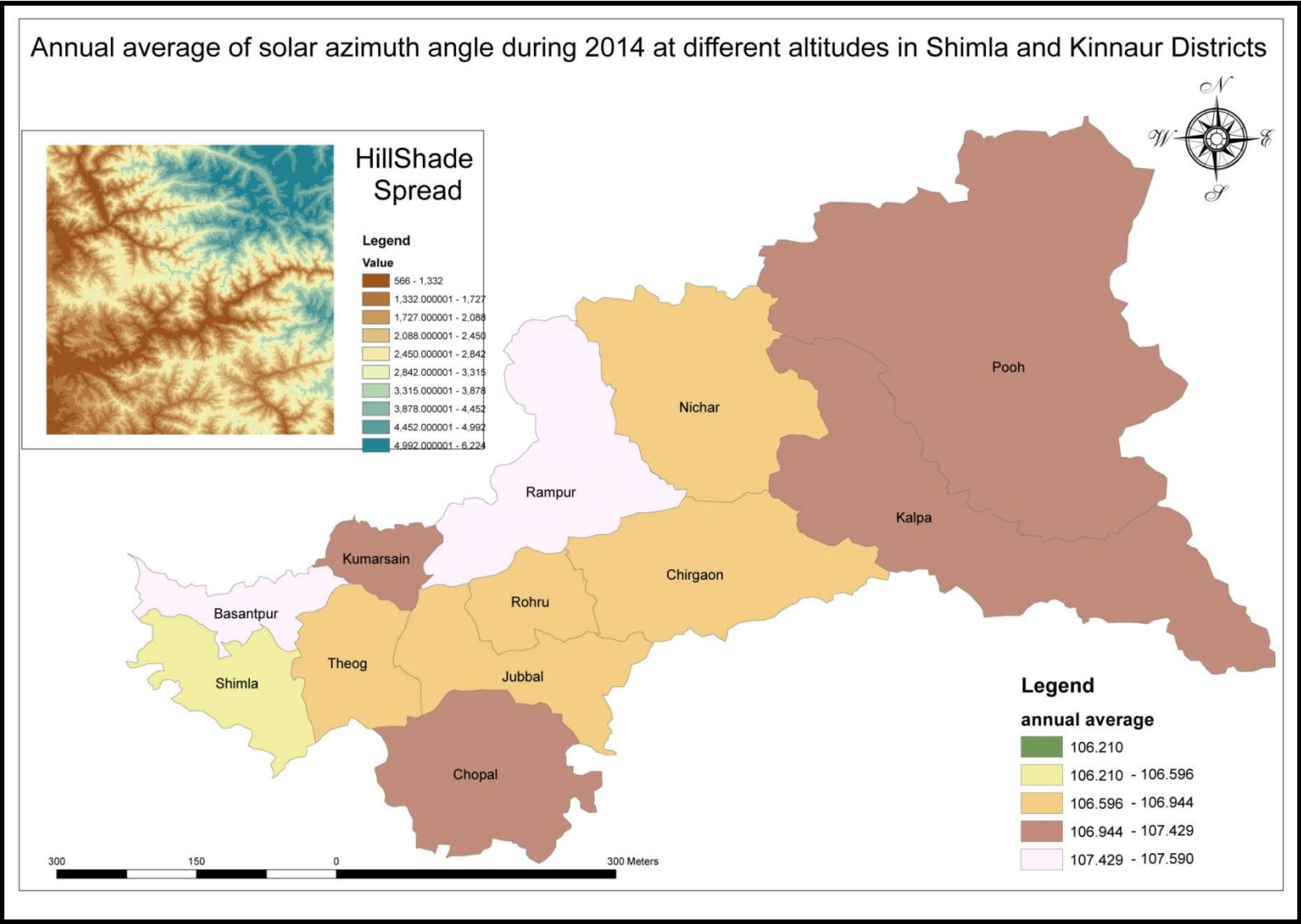


Figure 50

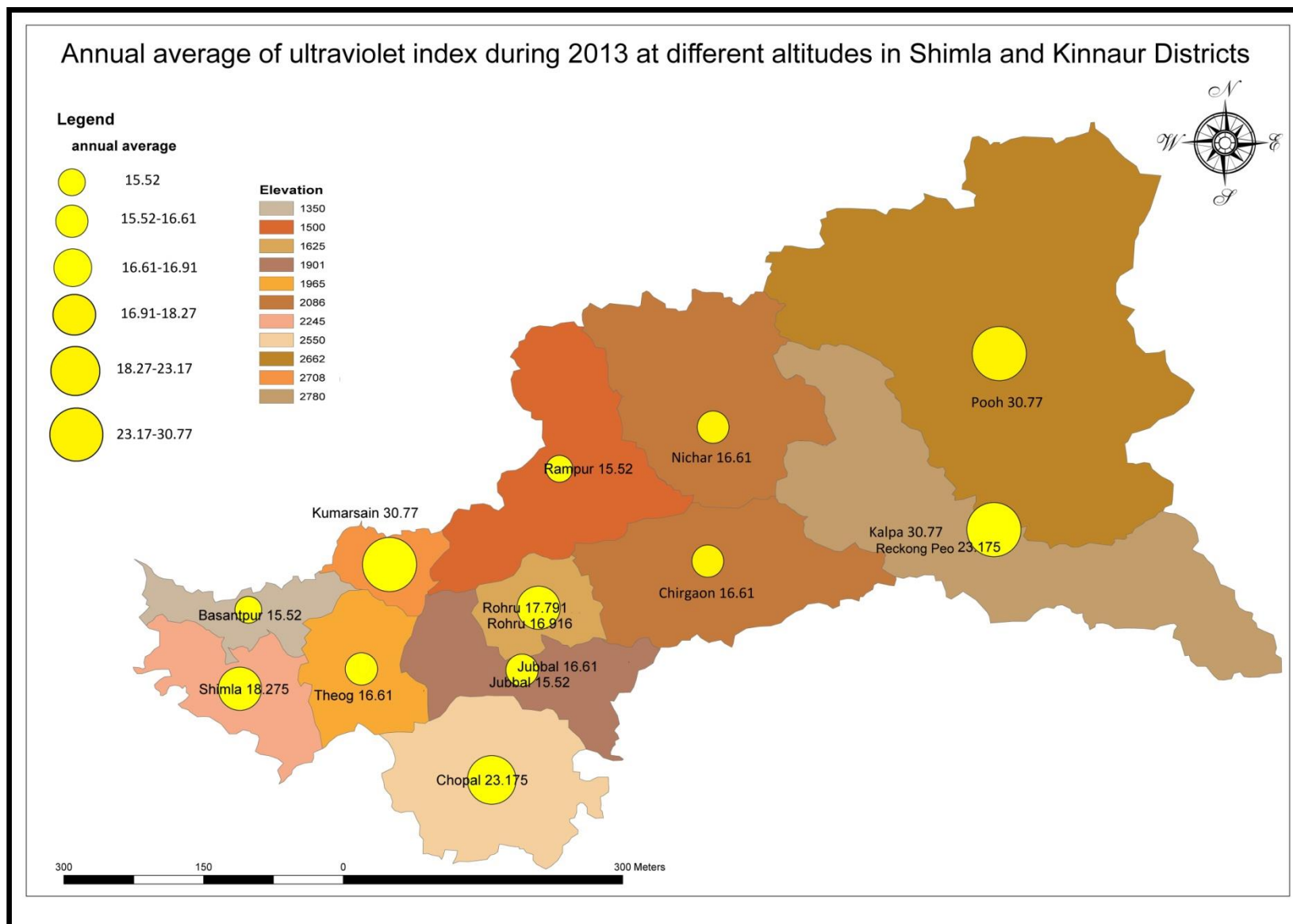


Figure 51

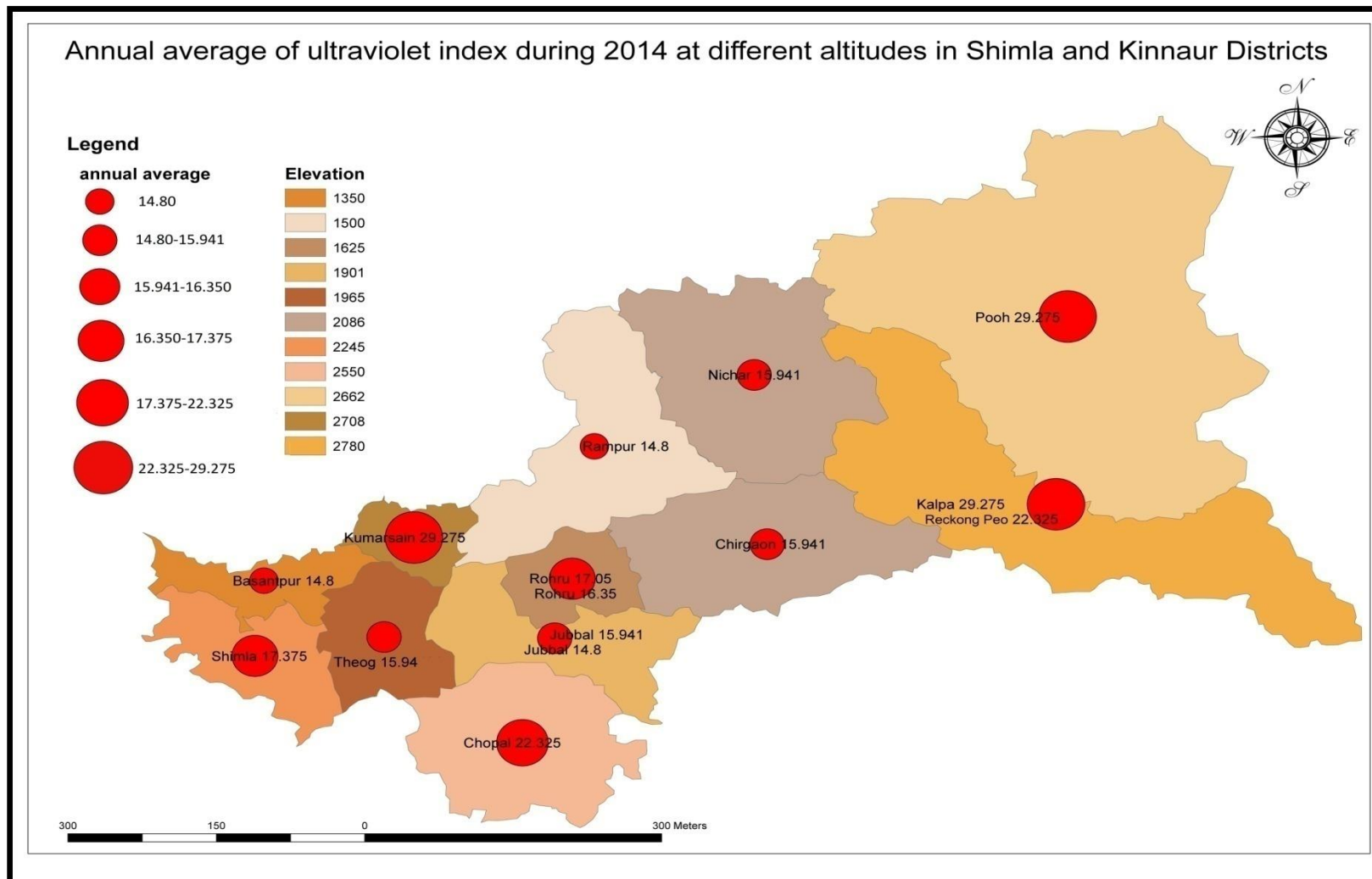


Figure 52

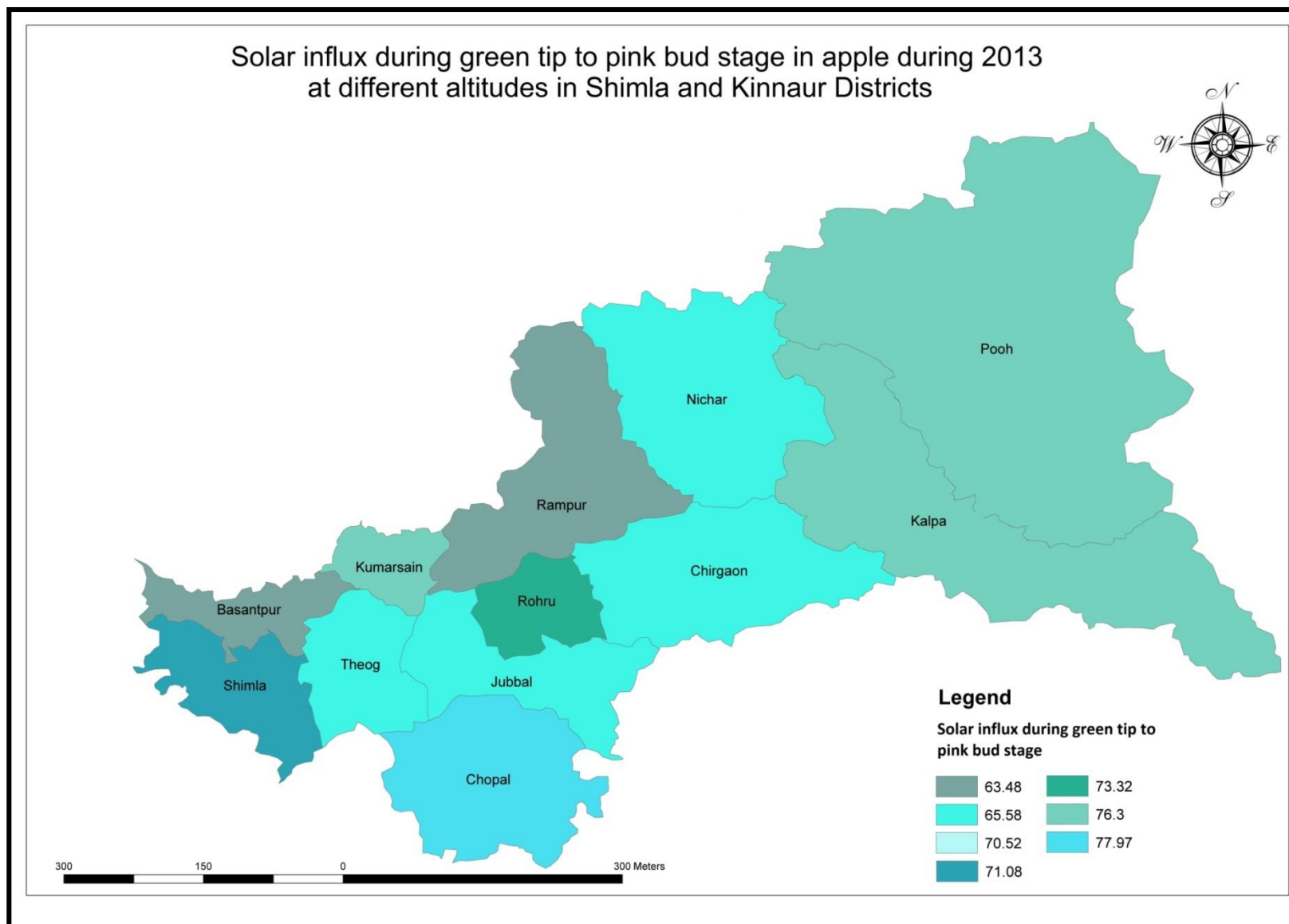


Figure 53

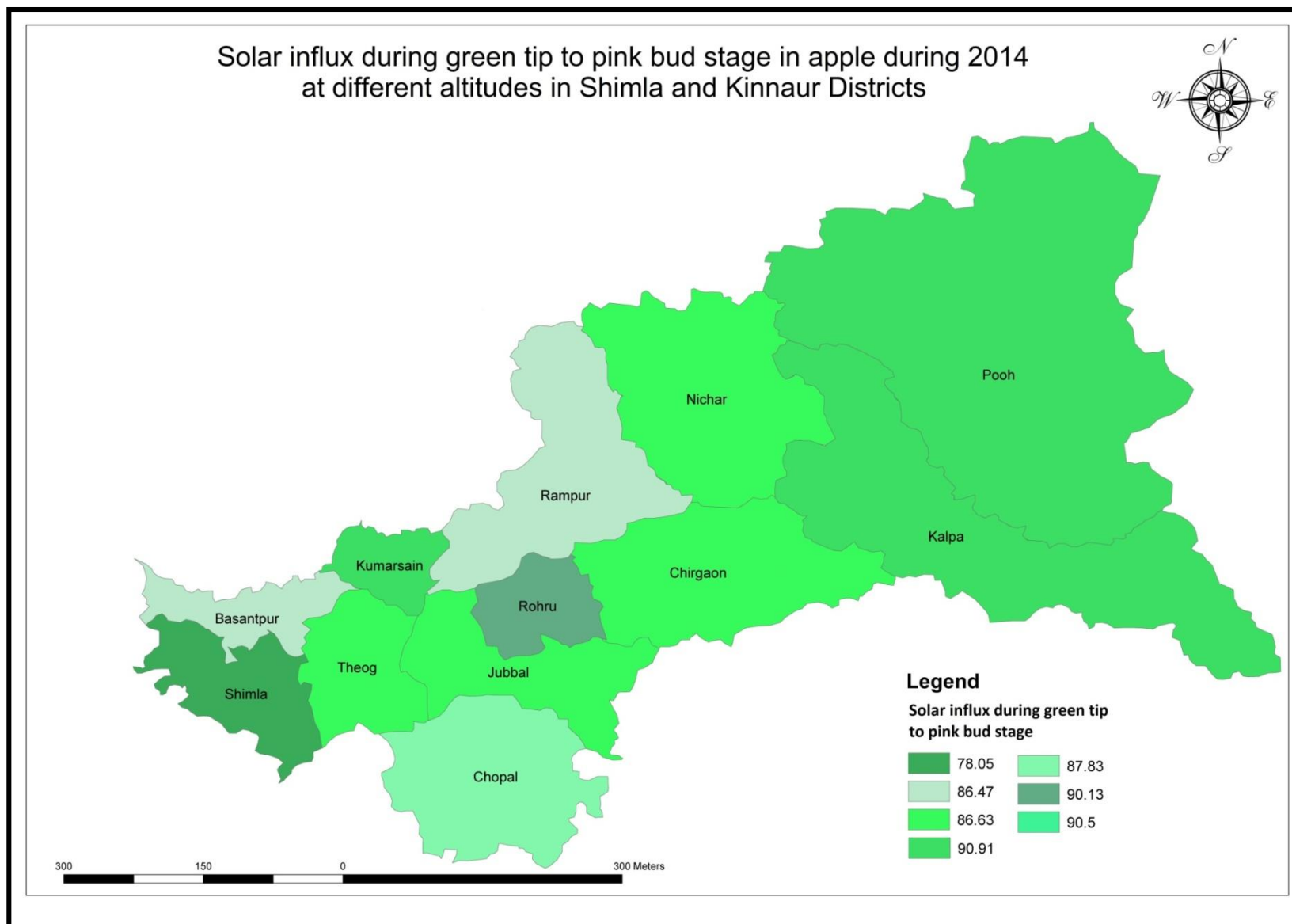


Figure 54

Rohru, Chirgaon and Nichar. In the year 2014, higher altitude blocks of Kalpa, Pooh, Chopal and Kumarsain had 106.4 to 107.4 azimuth angle and 106.2 to 106.5 azimuth angle has been depicted for Shimla whereas, the corresponding value for Theog, Jubbal, Chirgaon and Nichar has been shown to be between 106.5 to 106.9 and for Basantpur and Rampur between 107.4 to 107.5.

4.2.7 UV Index

The thematic layer (Figure 51 & 52) indicates that there is a direct relationship of UV index with the altitudes in Shimla and Kinnaur districts during both the years i.e. UV index increased with the increase in altitude. In the year 2013, map depicts that higher UV index values at Shimla (18.27), Chopal (23.17), Rohru (17.79), Kumarsain, Kalpa and Pooh (30.77). Remaining altitudes *viz*, Theog, Jubbal, Basantput, Rampur, Nichar, Chirgaon have been shown to receive low UV radiation. Likewise, during the year 2014, higher UV index values have been depicted at Rohru (17.05), Kalpa and Pooh (29.28), Chopal (22.33) and Shimla (17.38) whereas, Basantpur and Rampur (14.80), Theog, Jubbal, Nichar and Chirgaon (15.94) received moderate amount of UV radiation. In this study, higher altitudes like Kalpa, Pooh, Kumarsain and Chopal received higher UV radiation, which can be attributed to lesser absorption of UV radiations in a thinner atmosphere at higher altitudes than the lower altitudes where atmospheric turbidity like dust, water vapour concerns their role in absorption of radiations (McKenzie *et al.*, 2003).

4.2.8 Solar influx at different growing stages

4.2.8.1 Solar influx (green tip to pink bud stage)

The thematic map (Figure 53) revealed that the solar influx at green tip to pink bud stage in 2013 was highest (77.97) at Chopal followed by Kalpa, Pooh and Kumarsain. However, map shows lowest solar influx value (63.48) for Basantpur and Rampur. In the study areas of Rohru and Shimla, this value has been depicted in the intermediate range. In the year 2014, (Figure 54) Kalpa, pooh and Kumarsain had highest (90.91) solar influx followed by Rohru (90.13) and Chopal (87.83). Solar influx value has been shown to be least (78.05) in respect of Shimla.

4.2.8.2 Solar influx (flowering to fruit set stage)

The thematic map (Figure 55) for the year 2013 revealed highest solar influx during flowering to fruit set stage at Chopal (74.05) followed by Shimla (69.2). Lowest solar influx 49.54 is however, shown jointly in respect of Theog, Jubbal, Chirgaon and Nichar. In the year 2014, (Figure 56) thematic map shows higher solar influx (83.19) during flowering to fruit set stage at Kalpa, Pooh and Kumarsain, followed by Rohru (81.32) and, Chopal (80.82), however, this value is shown least (72.6) at Shimla location.

4.2.8.3 Solar influx (walnut stage)

At walnut stage of the year 2013, the thematic map (Figure 57) shows highest solar influx (69.45) at Chopal, jointly followed by Kalpa, Pooh and Kumarsain (63.99). However, this value has been depicted to be lowest (48.42) at Basantpur and Rampur. In the year 2014, (Figure 58) solar influx at walnut stage however, has been shown highest (76.42) at Kalpa, Pooh and Kumarsain and lowest (67.78) at Basantpur and Rampur.

4.2.8.4 Solar influx (fruit development stage)

During the rapid fruit development stage in 2013 (Figure 59), the thematic map (fig) depicts highest solar influx at Chopal (65.9) followed by Shimla (55.79) whereas, it has been marked lower (36.31) at Basantpur and Rampur. In the year 2014, (Figure 60) solar influx has been marked highest (69.64) jointly at Kalpa, Pooh and Kumarsain, followed by Chopal (68.58) whereas, it is shown lowest at Basantpur and Rampur (58.66).

4.2.8.5 Solar influx (pre-harvesting stage)

The thematic map (Figure 61) revealed that the solar influx at pre- harvesting stage in the year 2013 was highest (56.82) at Chopal followed by Rohru (50.58) whereas, the lower solar influx (45.87) at this stage has been depicted for Theog, Jubbal, Chirgaon and Nichar locations. During the year 2014, (Figure 62) solar

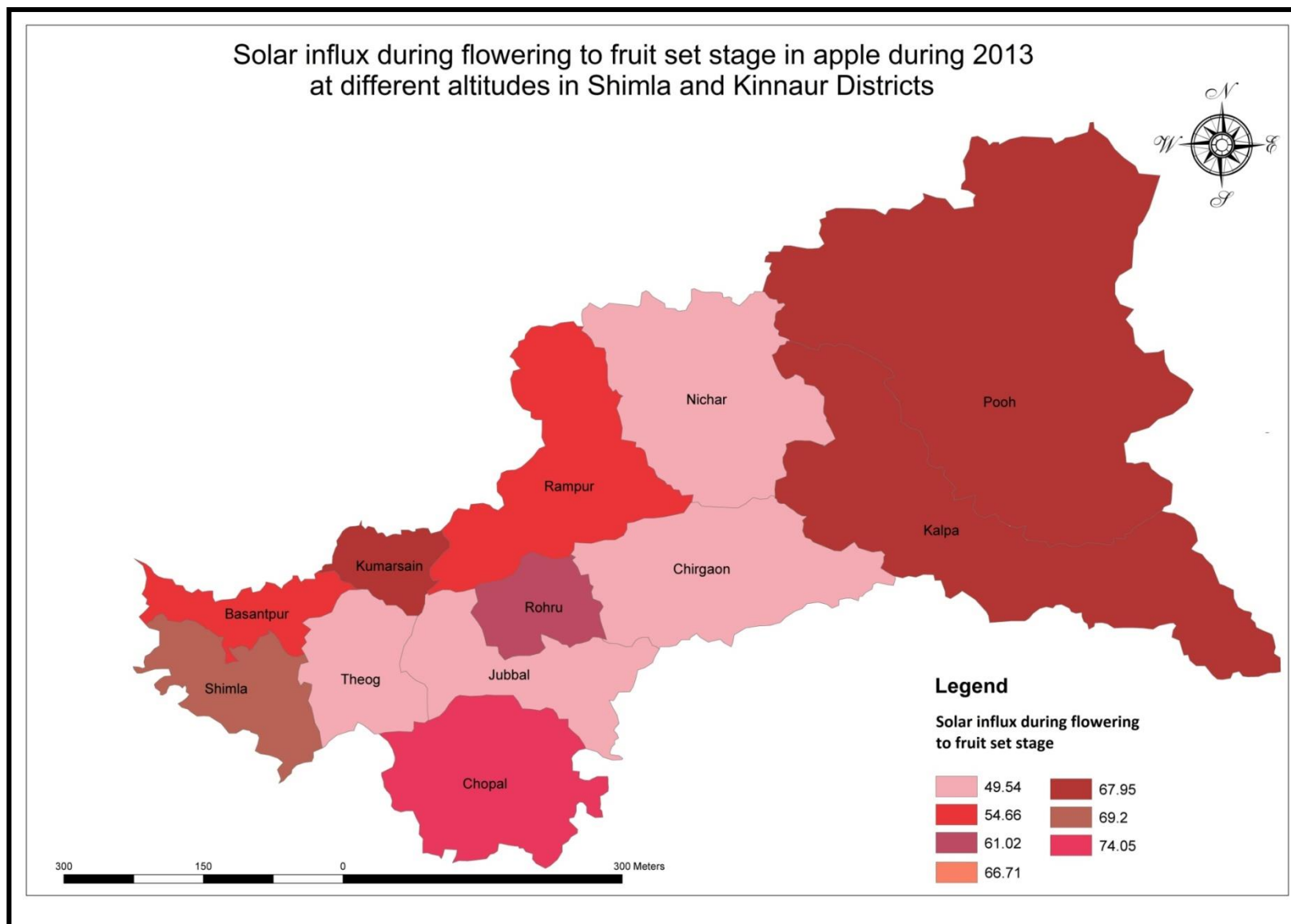


Figure 55

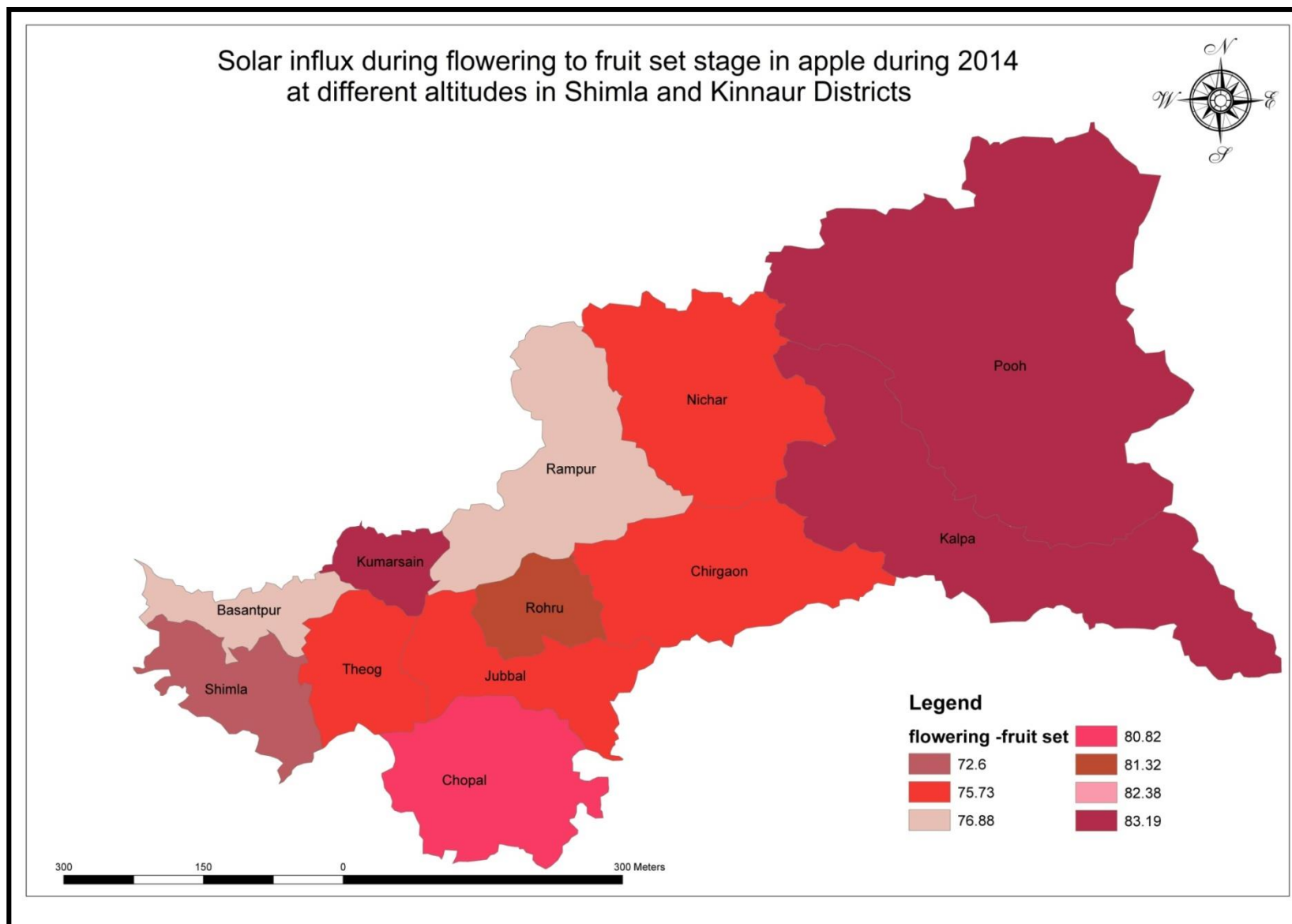


Figure 56

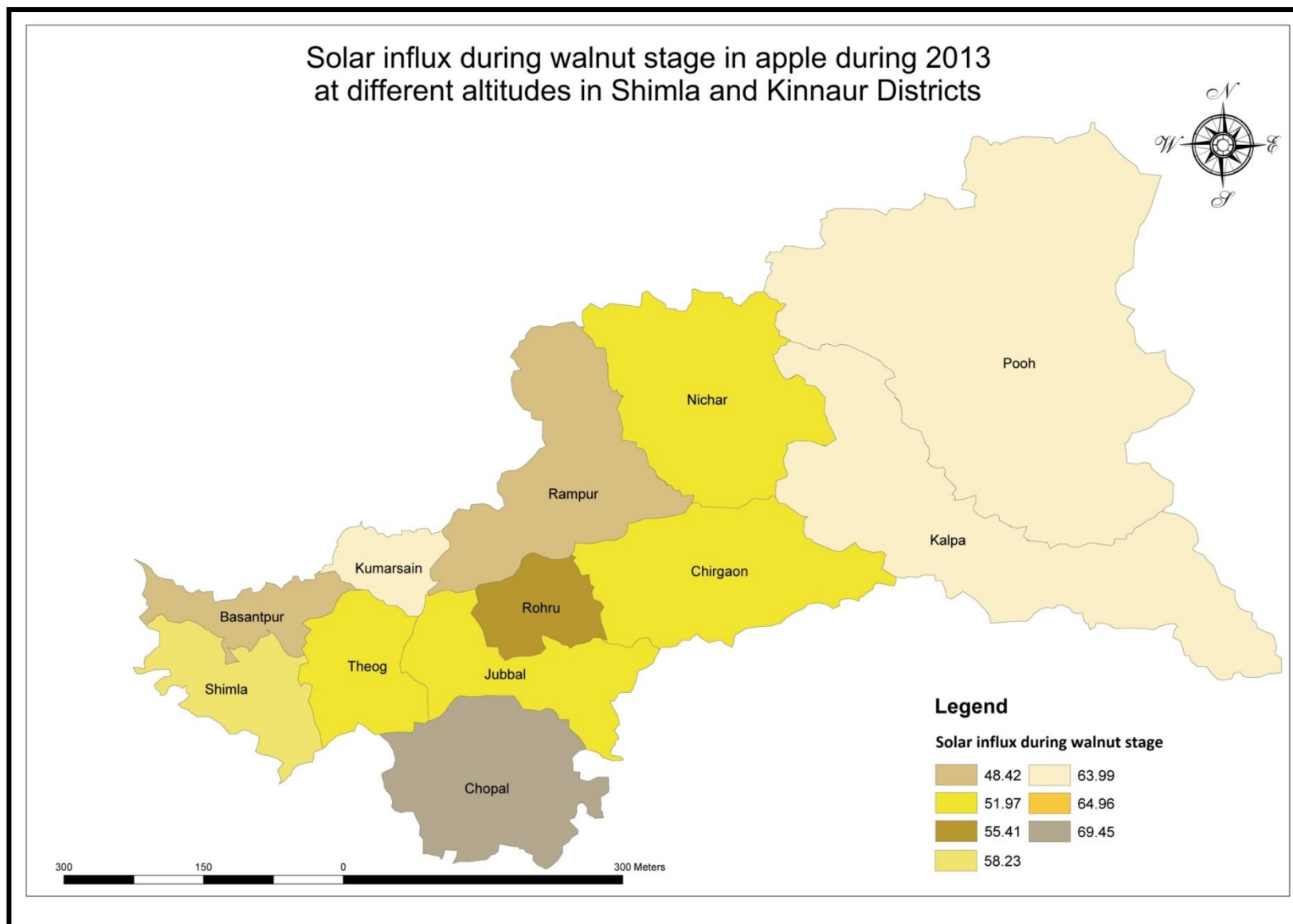


Figure 57

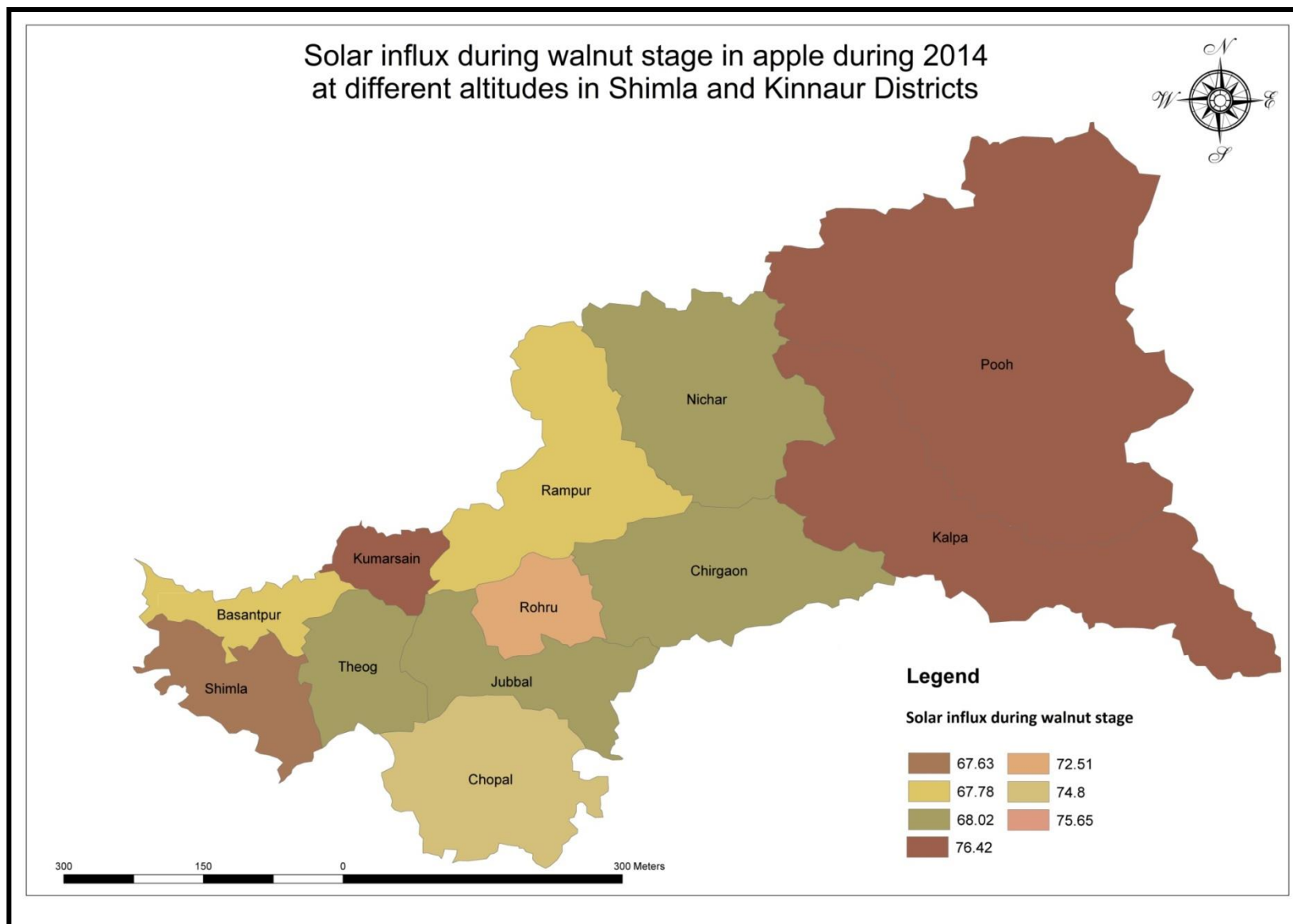


Figure 58

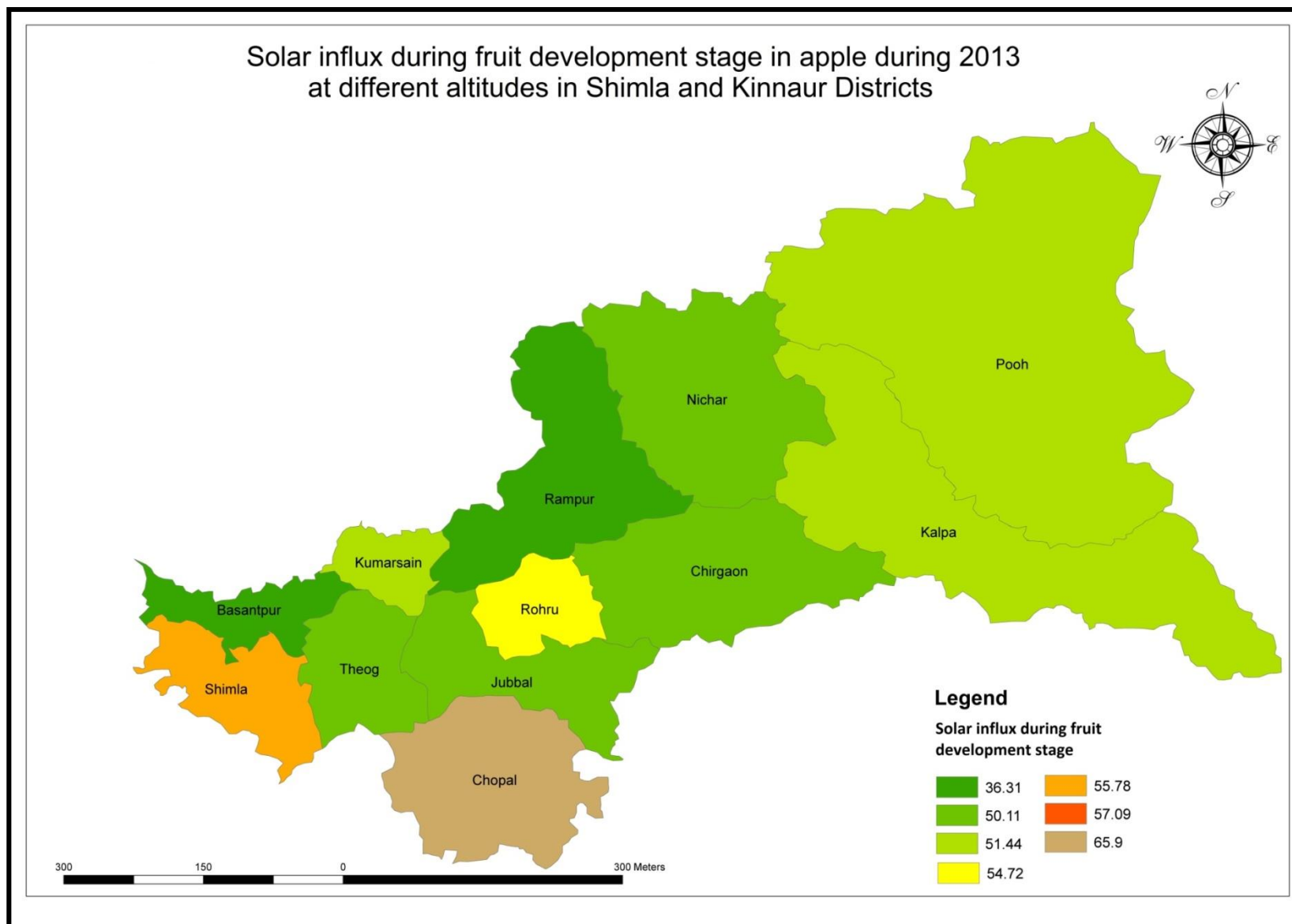


Figure 59

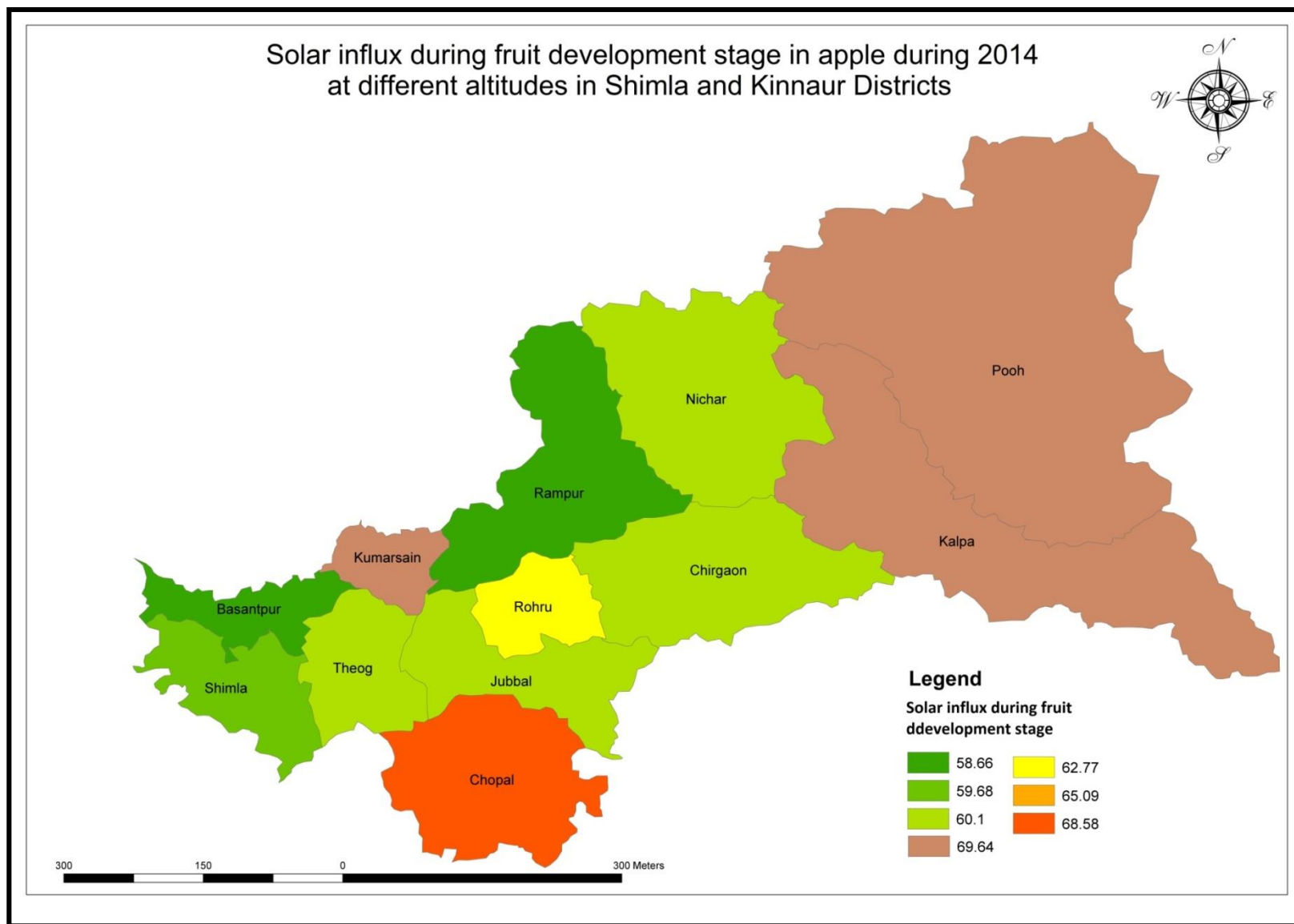


Figure 60

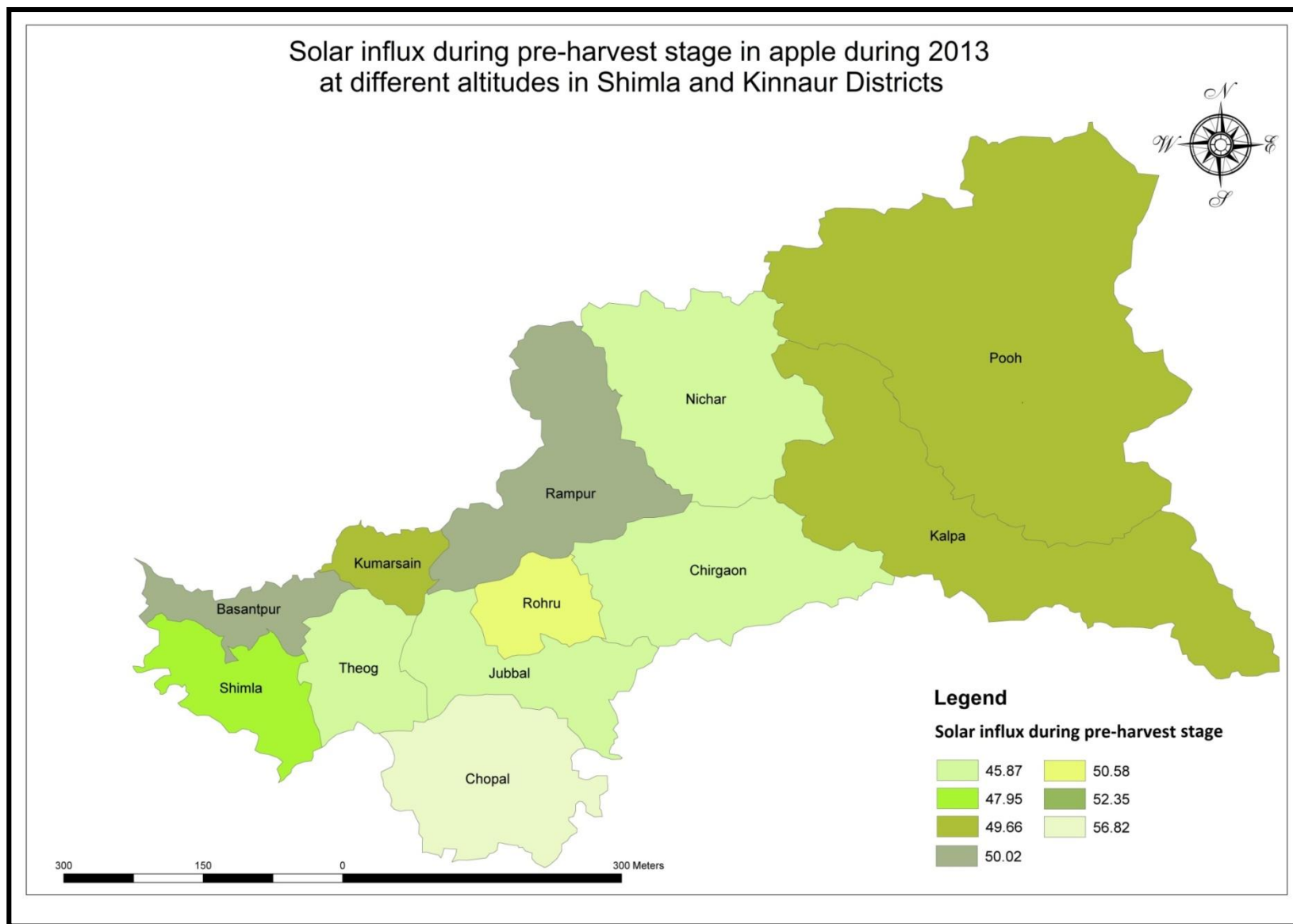


Figure 61

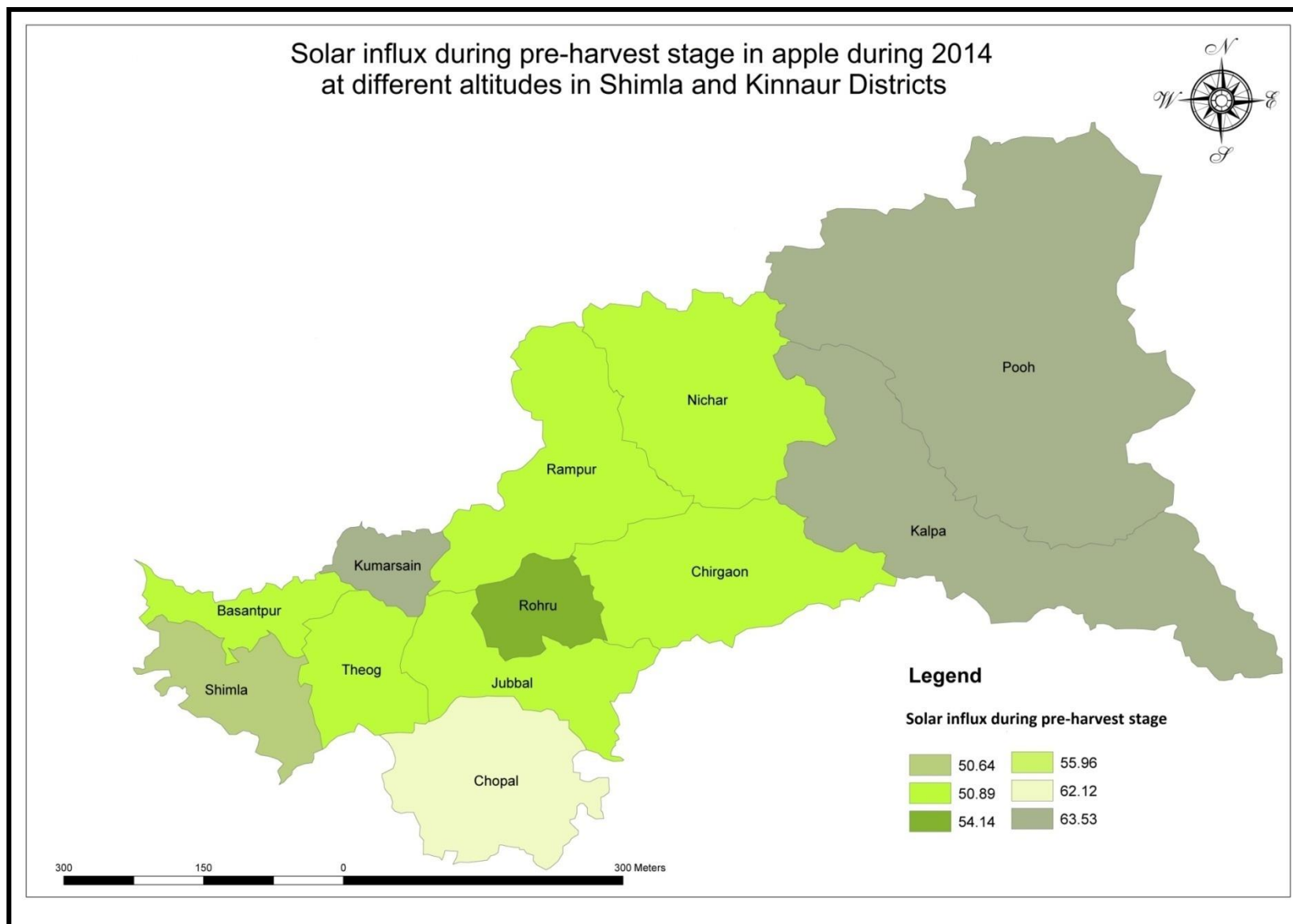


Figure 62

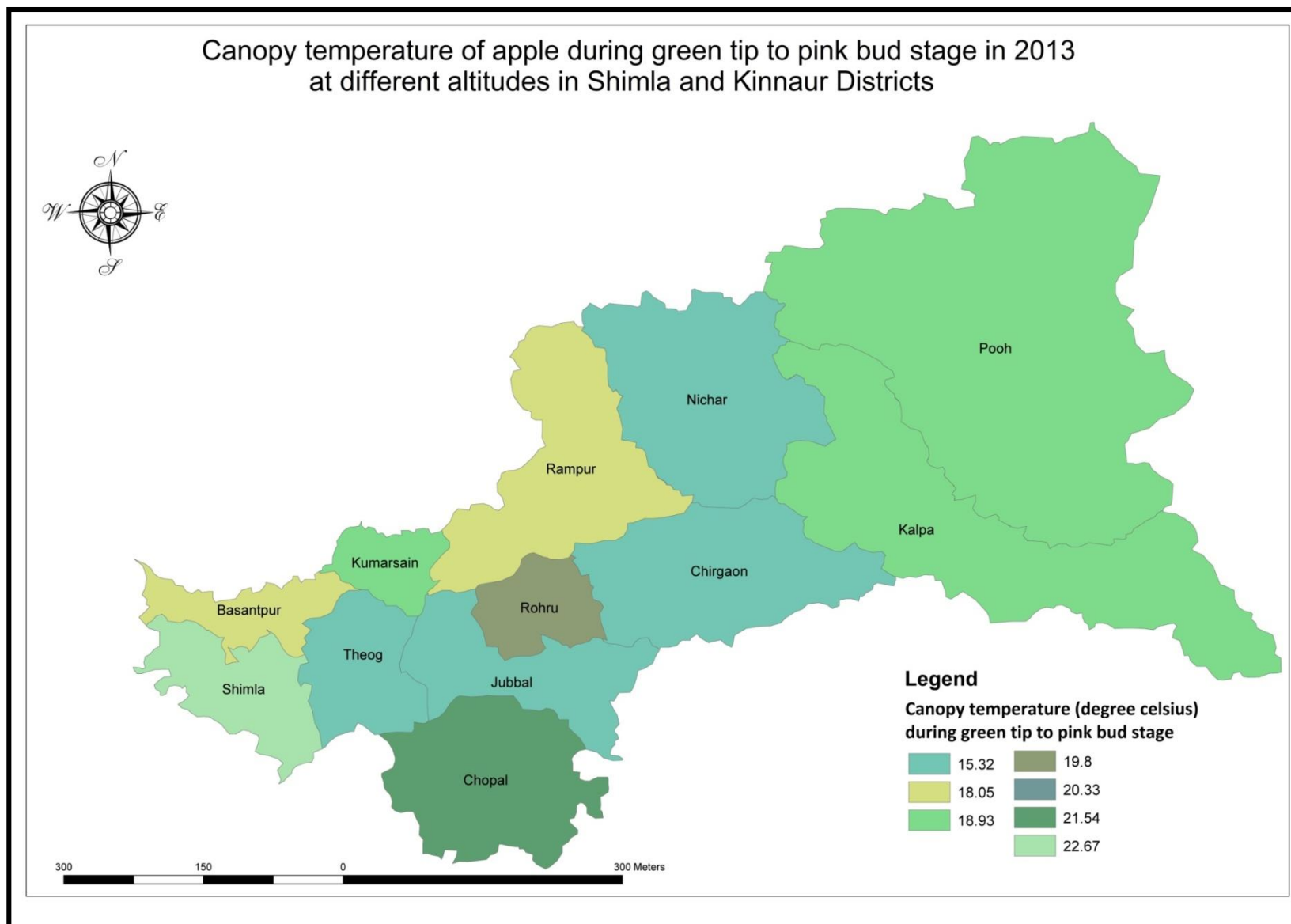


Figure 63

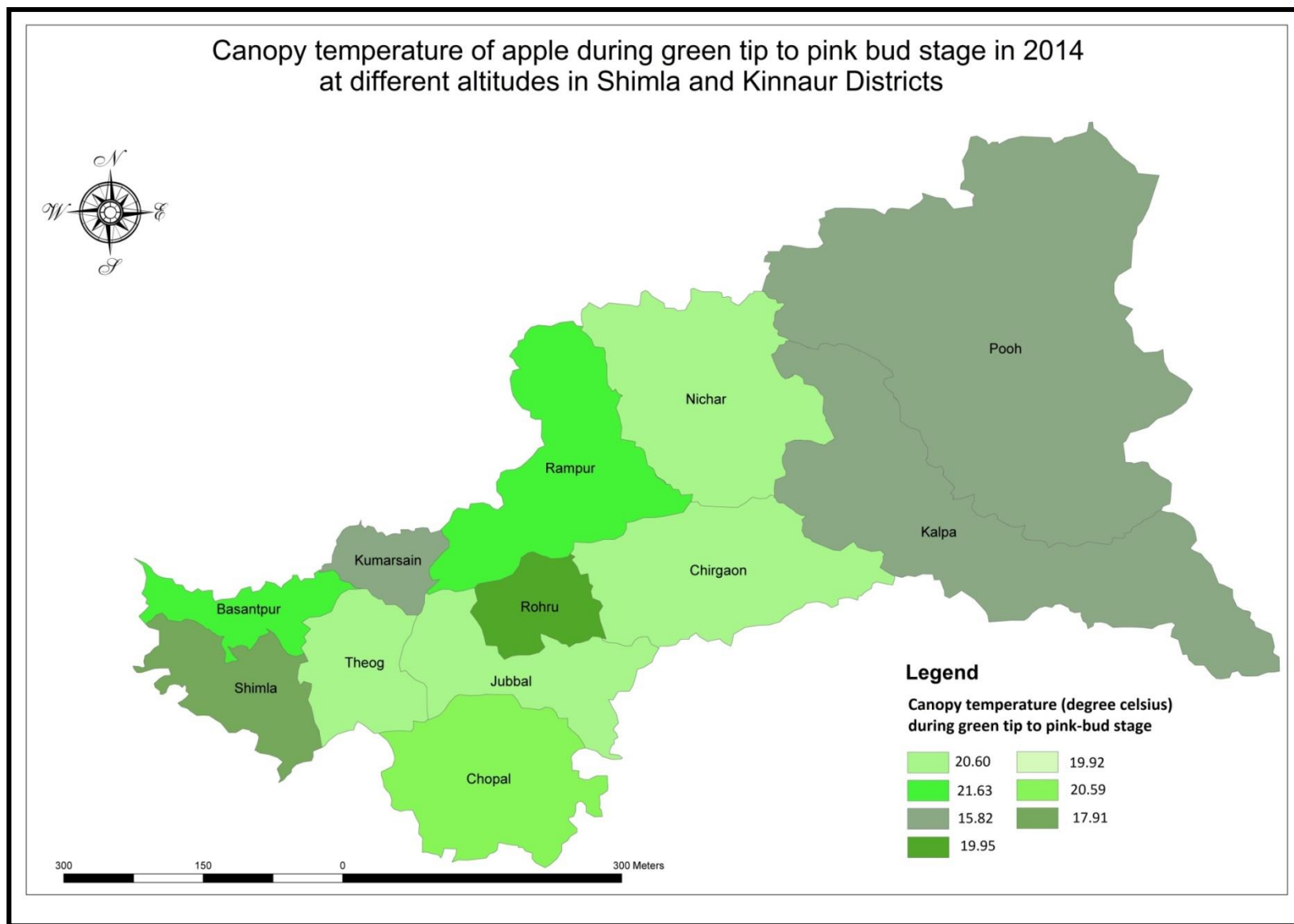


Figure 64

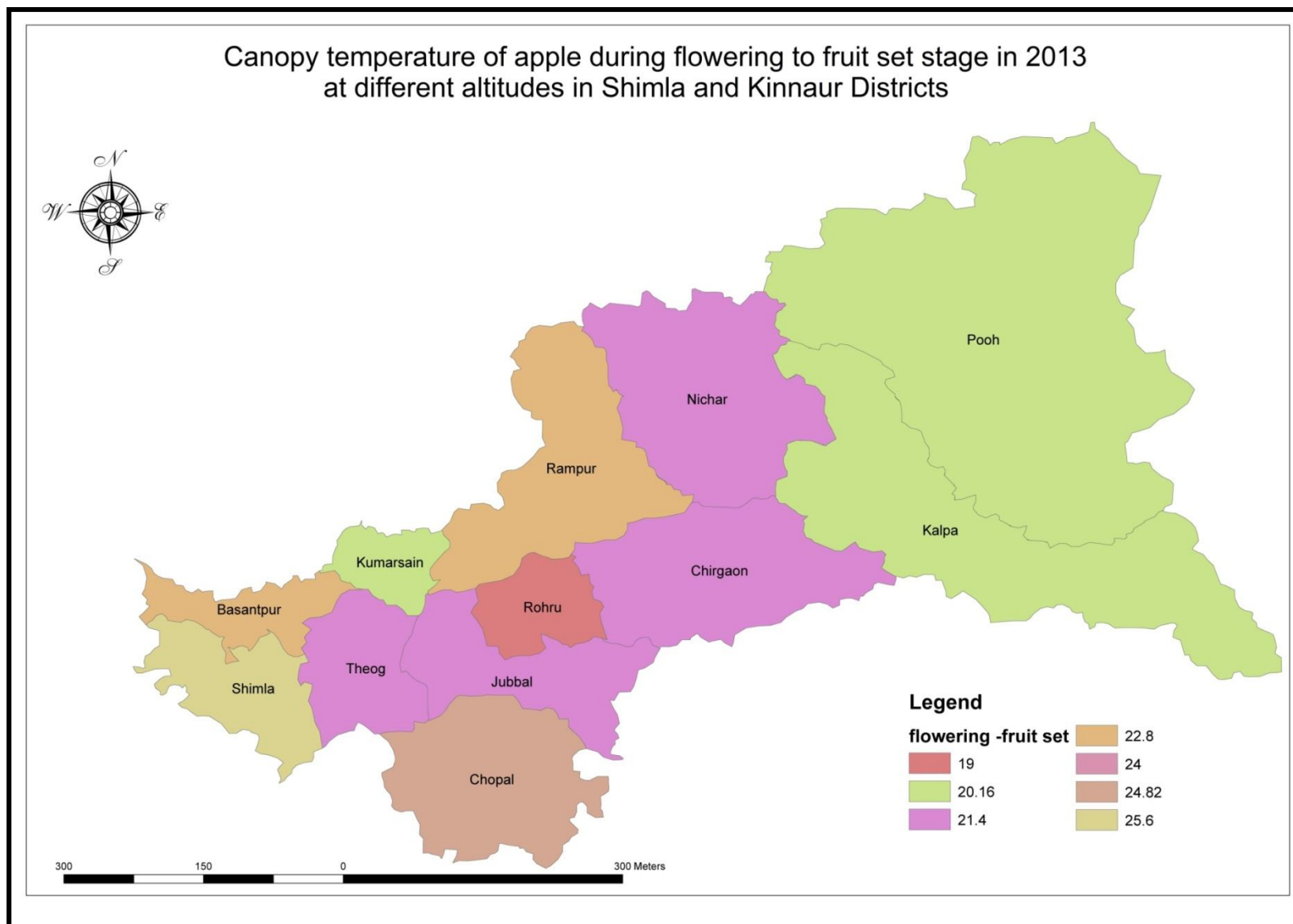


Figure 65

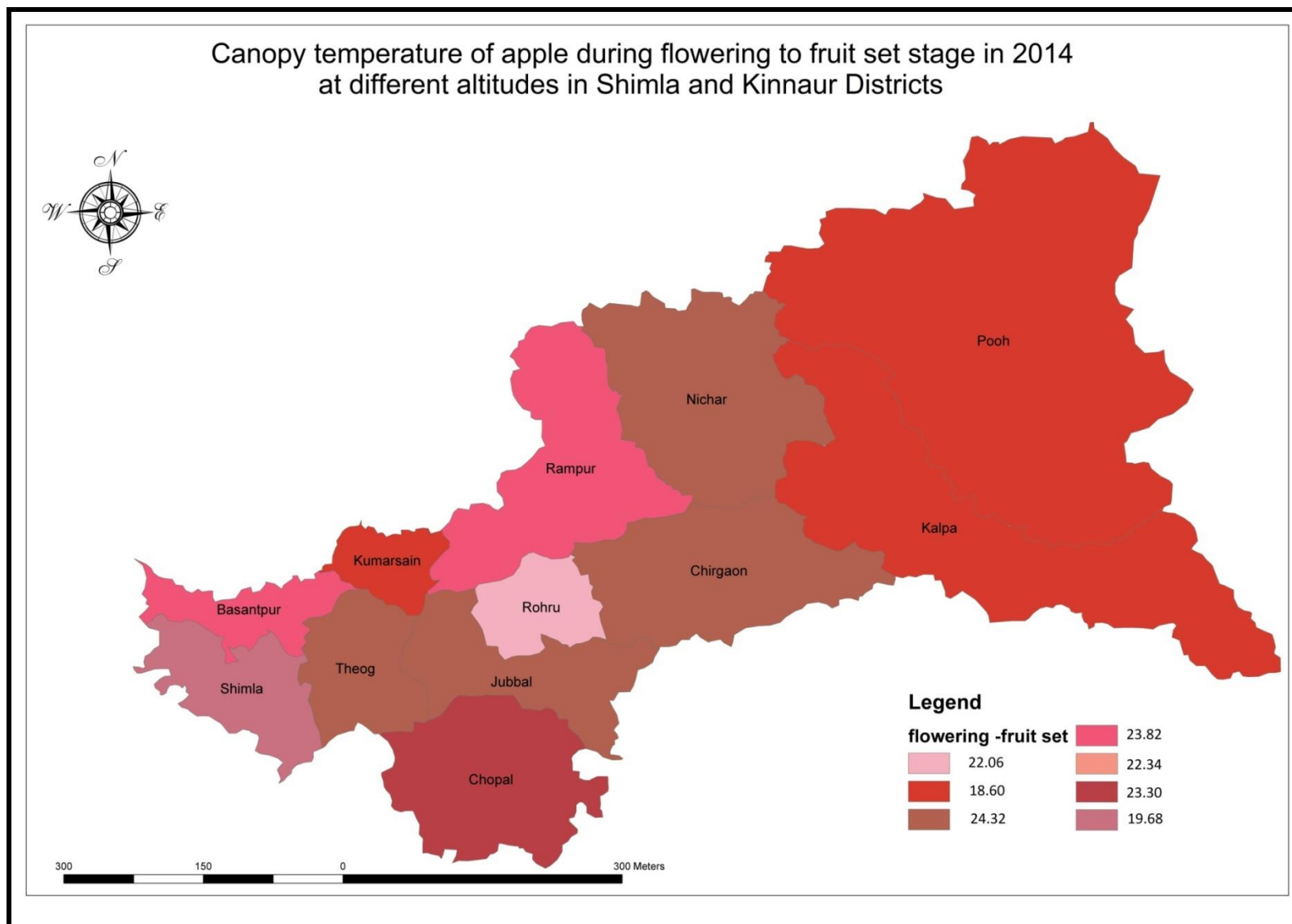


Figure 66

influx has been shown highest (63.53) at Kalpa, Pooh and Kumarsain followed by Chopal (62.12) however, it is projected lowest (50.64) at Shimla at this stage.

During the study, solar influx decreased as the fruit development progressed. Its highest values at green tip to pink bud stage can easily be predictable due to higher light interception in the tree having minimum canopy cover at this stage, and as anticipated, a linear decrease in solar influx occurred as the canopy developed. The lower solar influx values at lower altitudes like Rampur and Basantpur and higher values at higher altitudes at each stage depends upon the sun's altitude; lower the geographical altitude higher is the sun altitude (McKenzie *et al.*, 2003), because solar irradiation gets mostly absorbed by the atmosphere until it reaches the lower altitudes (US environmental protection agency). Whereas, at higher altitudes like Chopal, Kalpa, Pooh and Kumarsain more solar influx was observed due to thinner atmospheric air.

4.2.9 Canopy temperature at different growing stages

4.2.9.1 Canopy temperature (green tip to pink bud stage)

In the year 2013, the thematic map (Figure 63) revealed that the maximum canopy temperature (22.67°C) between green tip to pink bud at Shimla followed by Chopal (21.54°C) and Rohru (19.8°C). The minimum canopy temperature (15.32°C) however, has been shown in the map at Theog, Jubbal, Chirgaon and Nichar. In the year 2014, Figure 64 shows the maximum canopy temperature at Shimla (17.91°C) followed by Chopal (20.59°C). It has been depicted however, minimum (20.60°C) at Theog, Jubbal, Chirgaon and Nichar.

4.2.9.2 Canopy temperature (flowering to fruit set stage)

The thematic map of canopy temperature between flowering to fruit set stage during the year 2013 (Figure 65) depicted its maximum value at Shimla (25.60°C), jointly followed by Theog, Jubbal, Chirgaon and Nichar (24.82°C). It is however, shown minimum at Rohru (19.00°C). In the year 2014, (Figure 66) the maximum canopy temperature (23.82°C) has been depicted at Basantpur and Rampur

followed by Chopal (23.30°C) and it is shown minimum (18.60°C) at Kalpa, Pooh and Kumarsain.

4.2.9.3 Canopy temperature (walnut stage)

In the year 2013, the canopy temperature during walnut stage was recorded highest at Rohru (26.50°C), followed by Shimla (Figure 67). The map however, depicted its minimum value (21.11°C) at Kalpa, Pooh and Kuarsain. In the year 2014, (Figure 68) the maximum canopy temperature (26.04°C) during walnut stage of apple fruit development has been depicted at Basantpur and Rampur, followed by Rohru (25.25°C). Kalpa, Pooh and Kumarsain blocks have been shown to have minimum canopy temperature (22.48°C) during this period.

4.2.9.4 Canopy temperature (fruit development stage)

The thematic map (Figure 69) on canopy temperature during fruit development stage in the year 2013 depicted its maximum value at Rohru (25.00°C), followed by Kalpa, Pooh and Kumarsain (23.84°C). During this period, the minimum canopy temperature (22.32°C) is depicted at Chopal. In the year 2014, (Figure 70) the maximum canopy temperature is depicted at Rohru (24.39°C), followed by Kalpa, Pooh and Kumarsain (23.34°C). It has however, been shown minimum (24.07°C) at Shimla.

4.2.9.5 Canopy temperature (pre-harvest stage)

The thematic map on canopy temperature at the time of apple pre-harvest stage in the year 2013 presented in Figure 71 depicts the maximum temperature at Shimla (25.00°C), followed by Rohru (24.52°C). It is however, shown minimum (19.22°C) at Chopal. In the year 2014, (Figure 72) the maximum canopy temperature during pre-harvest stage of apple projected at Chopal (25.67°C), followed by Kalpa, Pooh and Kumarsain (25.01°C) and Shimla (24.71°C). It is however, depicted minimum (21.14°C) at Basantpur and Rampur.

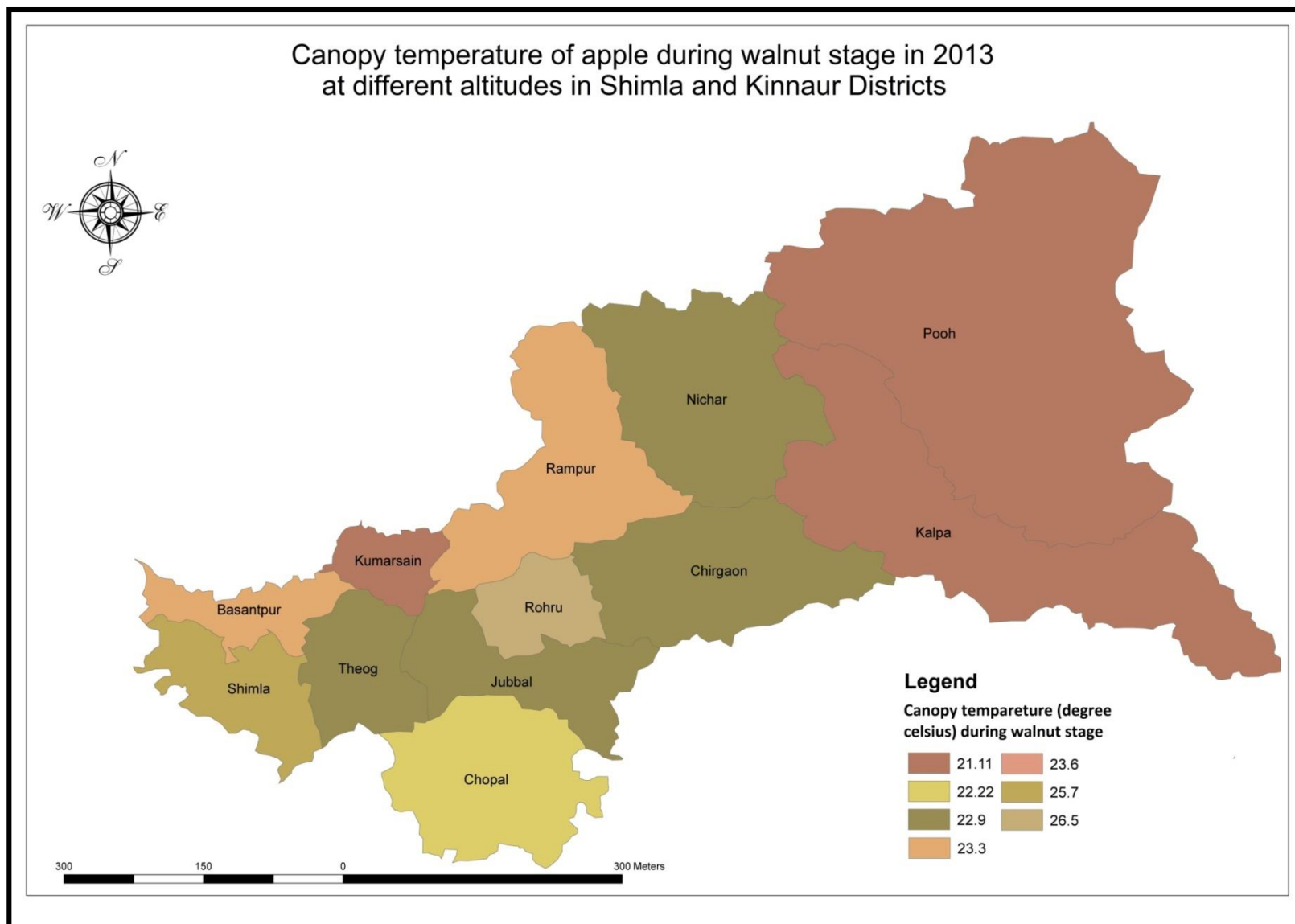


Figure 67

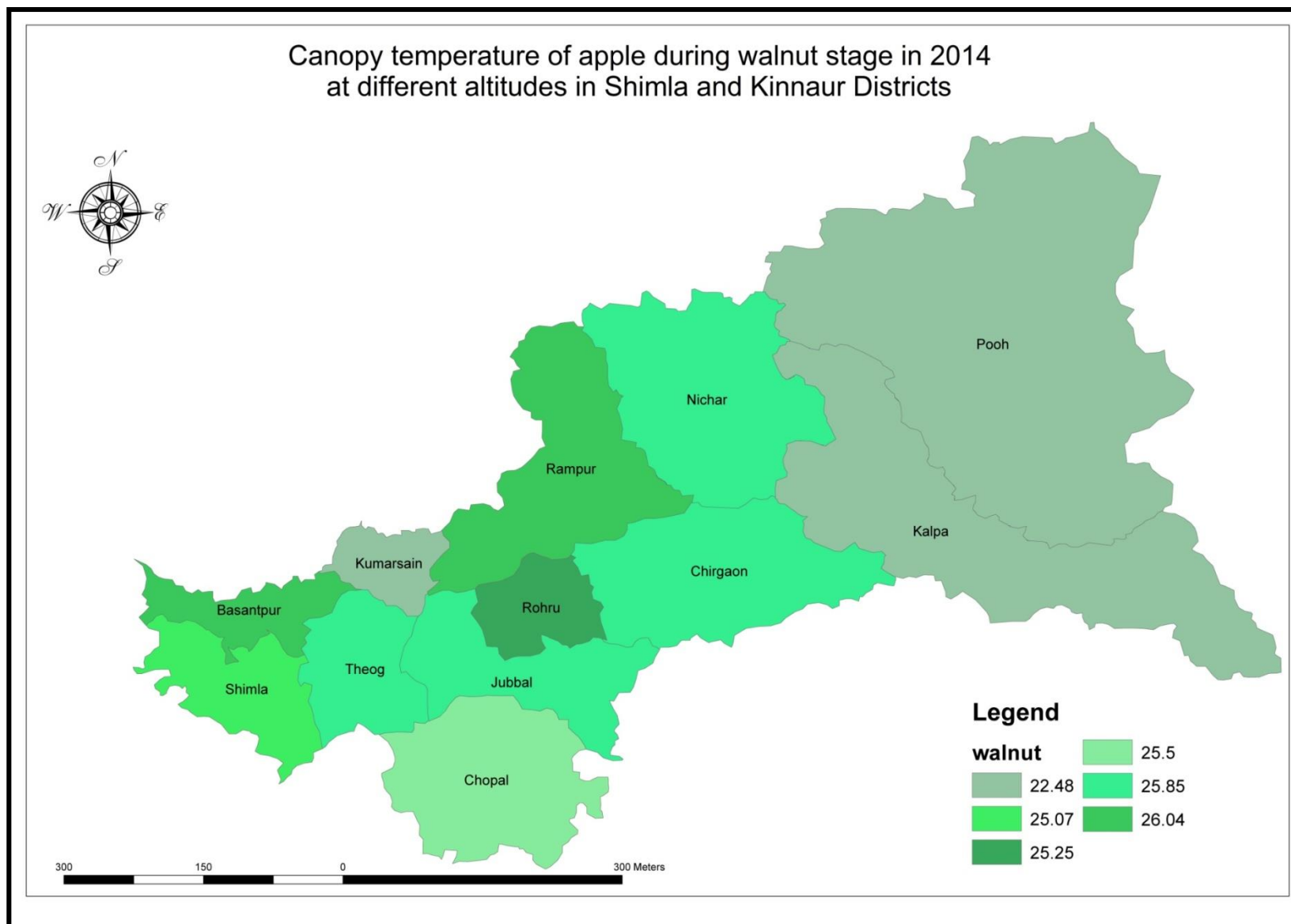


Figure 68

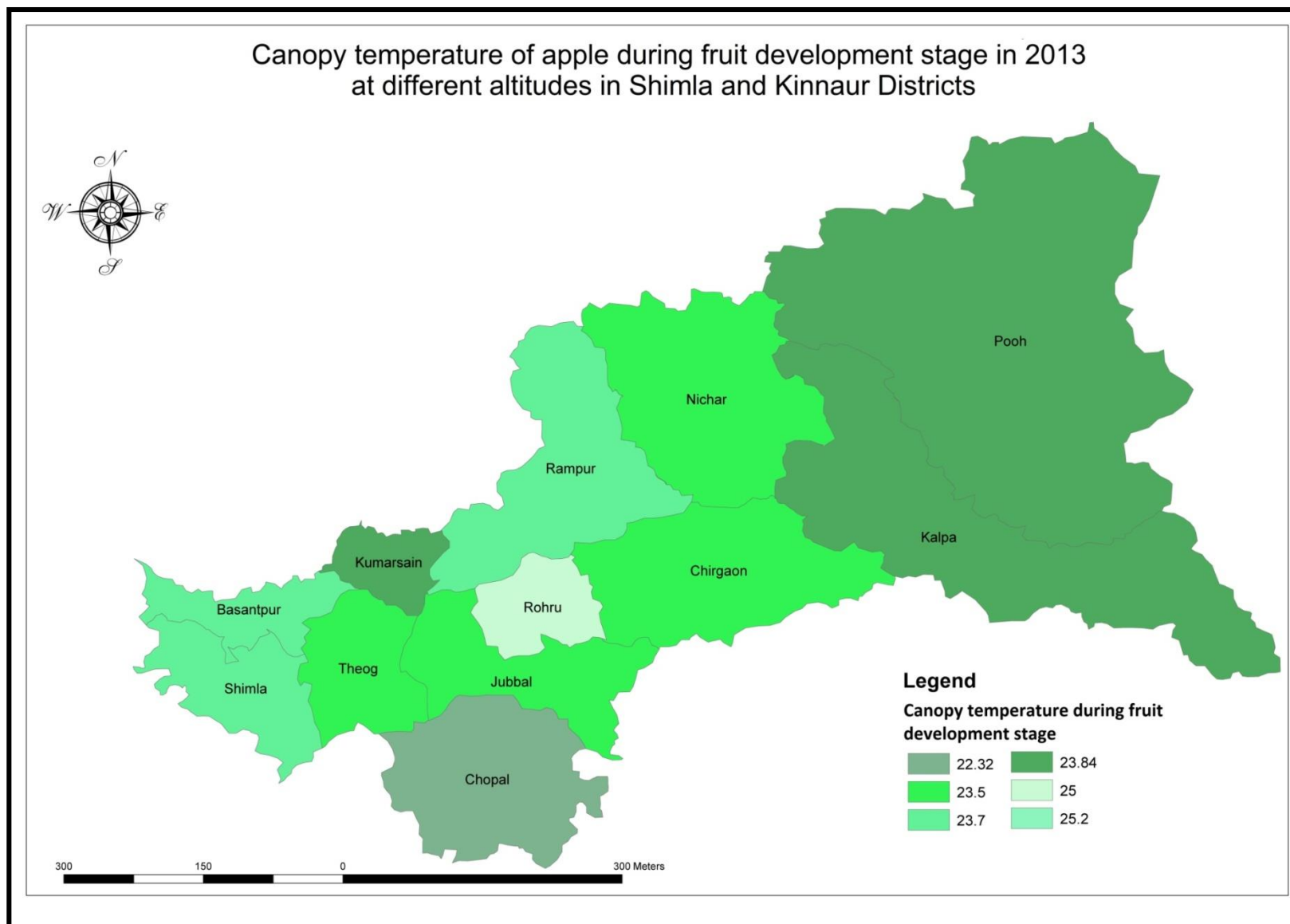


Figure 69

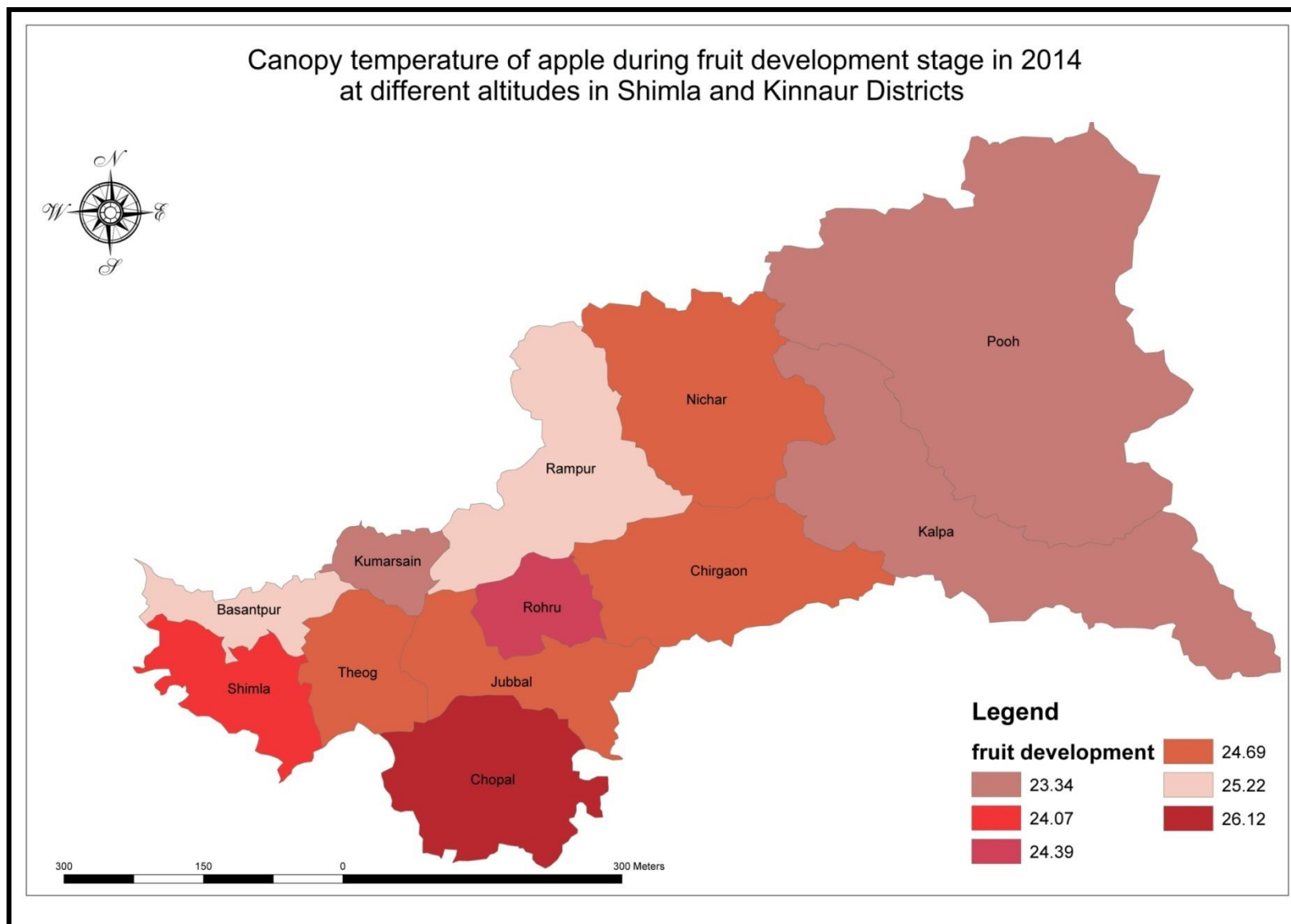


Figure 70

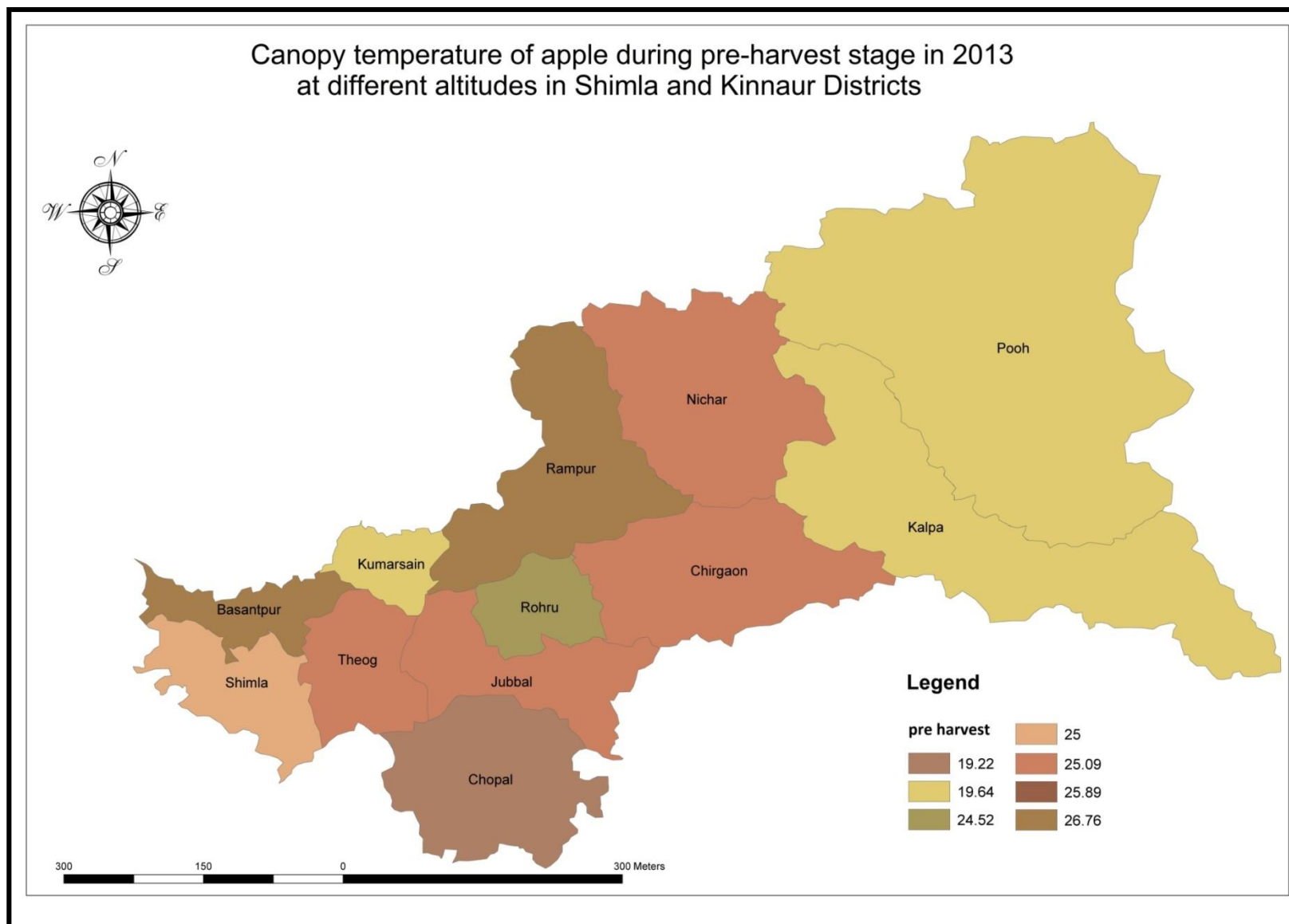


Figure 71

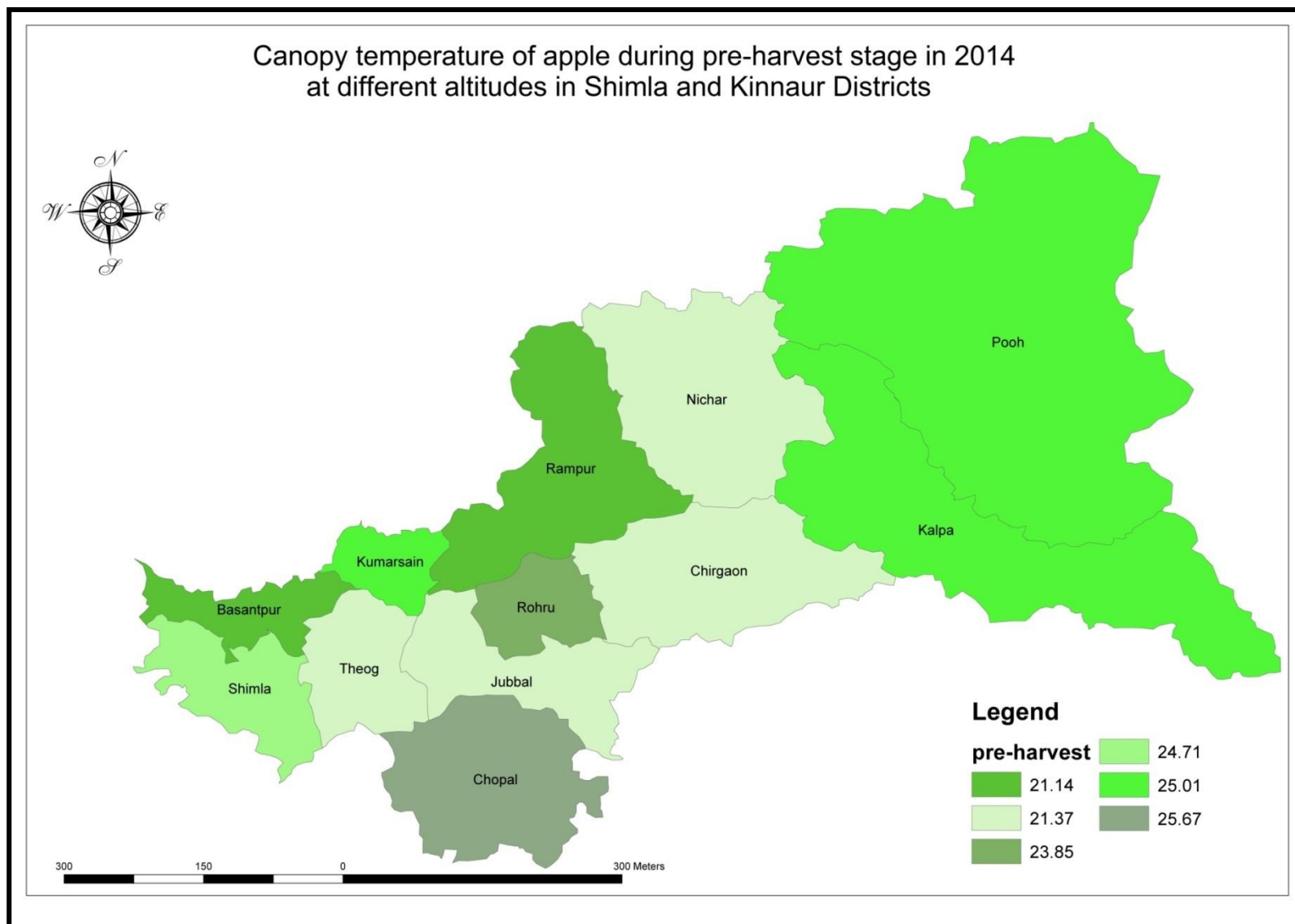


Figure 72

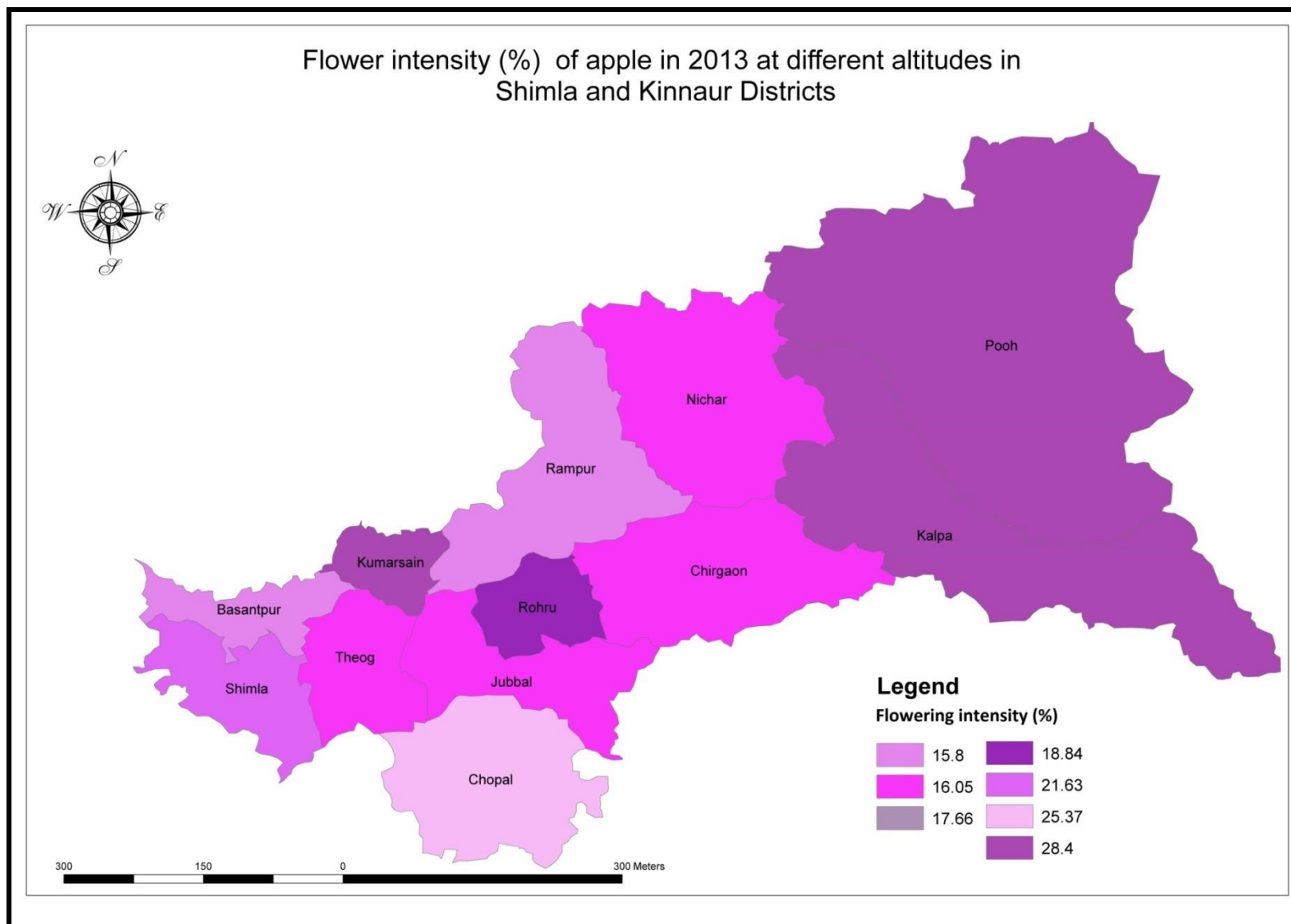


Figure 73

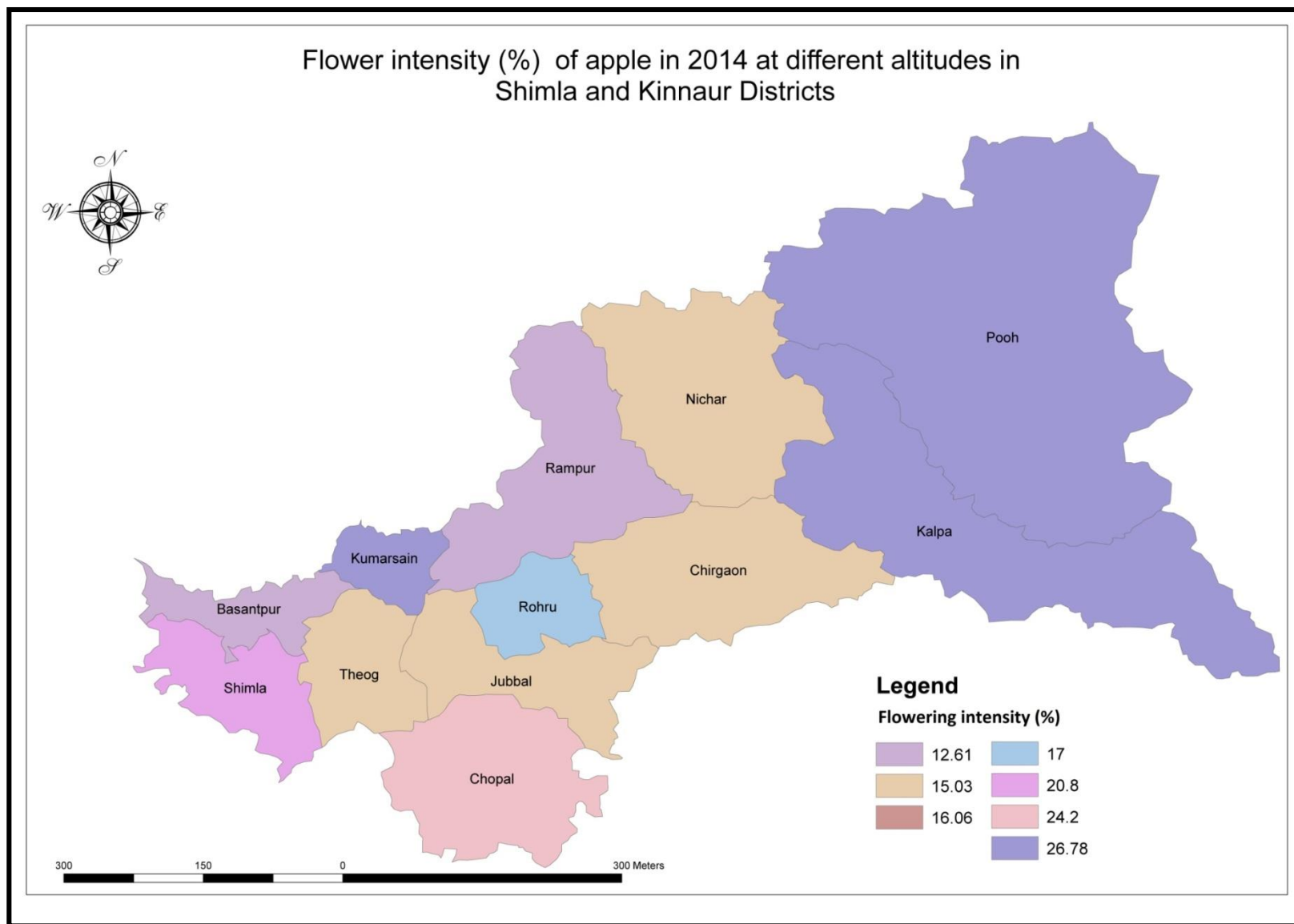


Figure 74

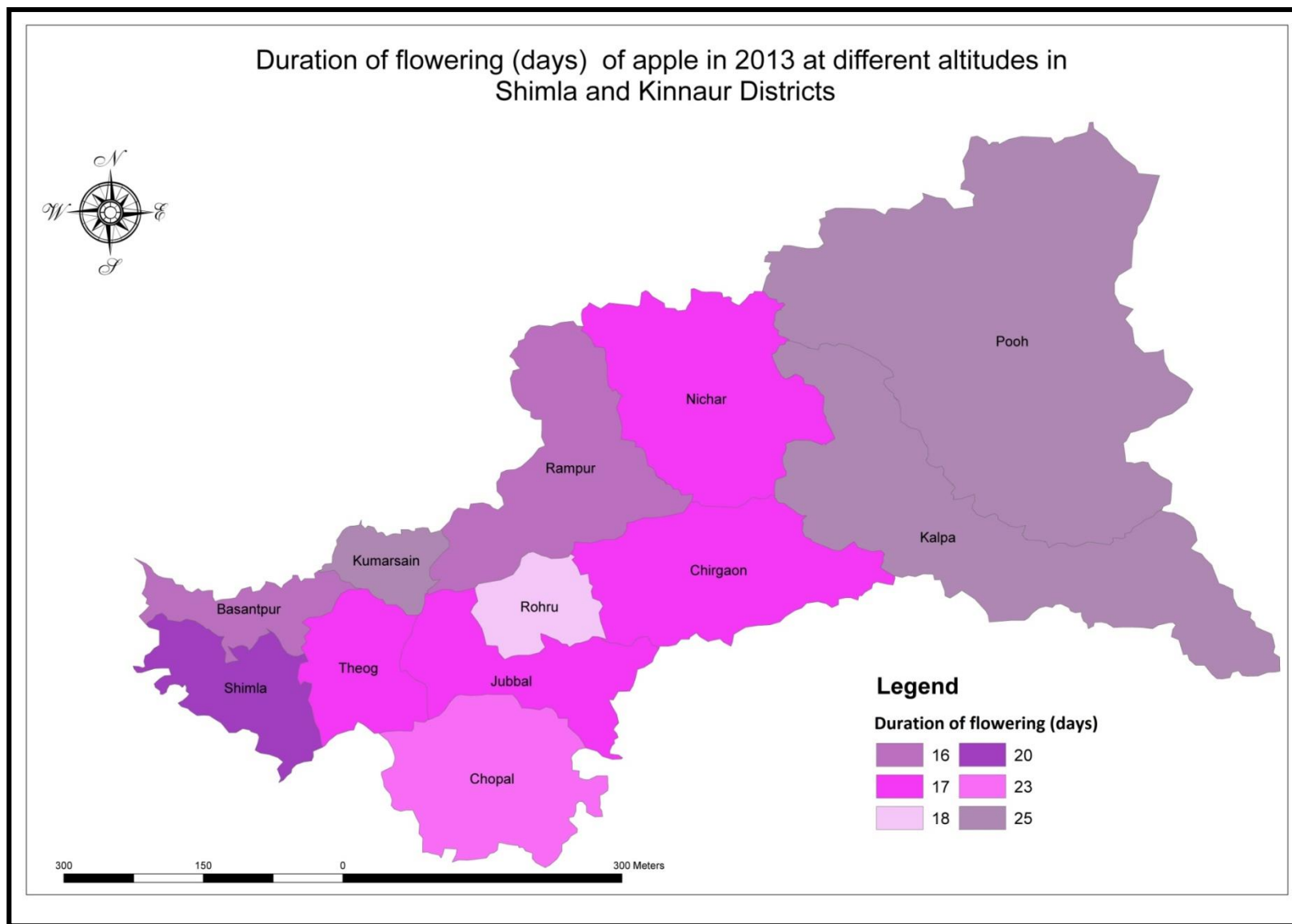


Figure 75

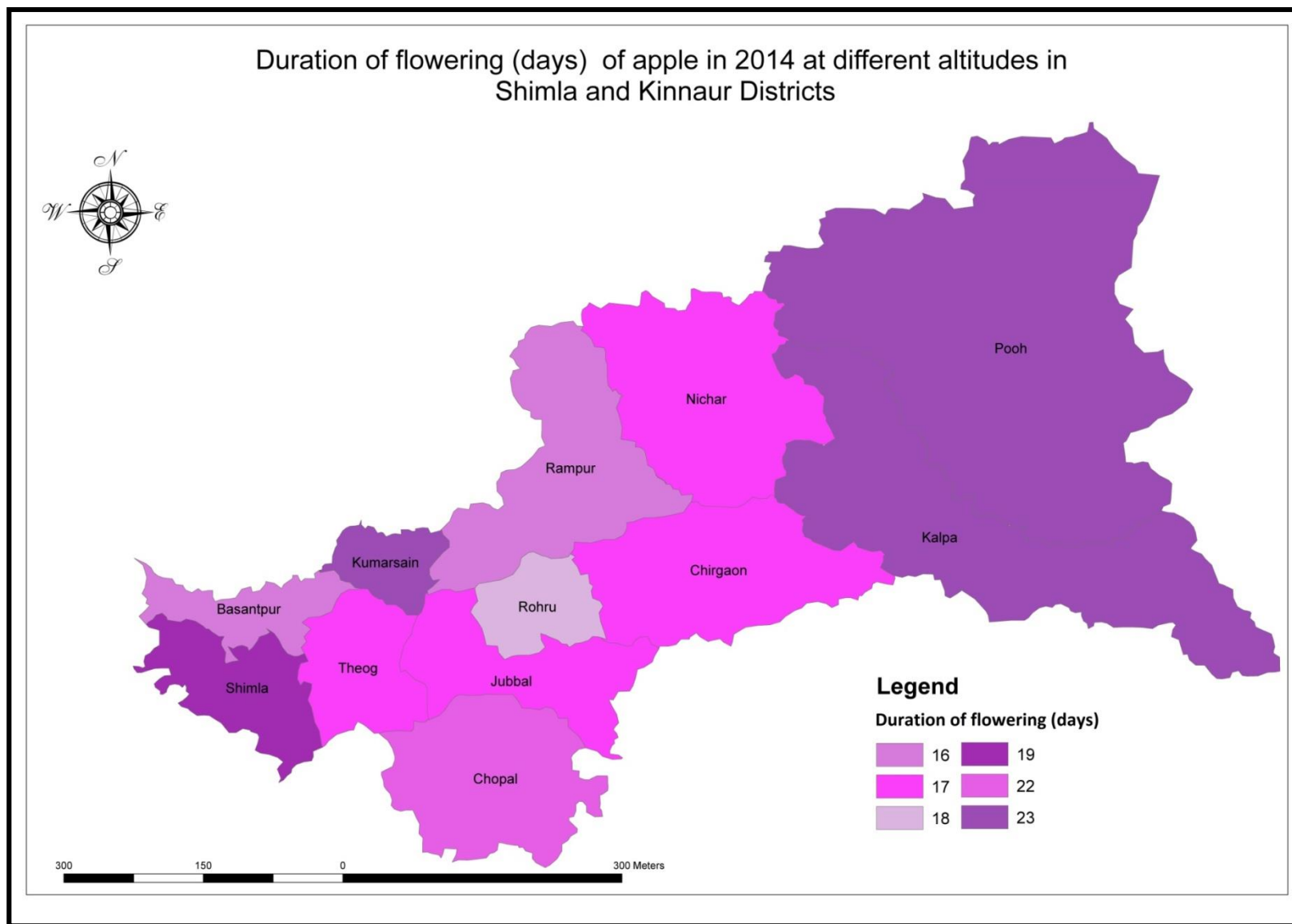


Figure 76

As expected, the canopy temperature at different locations increased gradually with the increase in air temperature (Appendix II) from green tip stage up to pre harvest stage, during the study.

4.2.10 Flowering parameters

4.2.10.1 Flowering intensity

The thematic map (Figure 73 & 74) indicates that there was a direct relationship between different altitudes in Shimla and Kinnaur districts with the flowering intensity. i.e flowering intensity increased with the increase in altitude. In the year 2013, map (Figure 73) depicts the maximum flowering intensity (28.4 %) at Kumarsain, Kalpa and Pooh, followed by Chopal (25.37 %). The minimum flowering intensity (15.8 %) has been indicated at Basantpur and Rampur. In the year 2014, flowering intensity followed the same trend, as its maximum value (26.78 %) is recorded at Kalpa, Pooh and Kumarsain, followed by Chopal (24.2 %). The lowest flowering intensity (12.61 %) is shown at Basantpur and Rampur (Figure 74). As explained in experiment I, flowering intensity had somewhat inverse correlation with annual mean temperature (Table 36 & 37).

4.2.10.2 Duration of flowering (Days)

In the year 2013, the duration of flowering was maximum (25 days) at Kalpa, Pooh and Kumarsain (Figure 75). In respect of this attribute, the least value (16 days) was recorded at Rampur and Basantpur followed by Nichar, Chirgaon, Jubbal and Theog (17 days). Shimla, Chopal and Rohru recorded intermediate values of flowering duration (18-23 days). During 2014, longest flowering duration (23 days) has been depicted at Kalpa, Pooh and Kumarsain (Figure 76). However, the flowering duration is shown shortest (16 days) at Rampur and Basantpur. Flowering duration at the remaining locations ranged from 17 – 22 days. Air temperature at the time of flowering influenced the flowering duration, higher the temperature shorter the flowering period and vice versa (Appendix II). In this study, flowering duration also had somewhat direct correlation with chilling period (Table 15 & 16) and (Table 32 & 33). The higher altitudes (Kalpa, Kumarsain) having more chilling period recorded longer flowering duration, whereas, lower

duration of flowering was noted at lower altitudes that registered shorter chilling period.

4.2.10.3 Days taken for harvesting

The number of days required for harvesting from full bloom at different locations have been shown in Figure 77 & 78. During the year 2013, (Figure 77) the maximum number of days (135 days) to be taken for harvesting is shown at Kalpa, Pooh and Kumarsain. Most parts of Shimla *viz.*, Nichar, Chirgaon, Rohru, Jubbal and Rohru required 132 days for harvesting, while, 133 days has been indicated for Shimla and Chopal. In this respect, least duration (131 days) has been shown for the lower altitude places as Rampur and Basantpur. In the year 2014, Kalpa, Pooh and Kumarsain required 134 days for harvesting while, Chopal required 133 days (Figure 78). The shortest duration from fruit set to harvesting (130 days) has been depicted for Nichar, Chirgaon, Theog and Jubbal. In this study, number of days taken for harvesting was mapped out at various locations in Shimla and Kinnaur districts, which revealed the higher altitudes required more days for harvesting as compare to lower altitudes. Similarly, spatio-temporal approach was carried out earlier to determine the optimum harvest date, in a site specific study (Gebber and Zude, 2010).

4.2.11 Production parameters

4.2.11.1 Average Fruit Set

During the year 2013, thematic map (Figure 79) reproduced the maximum fruit set (8.13 %) at Kalpa, Pooh and Kumarsain followed by Chopal (7.65 %) and Shimla (7.15 %) whereas, the minimum fruit set (5.16 %) has been depicted in the map at Rampur and Basantpur. In the year 2014, thematic map (Figure 80) displayed maximum fruit set (7.21 %) at Kumarsain, Kalpa and Pooh followed by Chopal (7.00 %) and Shimla (6.30 %) whereas, minimum fruit set (4.88 %) is depicted at Rampur and Basantpur.

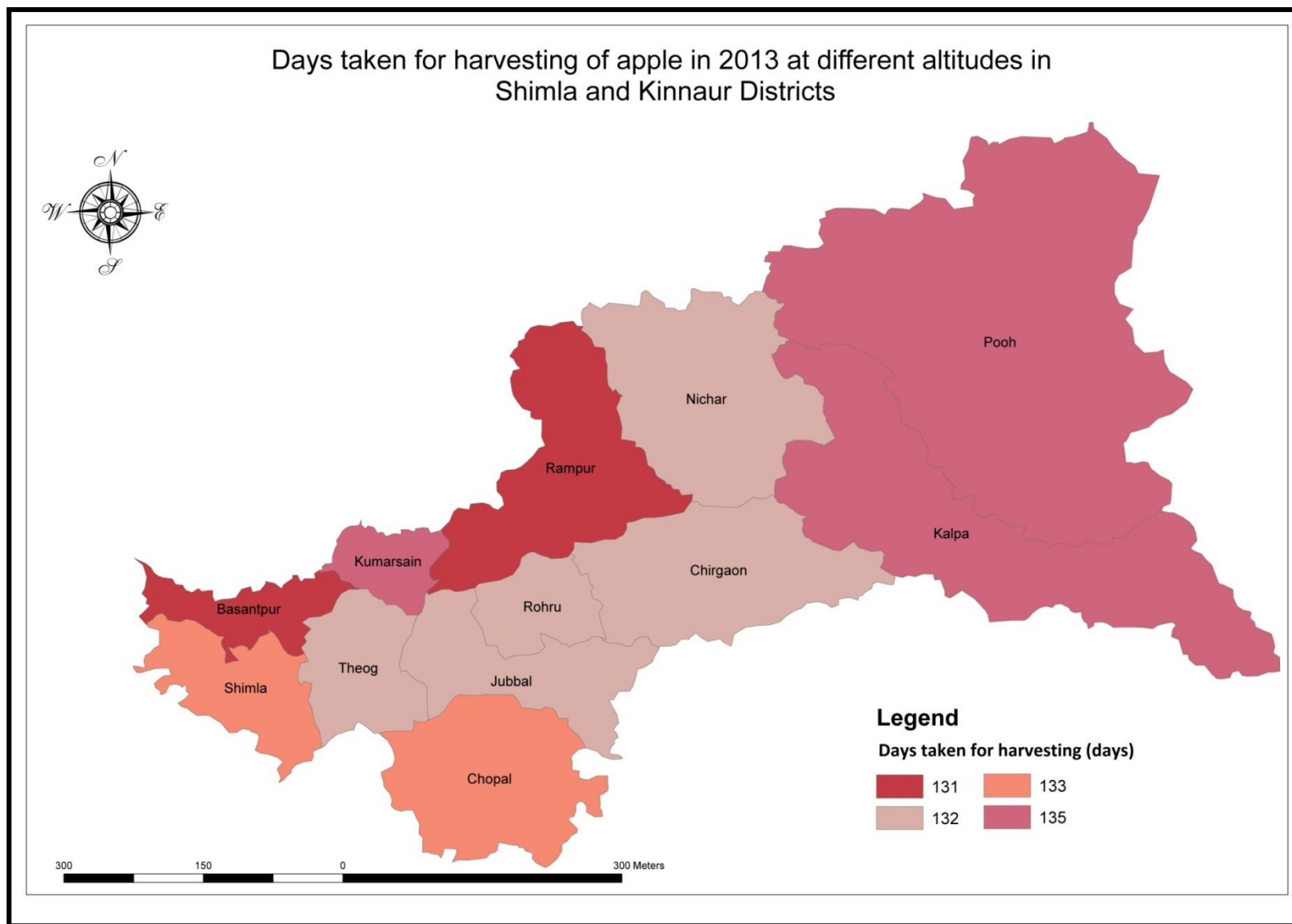


Figure 77

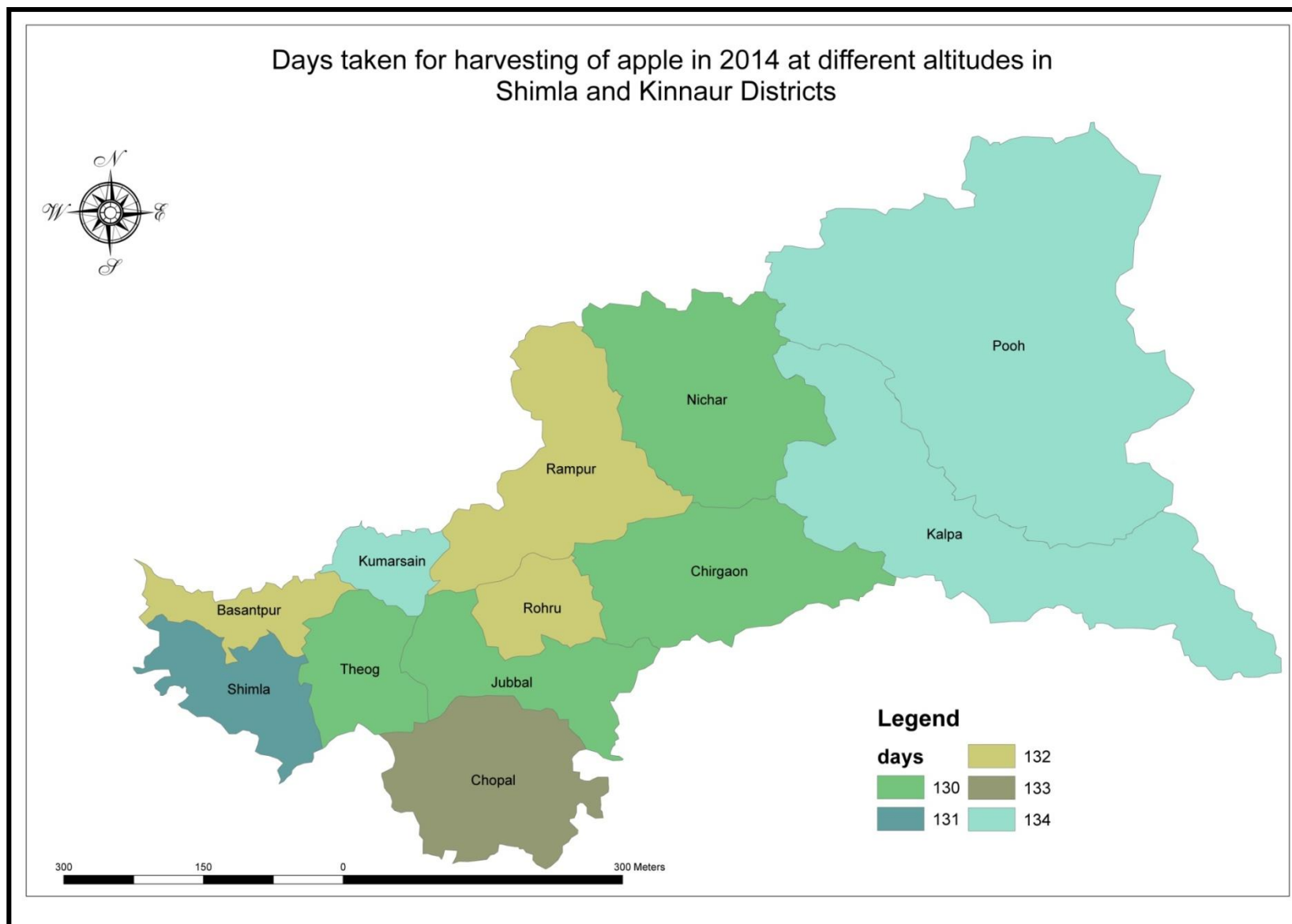


Figure 78

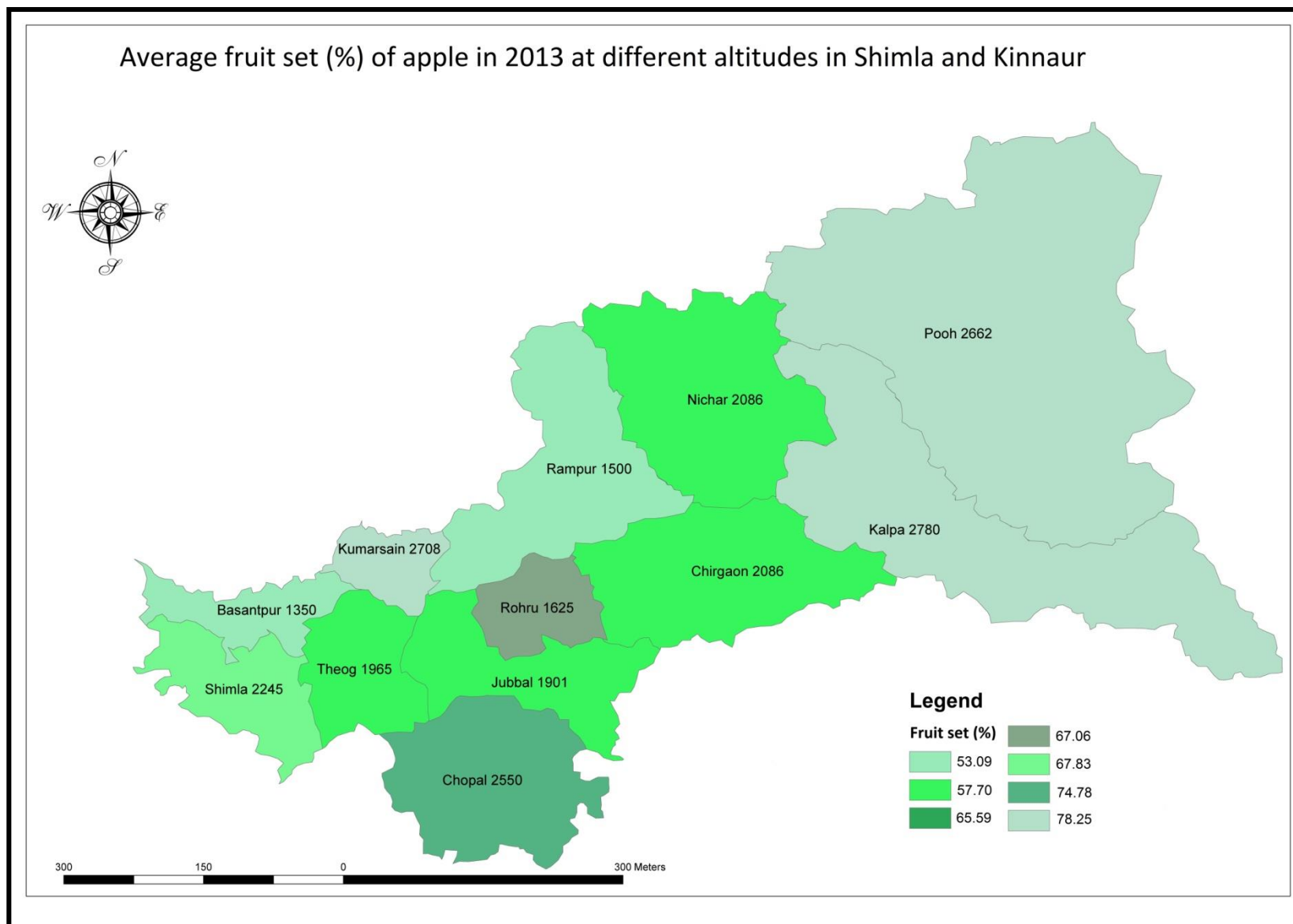


Figure 79

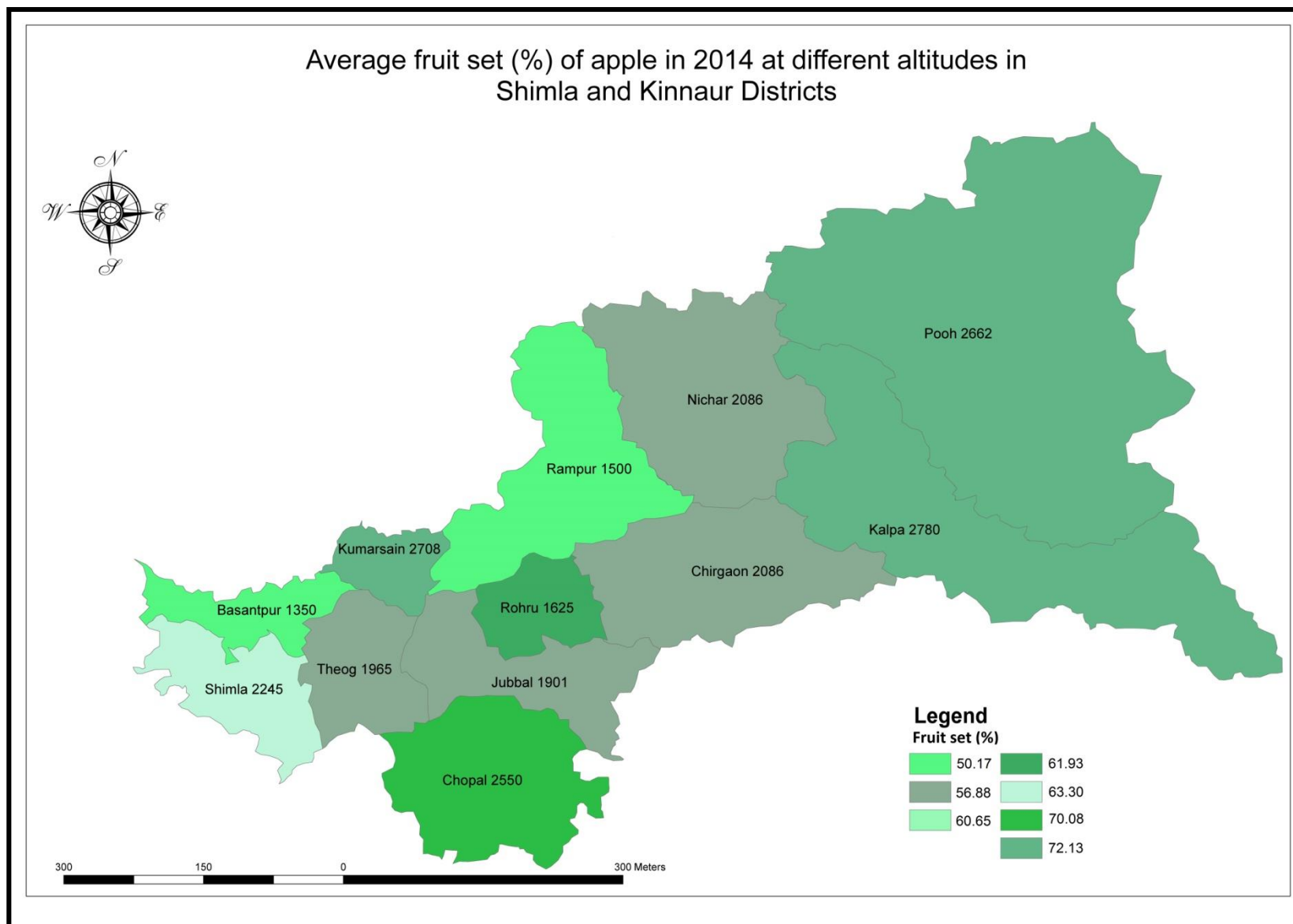


Figure 80

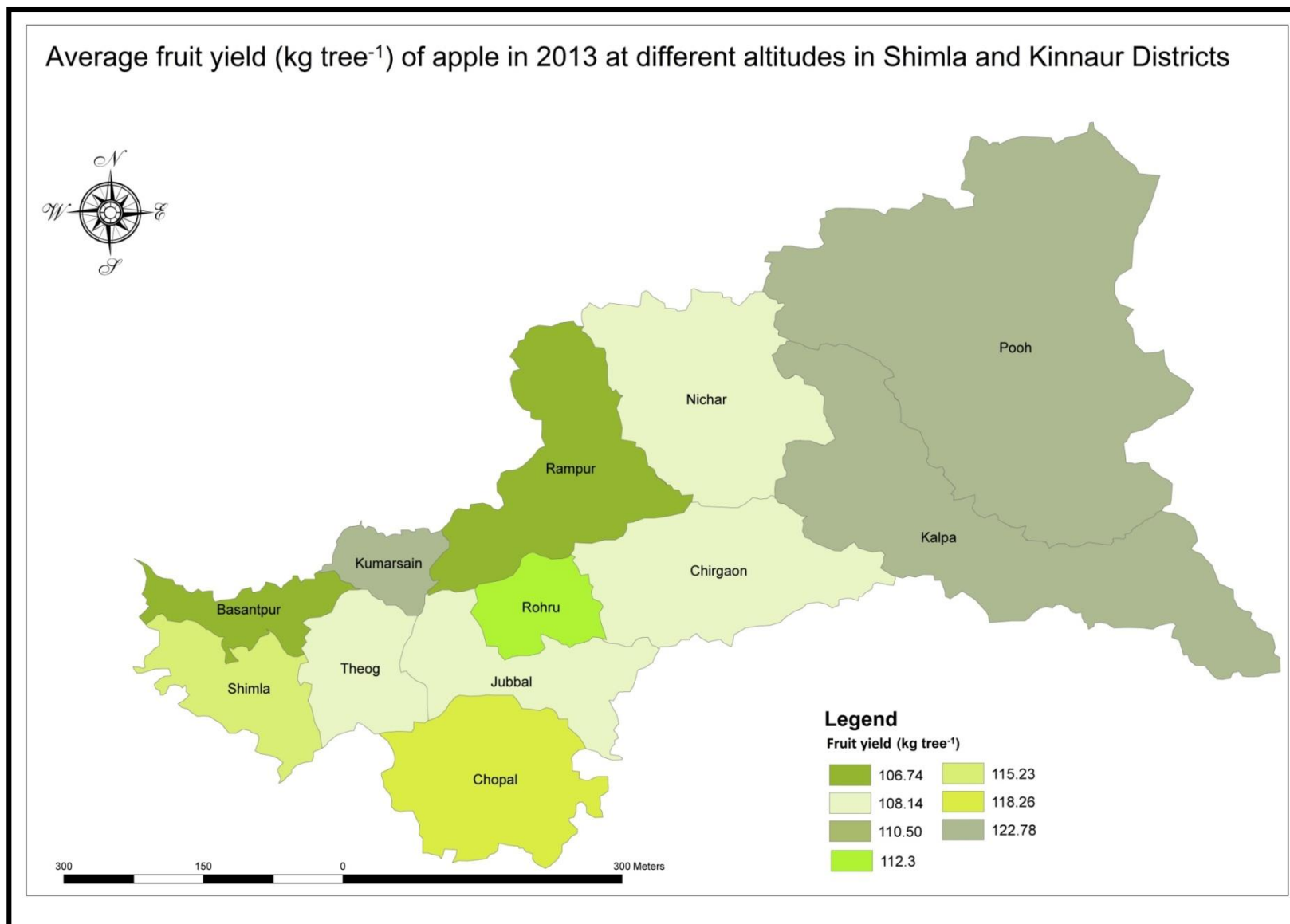


Figure 81

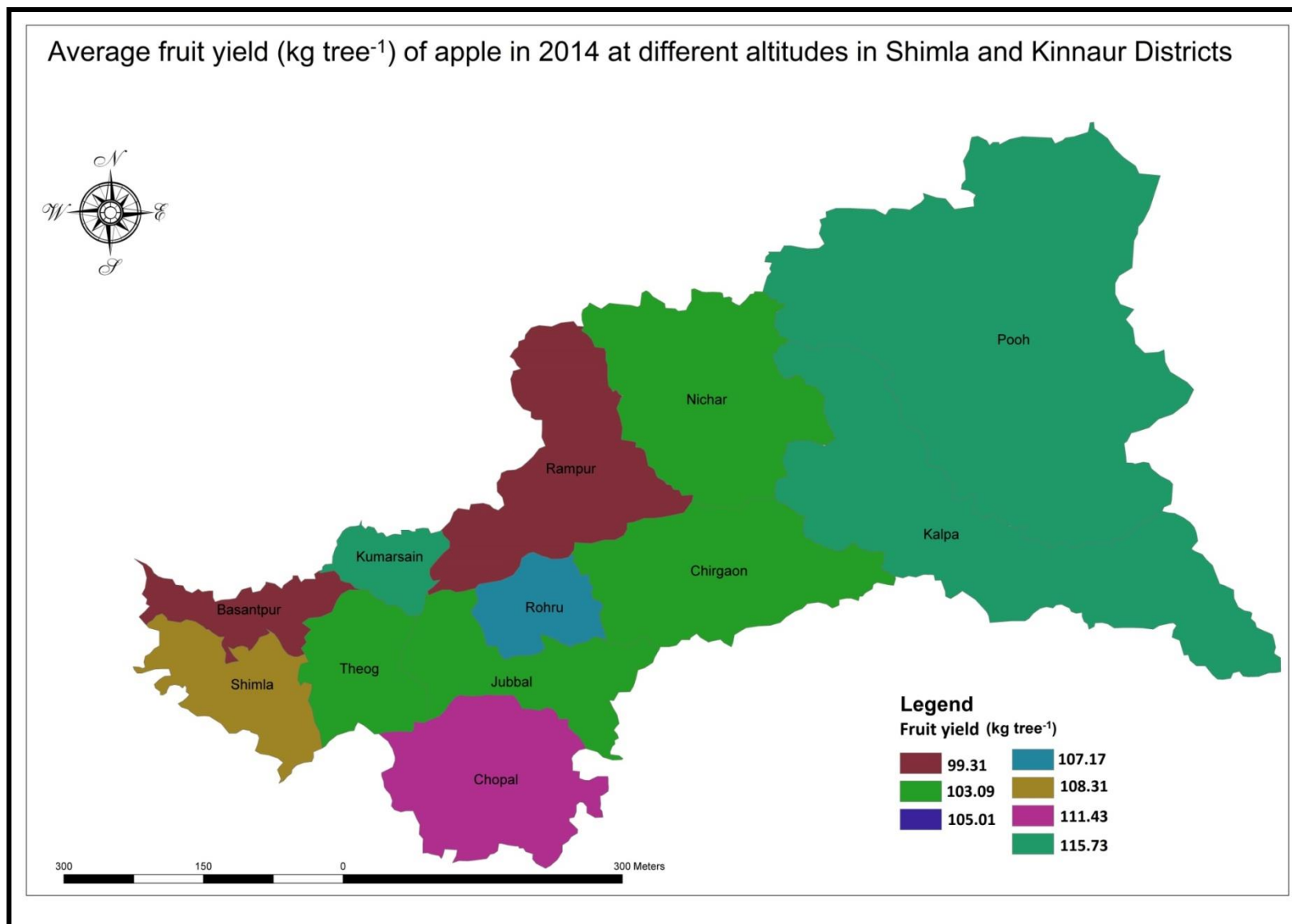


Figure 82

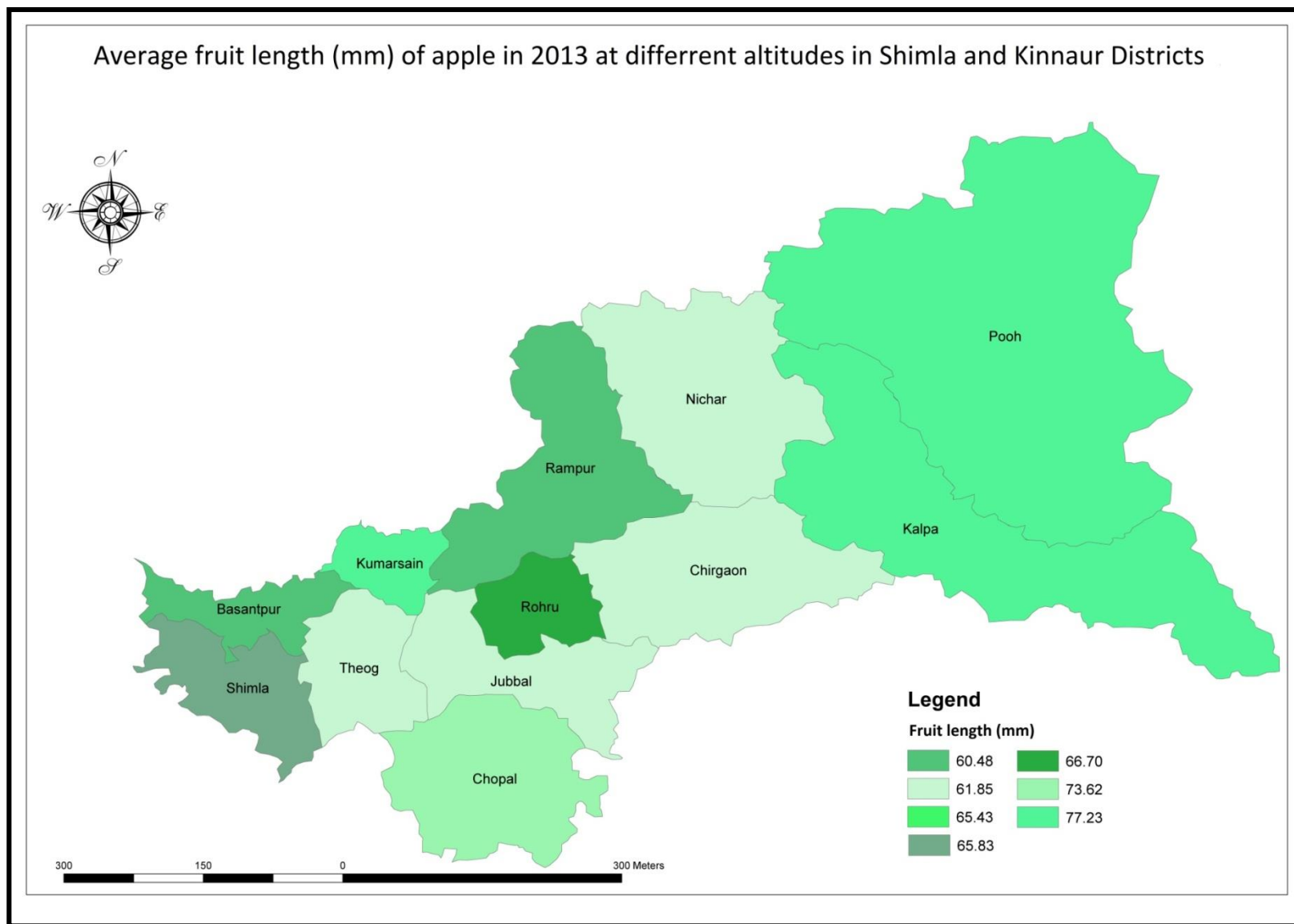


Figure 83

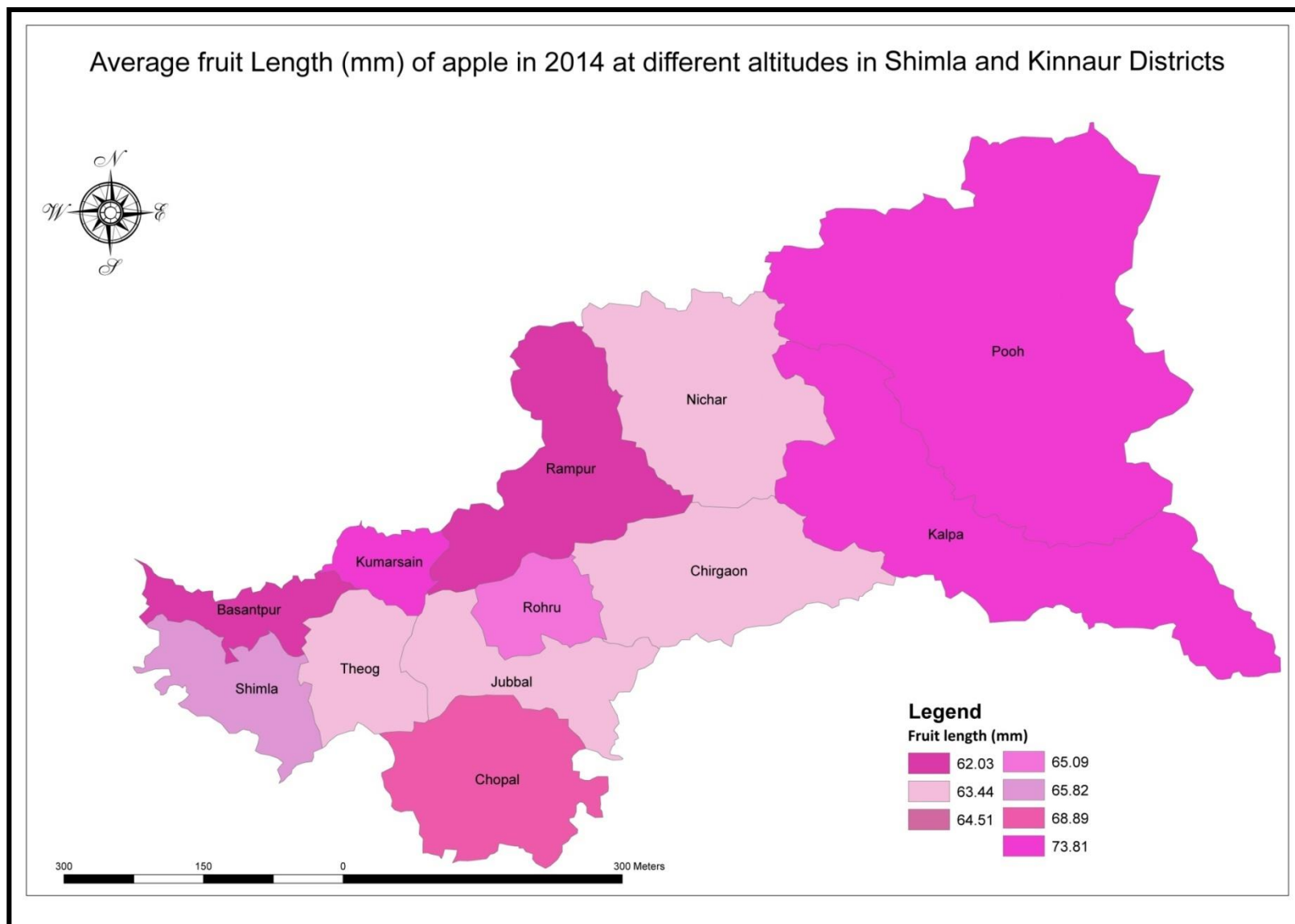


Figure 84

4.2.11.2 Fruit yield

The thematic map (Figure 81 & 82) indicates that there was a positive relationship of fruit yield with the different altitudes in Shimla and Kinnaur districts in both the years of study i.e. fruit yield increased with increase of altitude. During the year 2013, the map (Figure 81) displayed maximum fruit yield (122.78 kg tree⁻¹) at locations of Kalpa, Pooh and Kumarsain, followed by Chopal (118.94 kg tree⁻¹) and Shimla (115.91 kg tree⁻¹) whereas, minimum fruit yield has been shown at Rampur and Basantpur (107.42 kg tree⁻¹). In the year 2014, (Figure 82) maximum fruit yield is depicted at Kumarsain, Kalpa and Pooh (115.73 kg tree⁻¹) followed by the Chopal (111.43 Shimla kg tree⁻¹) whereas, map depicts minimum fruit yield of (99.31kg tree⁻¹) at Basantpur and Rampur. In the present study, fruit yield was mapped out at various blocks in Shimla and Kinnaur districts via geo statistical technique in GIS after which precise site specific maps were made. Swain *et al.* (2010) also developed an automated yield monitoring and mapping system for real time fruit yield estimation in blueberry. Further, yield maps along with topography were developed for precise site specific programs for blueberry production. Present yield estimation in apple through GIS technique is in line with the work of Mann *et al.* (2011), who mapped the productivity of a citrus grove to delineate zones of productivity. Manfrini *et al.* (2012) also used the spatial statistical techniques in which maps of apple crop production were generated by punctual kriging with global variogram on a common grid.

4.2.11.3 Average fruit length

The thematic map on fruit length for the year 2013 (Figure 83) revealed the maximum fruit length (77.23 mm) at Kalpa, Pooh and Kumarsain followed by Chopal (73.62). The minimum fruit length (60.48 mm) has been depicted at Basantpur and Rampur. In the year 2014, thematic map (Figure 84) reproduced the maximum fruit length (73.81 mm) at Kalpa, Pooh and Kumarsain followed by Chopal (68.89 mm) whereas, minimum fruit length (62.03 mm) is depicted at Basantpur and Rampur.

4.2.11.4 Average fruit diameter

The thematic map on fruit breadth for the year 2013 presented in Figure 85 revealed that fruit diameter was largest (76.70 mm) at Kalpa, Pooh and Kumarsain followed by Chopal (73.73 mm) whereas, it was smallest (69.42 mm) at Basantpur and Rampur. In the year 2014, (Figure 86) the fruit diameter was again computed largest (76.69 mm) at Kalpa, Pooh and Kumarsain followed by Chopal (74.22 mm). It is however, depicted smallest fruit diameter (64.42 mm) at Basantpur and Rampur.

4.2.11.5 Average fruit length/diameter ratio

In the year 2013, the thematic map (Figure 87) shows that maximum length/diameter ratio (1.0) at Kalpa, Pooh and Kumarsain followed Chopal (0.99) whereas, minimum length/breadth ratio has been depicted at Rampur and Basantpur (0.87%). During the year 2014, (Figure 88) the maximum length/diameter ratio (1.0 %) has been depicted in the map at Kalpa, Pooh and Kumarsain followed by Rohru (0.98 %) and Chopal (0.96 %) whereas, minimum length/diameter ratio (0.91%) is shown at Nichar, Chirgaon, Jubbal and Theog.

4.2.11.6 Average fruit weight

The thematic map (Figure 89) for the year 2013 depicts maximum fruit weight (223.24 g) at Kalpa, Pooh and Kumarsain followed Chopal (204.32 g) and Shimla (162.68 g) whereas, minimum fruit weight in the same year is indicated at Basantpur and Rampur (142.77 g). In the year 2014, map (Figure 90) again depicted maximum fruit weight (218.35 g) at Kalpa, Pooh and Kuarsain followed by Chopal (189.97 g) and Shimla (176.32 g). Whereas, the minimum fruit weight is indicated at Basantpur and Rampur (129.32 g).

4.2.11.7 Total Soluble Solid (TSS)

The thematic map for the year 2013 (Figure 91) indicates highest fruit TSS contents (15.99 °Brix) at Kalpa, Pooh and Kumarsain followed by Chopal (15.68 °Brix) and Shimla (15.38 °Brix) in the decreasing order. Whereas, the minimum

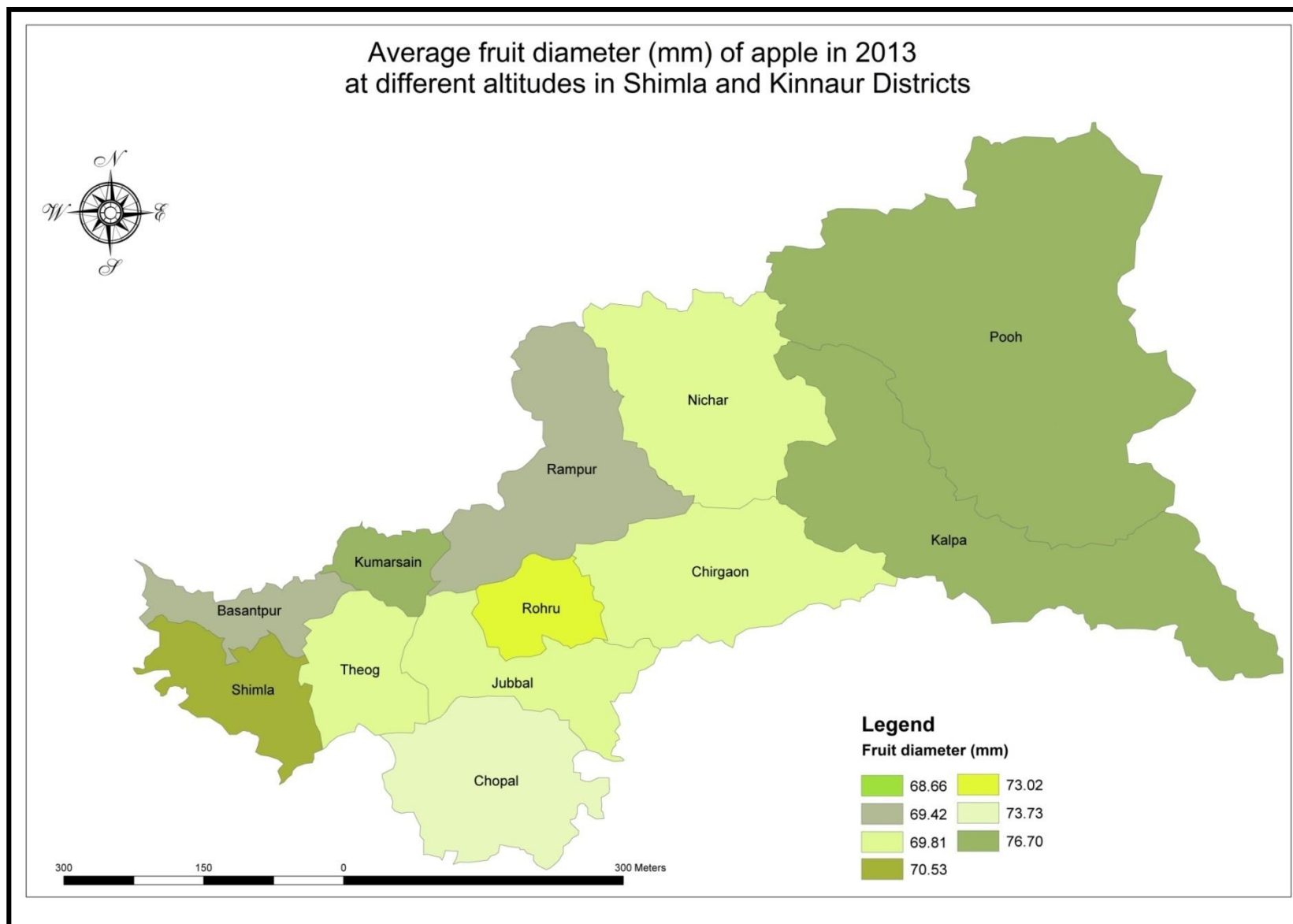


Figure 85

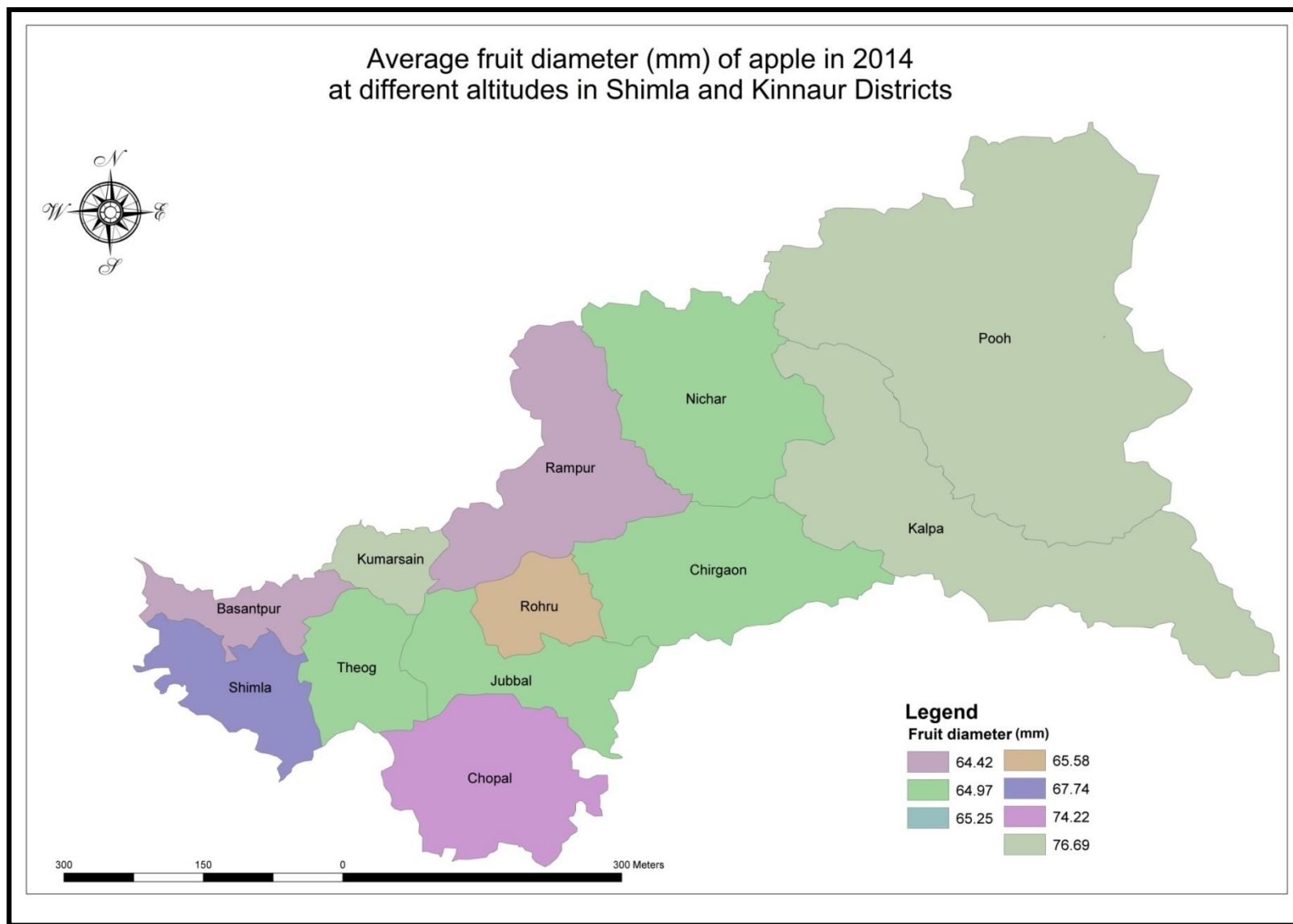


Figure 86

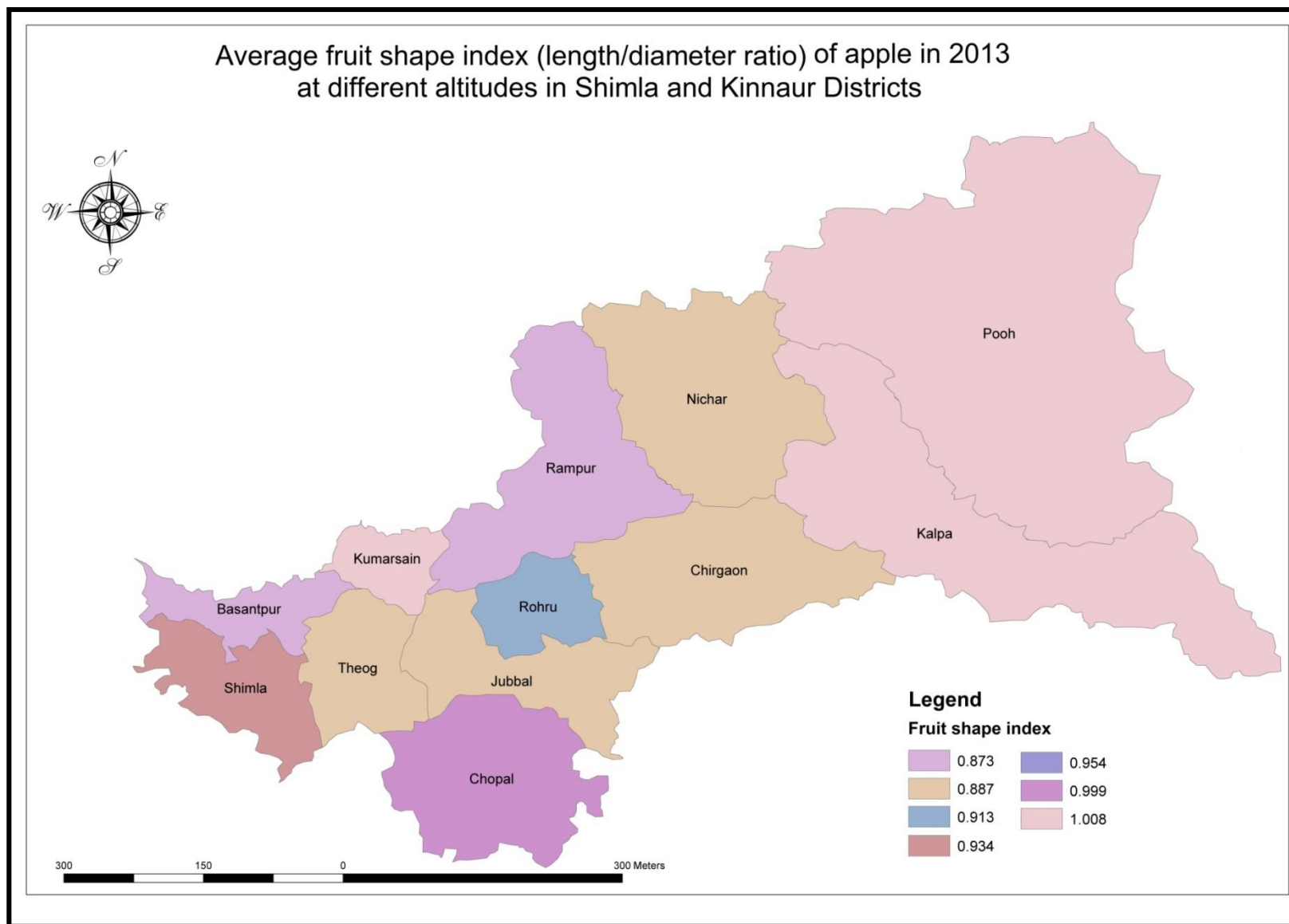


Figure 87

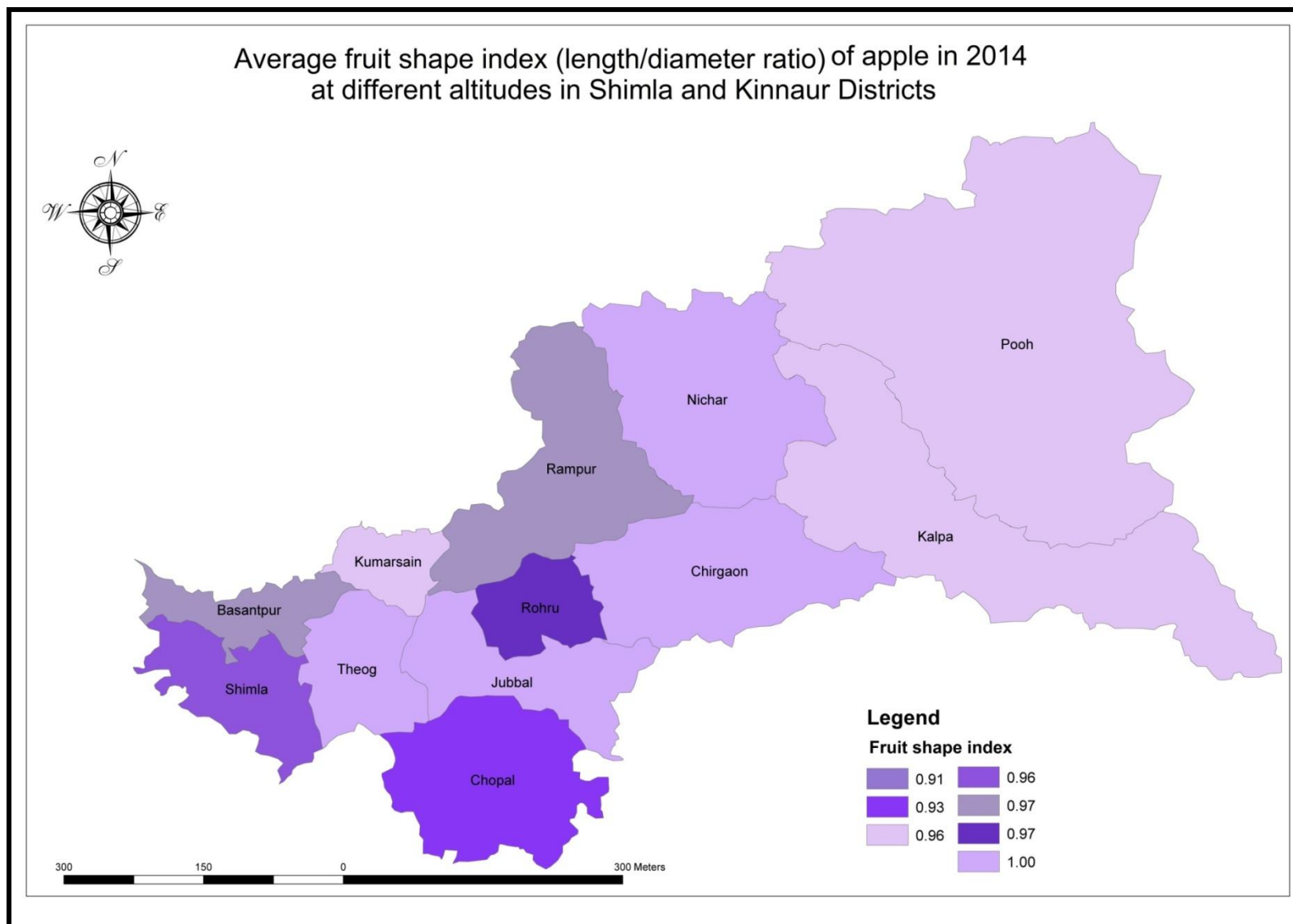


Figure 88

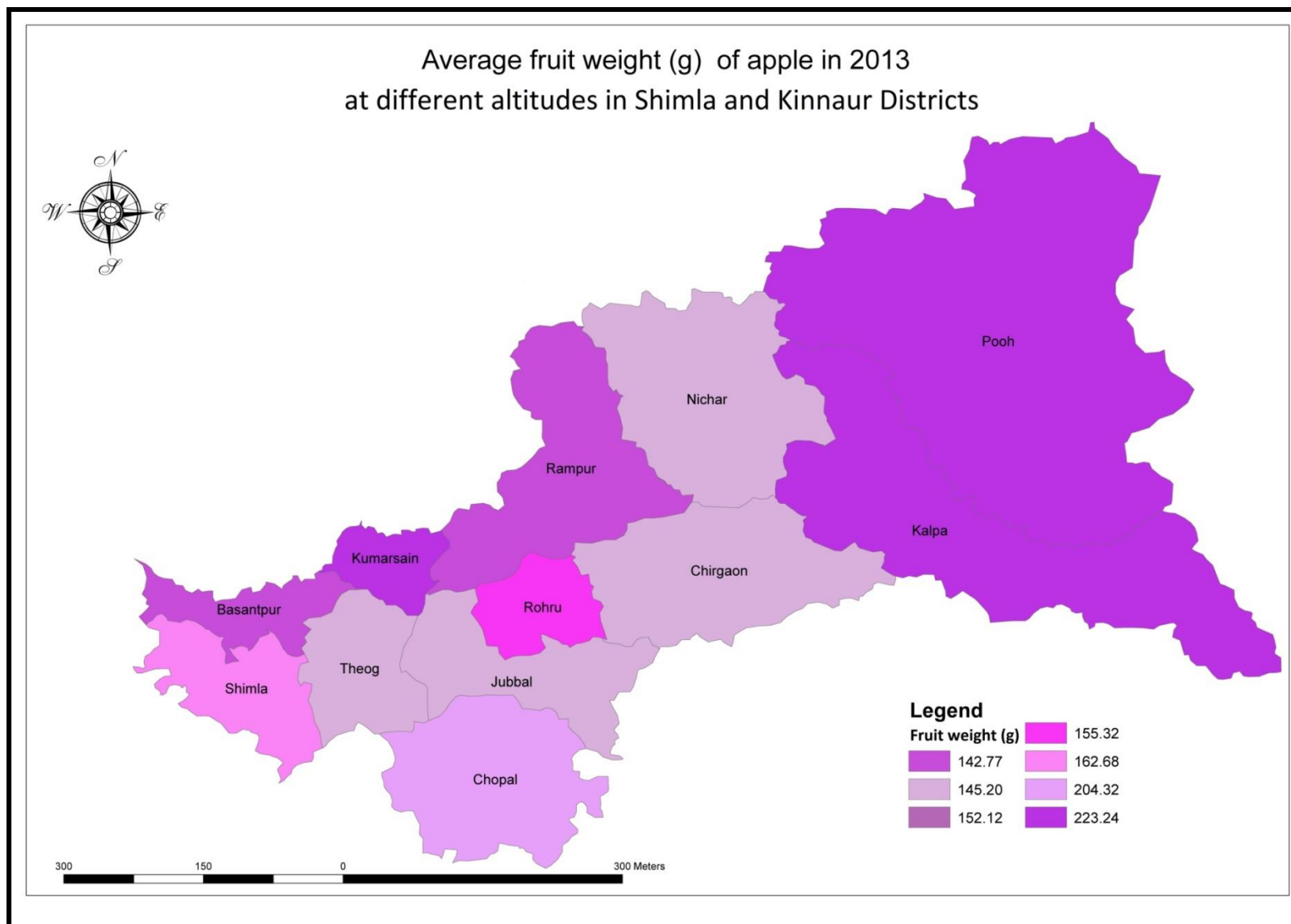


Figure 89

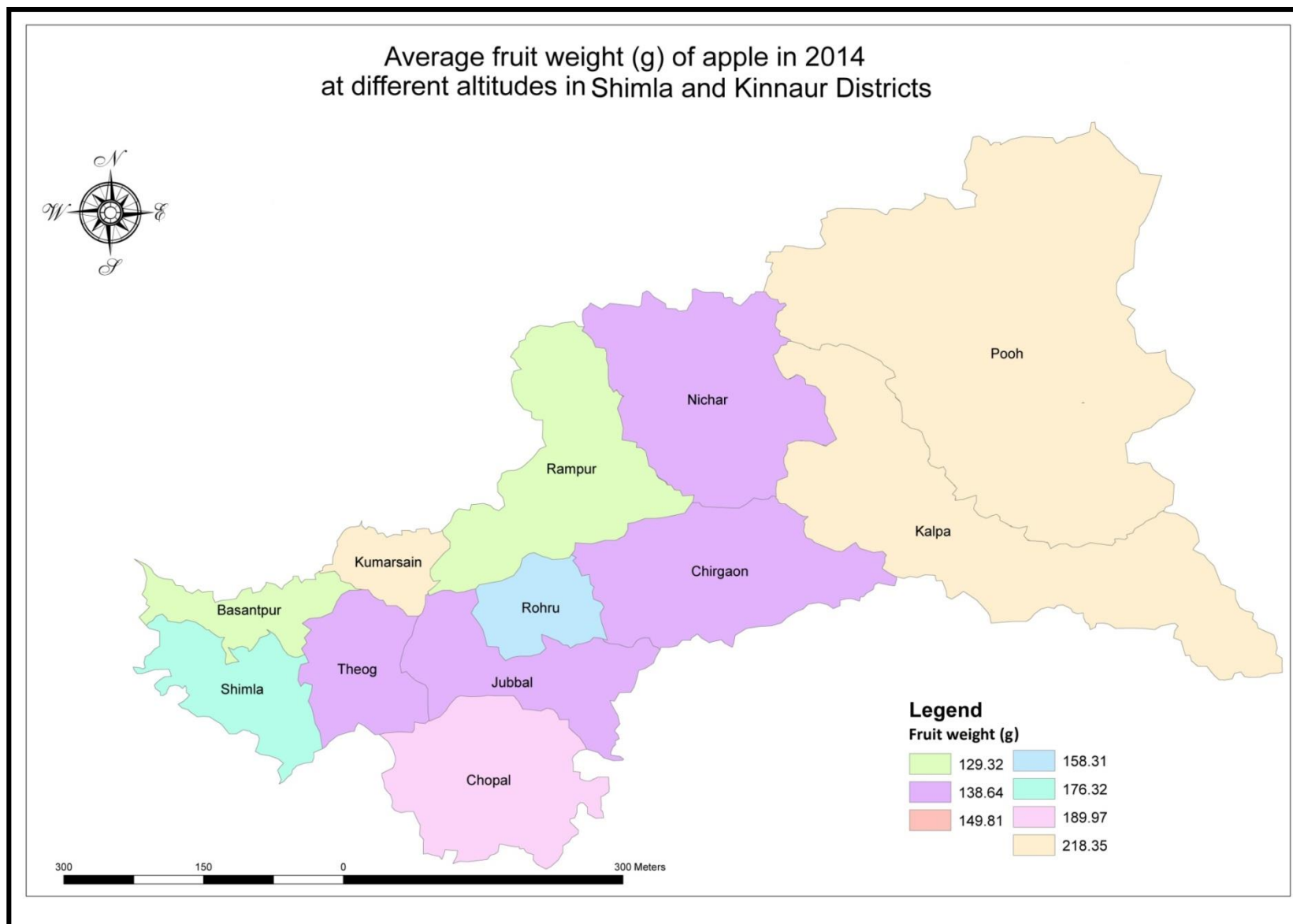


Figure 90

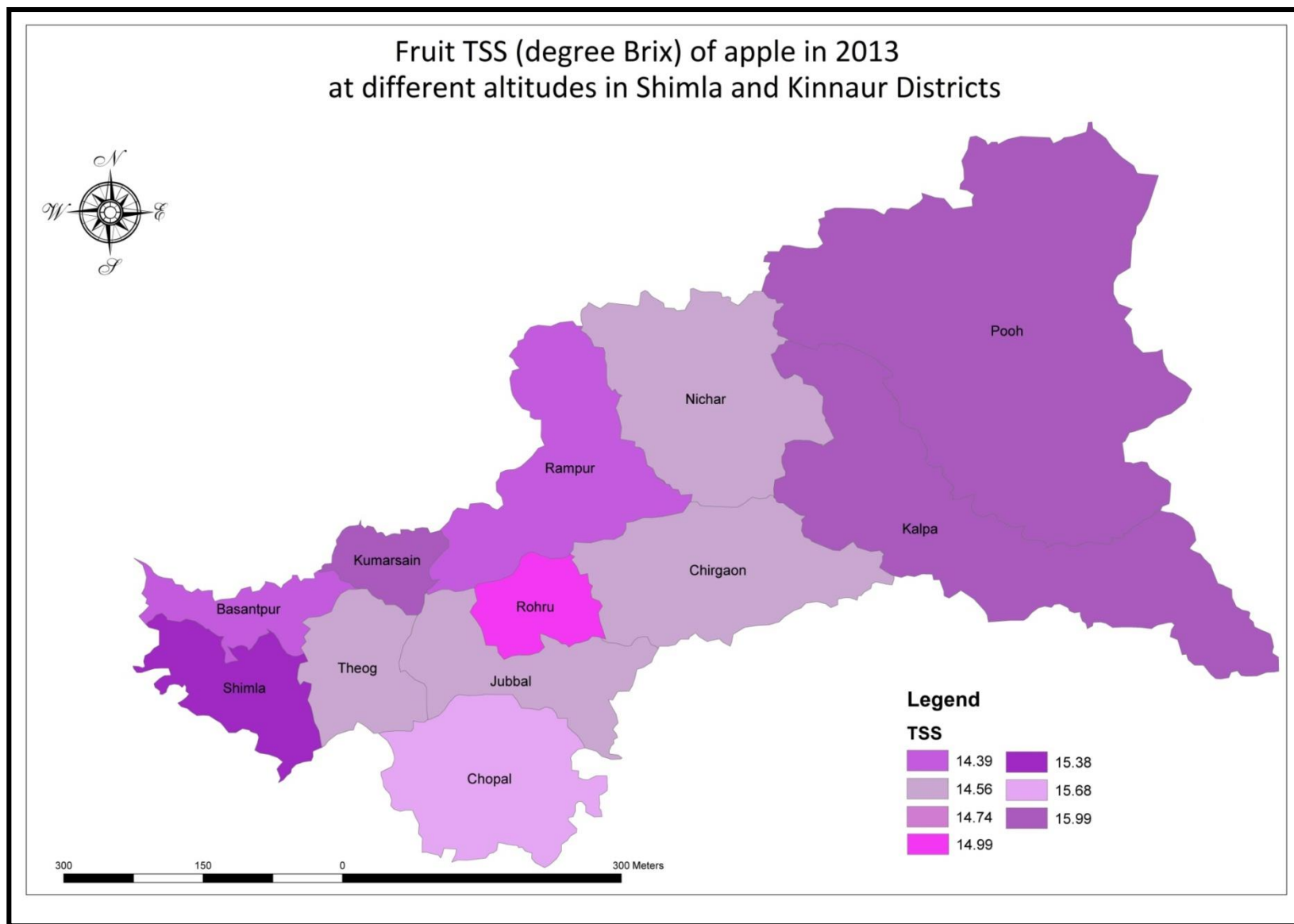


Figure 91

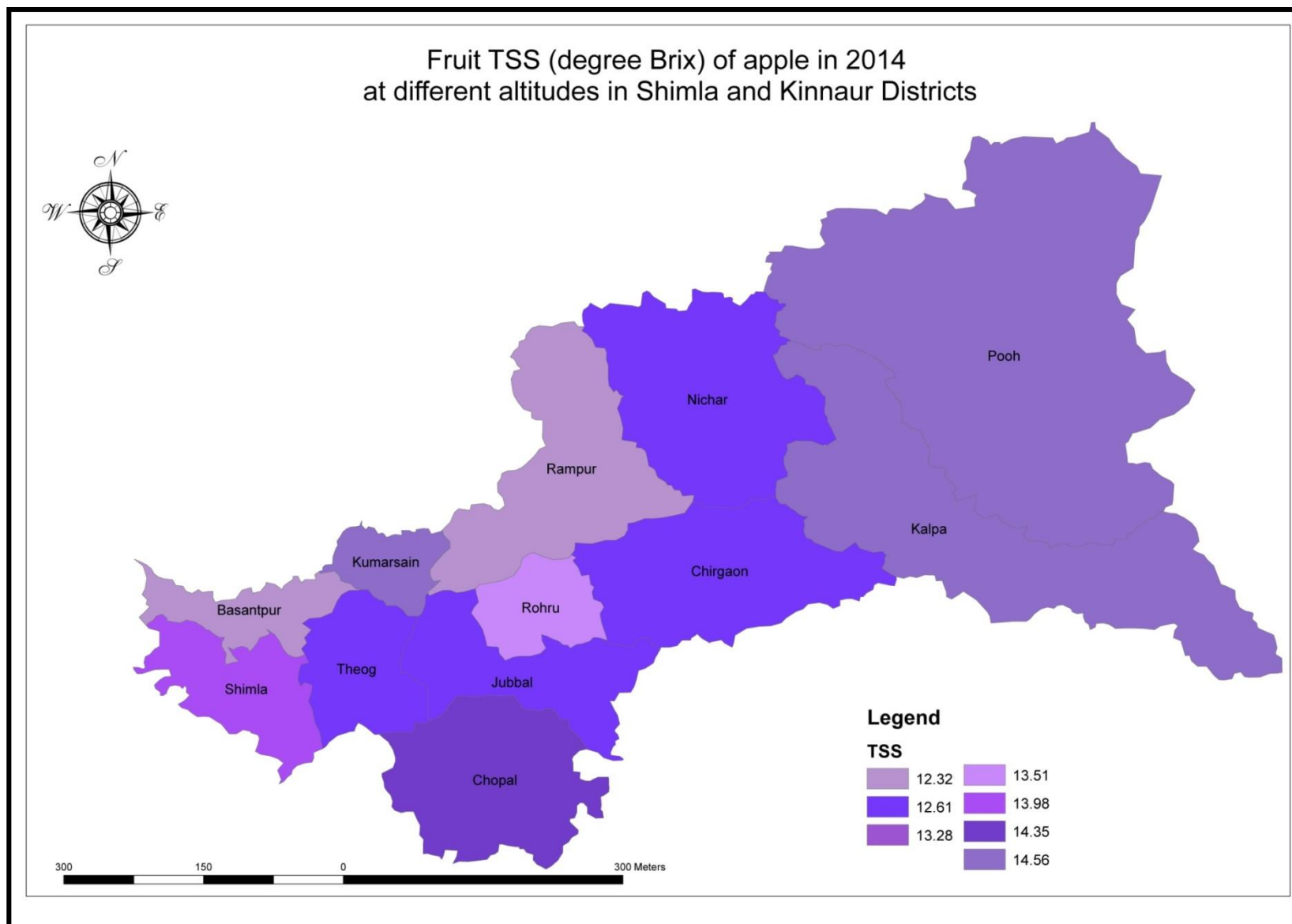


Figure 92

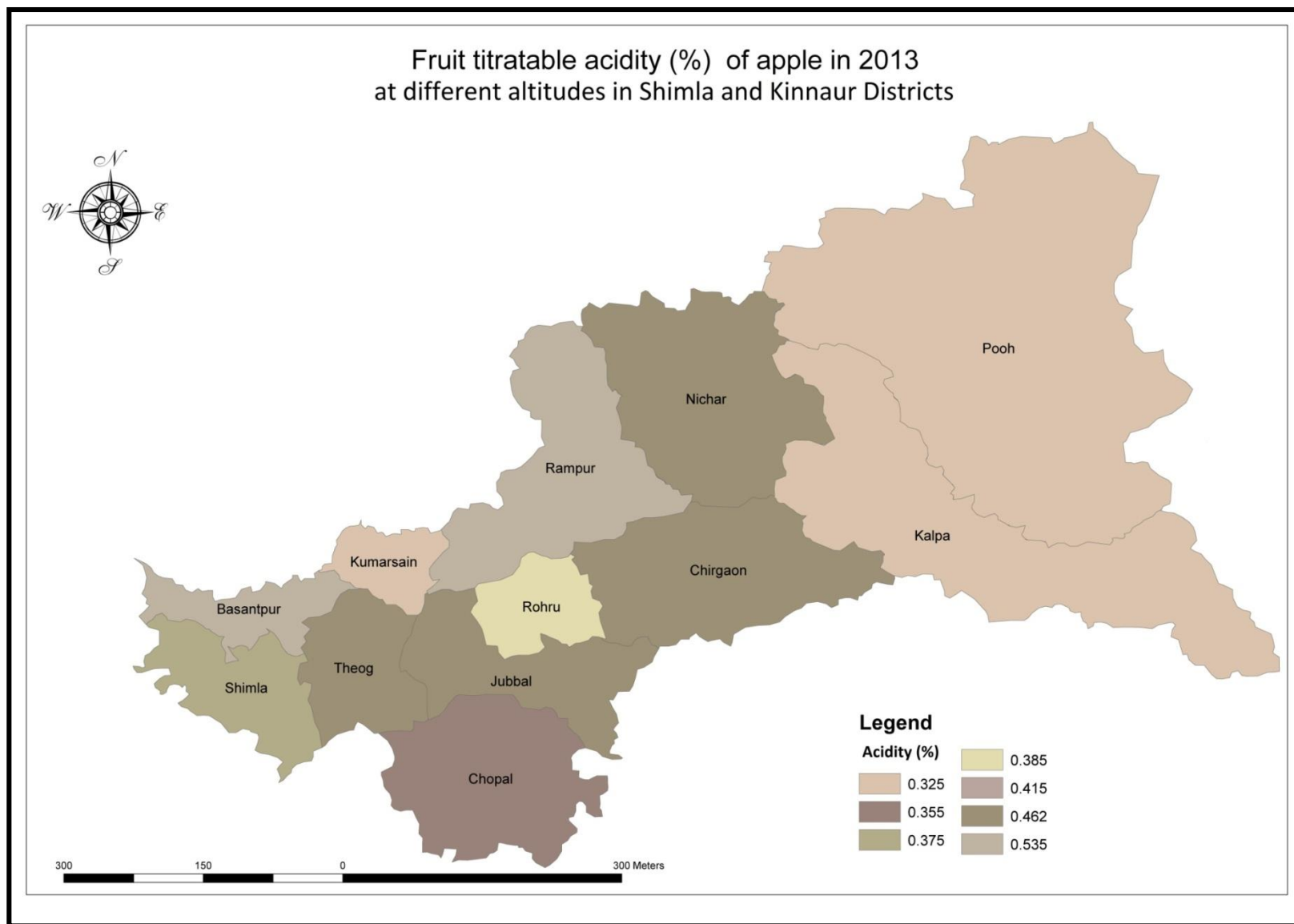


Figure 93

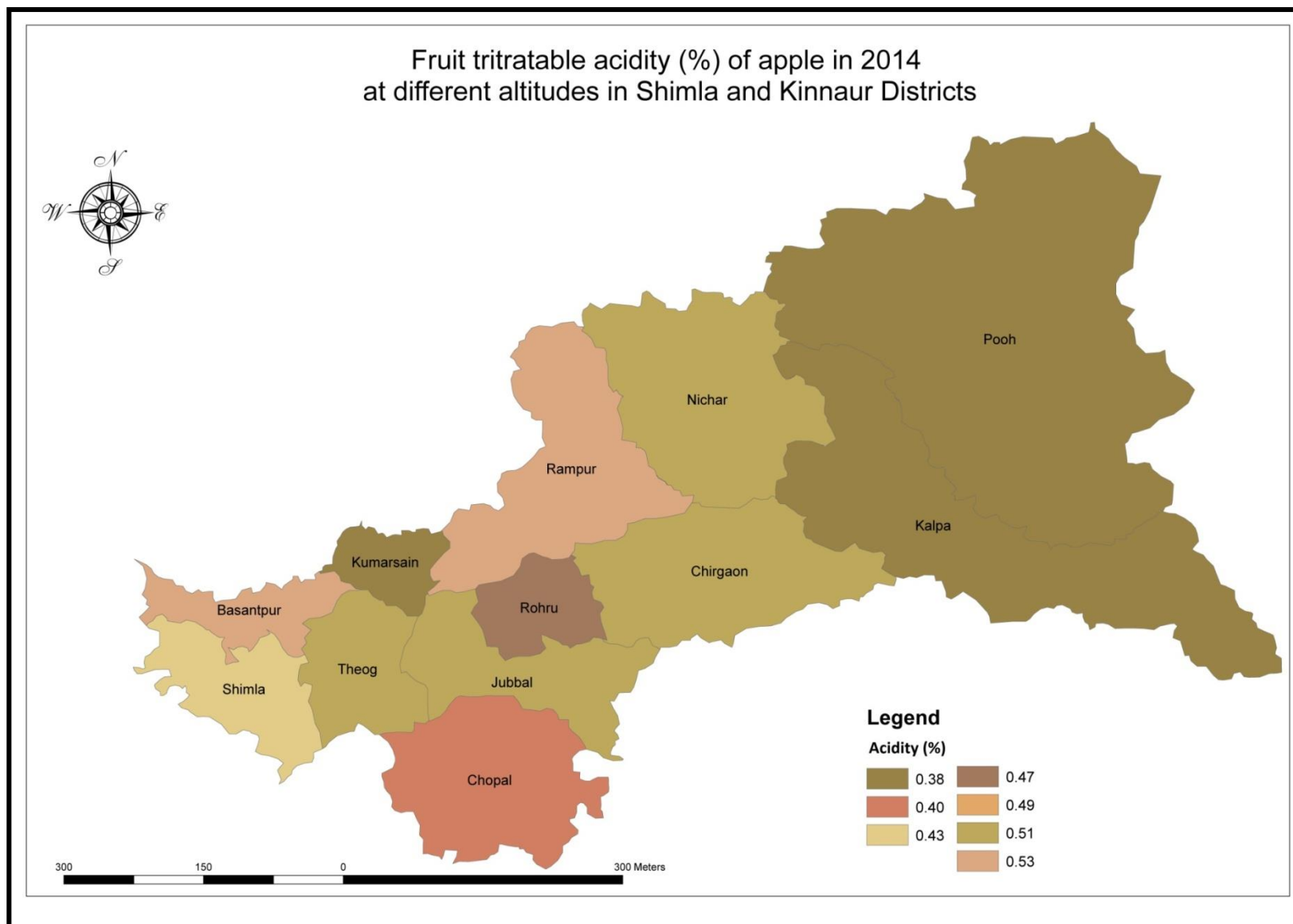


Figure 94

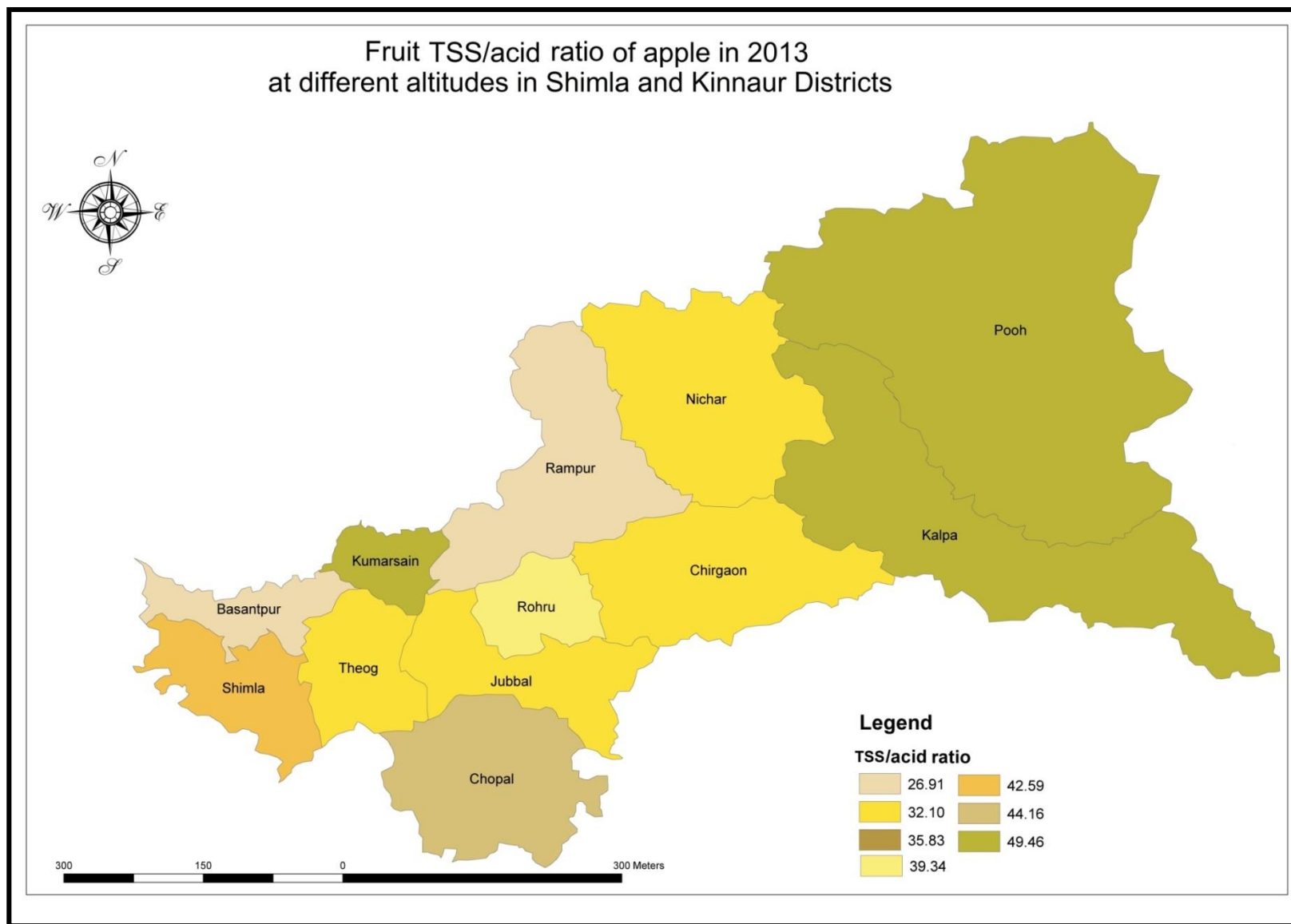


Figure 95

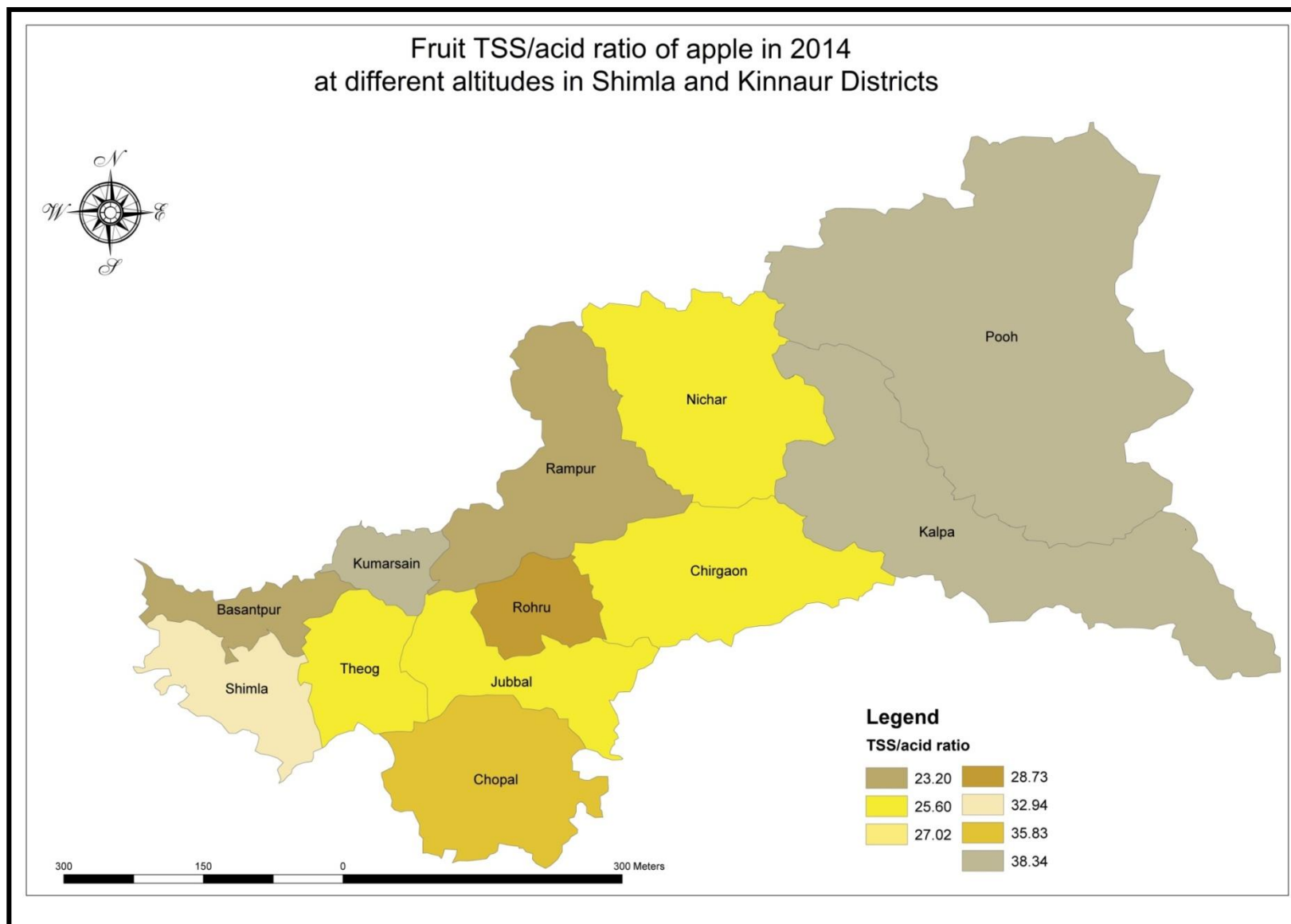


Figure 96

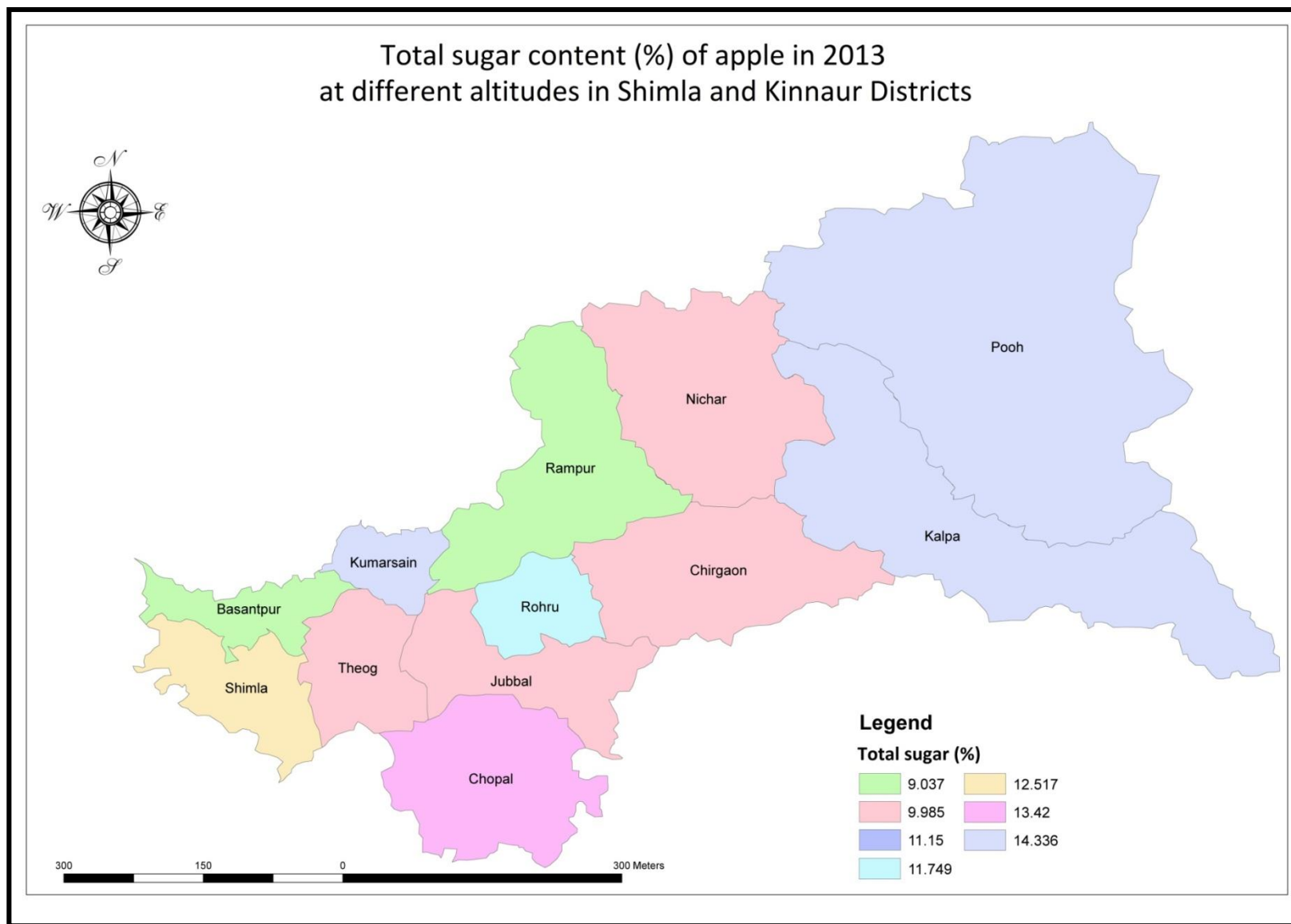


Figure 97

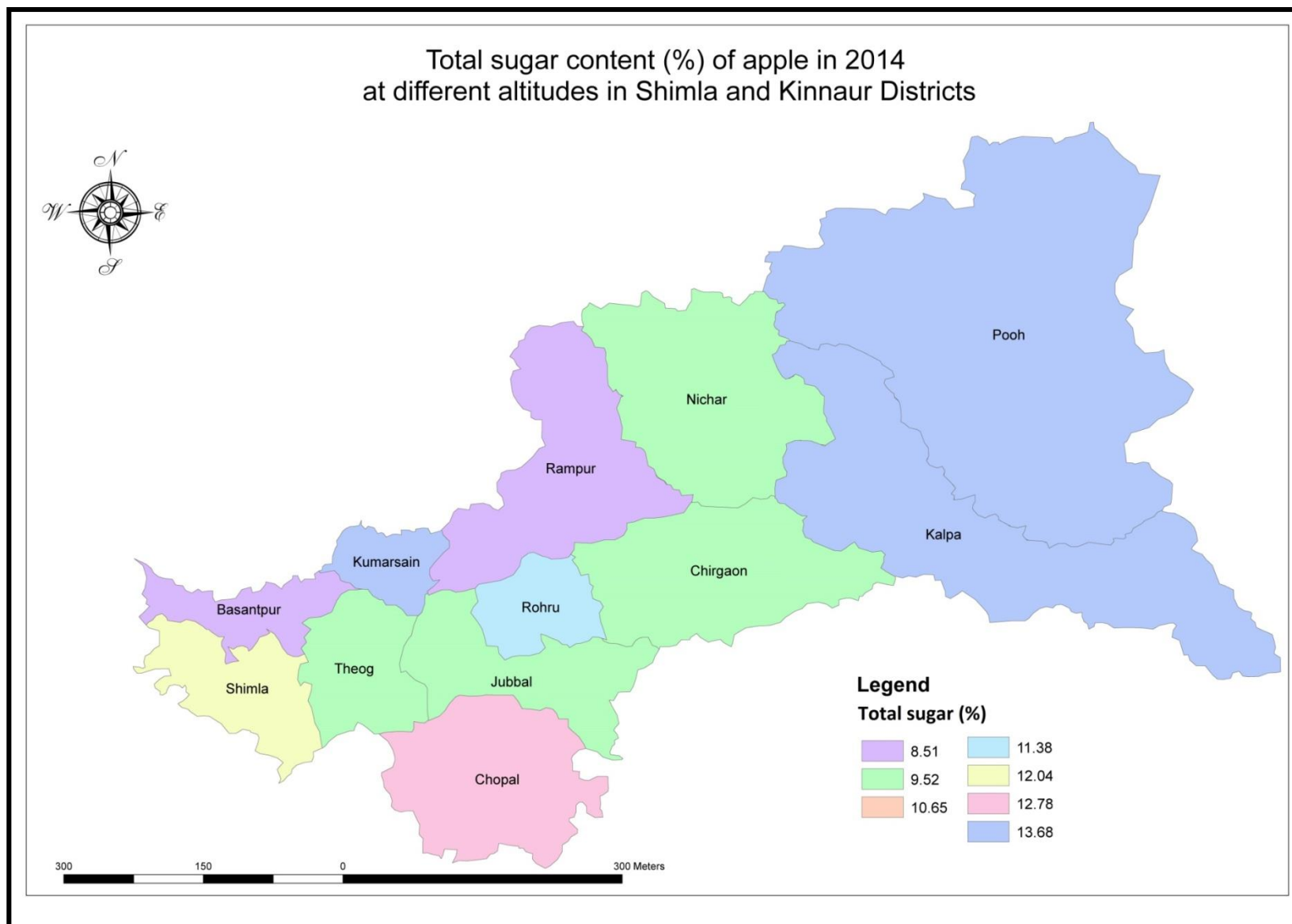


Figure 98

fruit TSS contents (14.39 °Brix) is depicted at Basantpur and Rampur. In the year 2014, the maximum fruit TSS contents (14.56°Brix) has been indicated (Figure 92) at Kumarsain, Kalpa and Pooh followed by Chopal (14.35°Brix) and Shimla (13.98 °Brix) whereas, the minimum TSS is shown at Rampur and Basantpur(12.32 °Brix).

4.2.11.8 Titratable Acidity

As per the thematic layer (Figure 93) for the year 2013, the minimum titratable acidity (0.32%) in fruits was at Kalpa, Pooh and Kumarsain followed by Chopal (0.35%) and Shimla (0.37%) in the increasing order. The maximum fruit titratable acidity (0.53 %) has been displayed at Basantpur and Rampur. In the year 2014, map (Figure 94) depicts the minimum titratable acidity (0.38 %) in fruit at Kumarsain, Kalpa and Pooh followed by Chopal (0.40 %) and Shimla (0.43 %). However, map reproduced the highest acid contents (0.53 %) in apple fruits at Rampur and Basantpur.

4.2.11.9 TSS/acid ratio

The thematic map (Figure 95) revealed that during the year 2013, fruit TSS/ acid ratio was highest at Kalpa, Pooh, and Kumarsain (49.46) followed by Chopal (44.16) and Shimla (42.59). Whereas, the lowest TSS/ acid ratio (26.91) is depicted in apples at Rampur and Basantpur. During the year 2014, the same trend has been displayed in the map (Figure 96) with higher fruit TSS/ acid ratio at Kalpa, Pooh and Kumarsain (38.34 %) and Chopal (35.83%) and lower TSS/ acid ratio (23.20) at Basantpur and Rampur.

4.2.11.10 Total sugars

The thematic map (Figure 97) indicates that during 2013, the total sugars content in fruit was highest (14.33 %) at Kumarsain, Kalpa and Pooh followed by Chopal (13.42 %). The lowest level of total sugars in fruit (9.03 %) is depicted at Basantpur and Rampur. In the year 2014, (Figure 98) the maximum fruit total sugars content has been displayed at Kalpa, Pooh and Kumarsain followed by

Chopal (12.78 %) and Shimla (12.04 %). Fruit total sugar counted has however, been depicted lowest (8.51%) at Basantpur and Rampur.

4.2.11.11 Reducing sugars

The thematic map (Figure 99) indicates that in the year 2013, blocks of Kalpa and Pooh in district Kinnaur and Kumarsain in Shimla should have highest level of fruit reducing sugars content (8.03 %) followed by Chopal (7.61 %) and Shimla (7.05 %), whereas, the minimum reducing sugars content (5.03 %) has been projected at Basantpur and Rampur. In the year 2014, map (Figure 100) depicts maximum reducing sugars content (7.08%) in fruits at Kumarsain, Kalpa and Pooh closely followed by Chopal (7.04 %). The minimum value with 3.94 per cent of reducing sugars in fruit has been shown at Rampur and Basantpur.

4.2.11.12 Non-reducing sugars

The thematic map (Figure 101) demonstrates that during 2013, apple fruits from Kalpa, Pooh and Kumarsain had highest non-reducing sugars (6.26 %) content distantly followed by Chopal (5.78%) and Shimla (5.43 %). Map shows the minimum non-reducing sugars (3.95%) in fruits from Basantpur and Rampur blocks. In the year 2014, map (Figure 102) depicts that Kumarsain, Kalpa and Pooh having maximum non-reducing sugar content with (6.58 %) followed by Chopal (6.11 %). The minimum non-reducing sugar in fruits is depicted at Rampur and Basantpur (4.56 %).

Aggelopoulou *et al.* (2010) considered the potential for site specific management based quality assessment for apples in which they found that spatial variation in several variables and suggested that changes in topography and aspect had important effects on apple quality. These findings supports the present study in which various quality parameters were mapped via GIS system in Shimla and Kinnaur district on the bases of actual data on different quality variable at different locations and these attributes had shown relationship with altitude, slope, aspect and climate variables. Cortellb *et al.* (2004) also used the geographical information system (GIS) in grape to create spatial maps for fruit quality parameters such as berry weight and sugars. Likewise, the spatial statistical techniques were used to

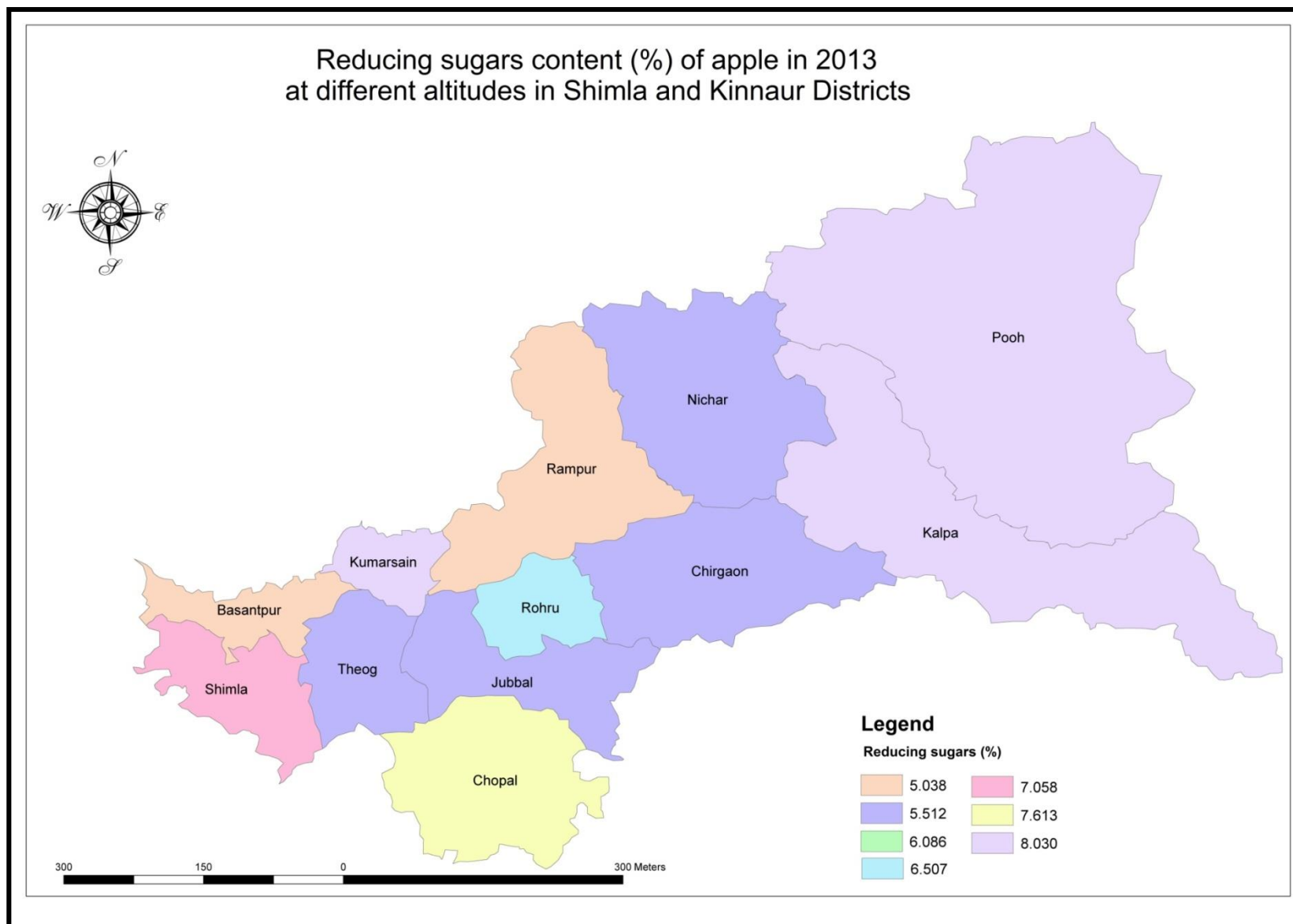


Figure 99

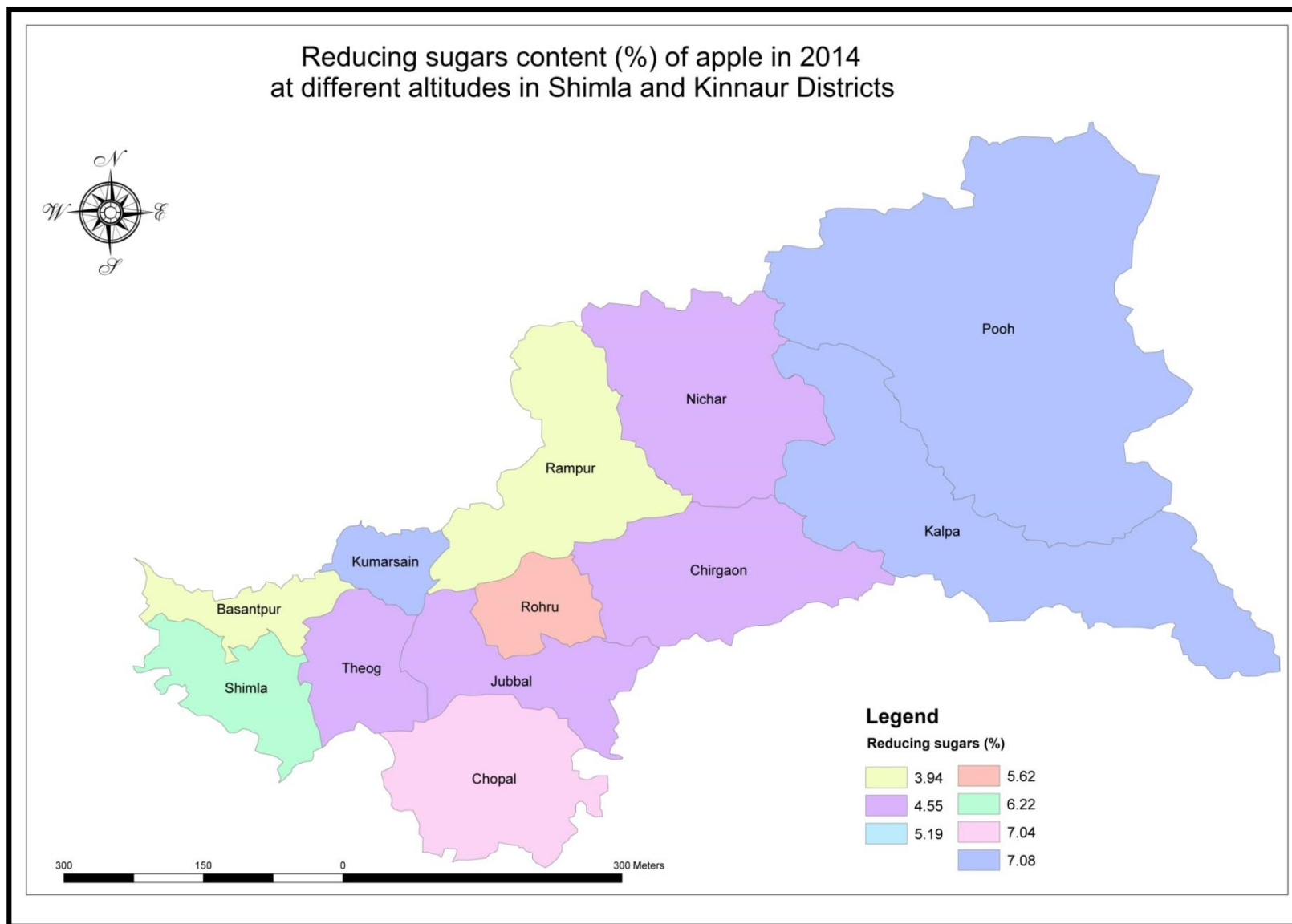


Figure 100

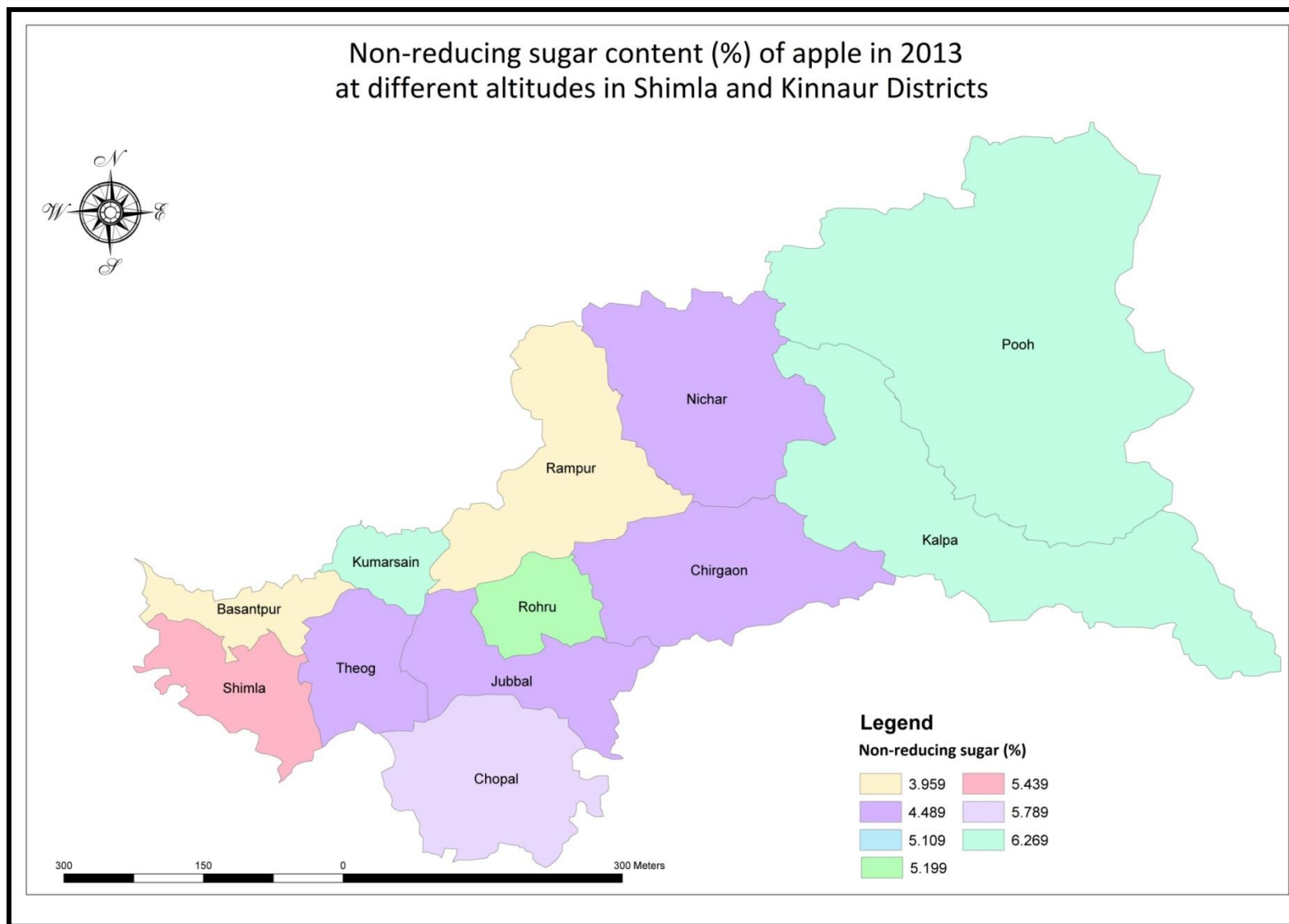


Figure 101

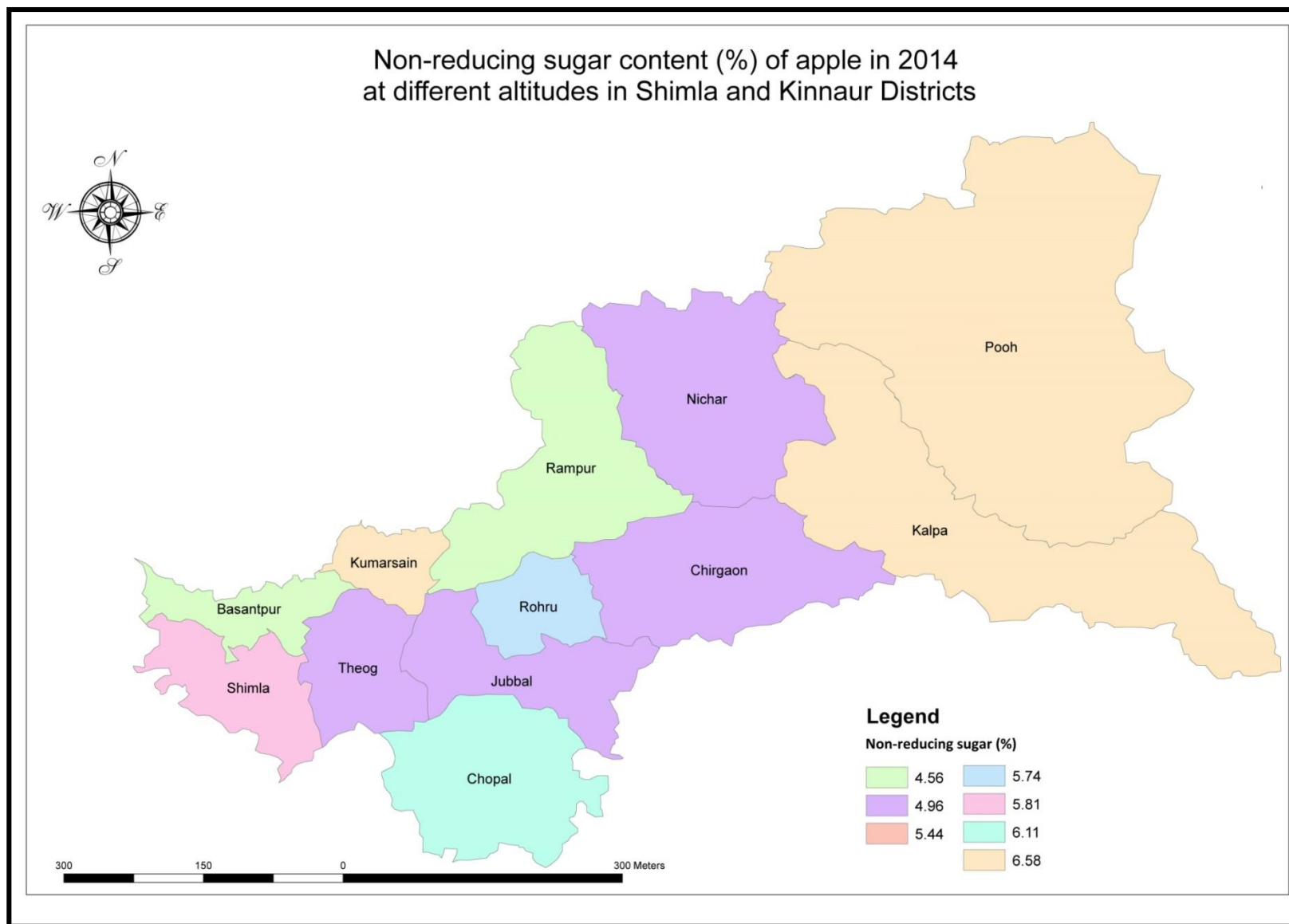


Figure 102

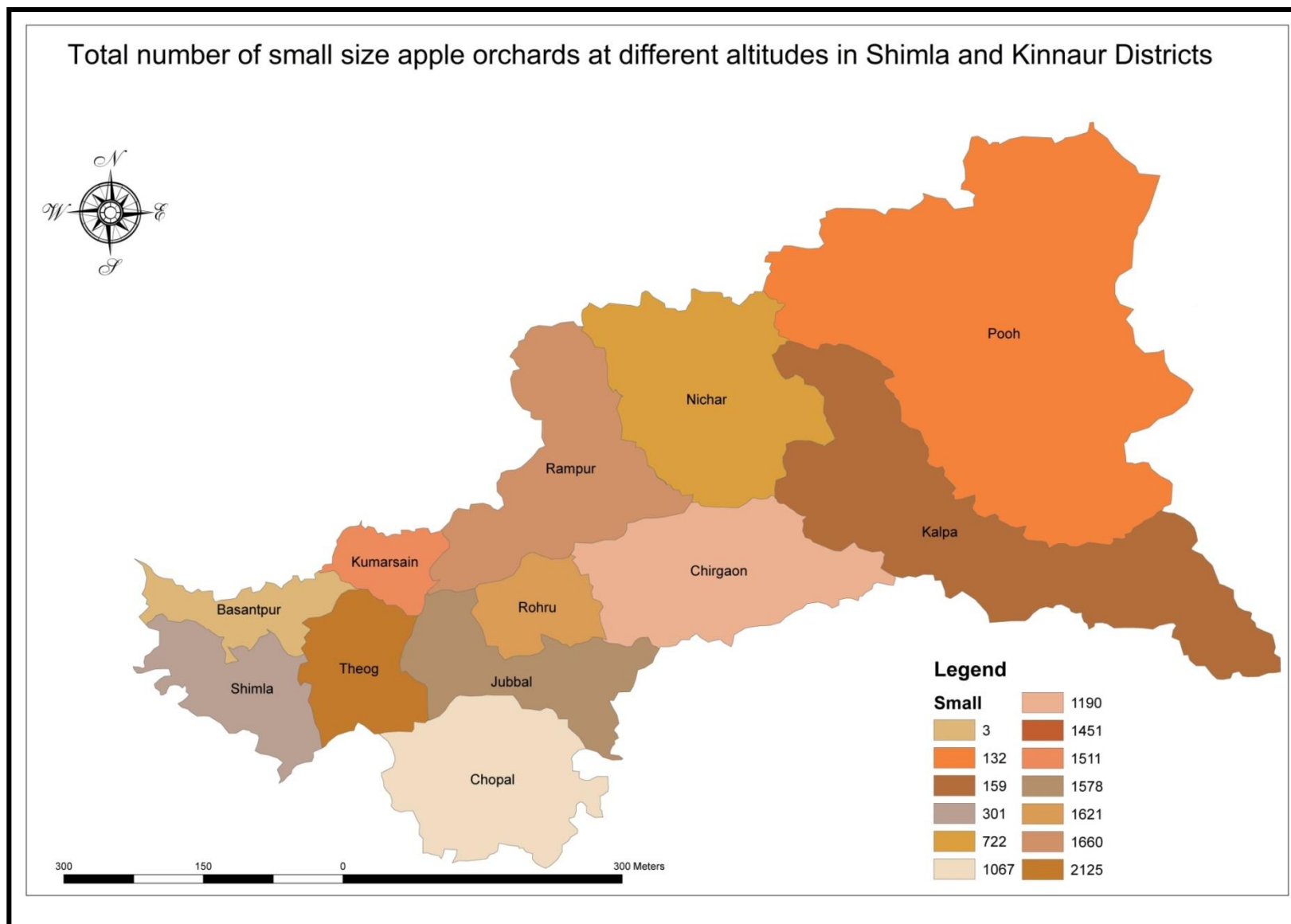


Figure 103

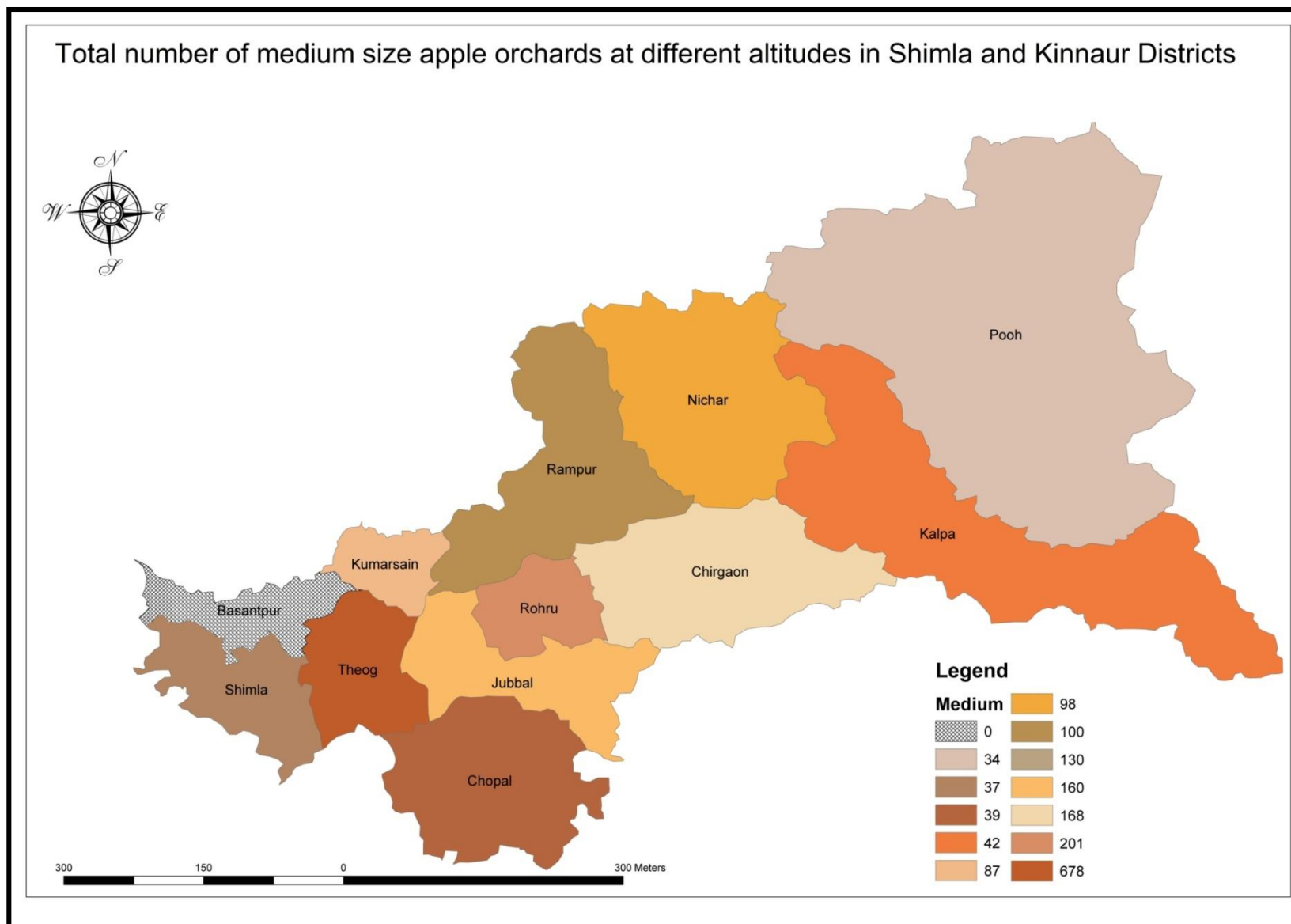


Figure 104

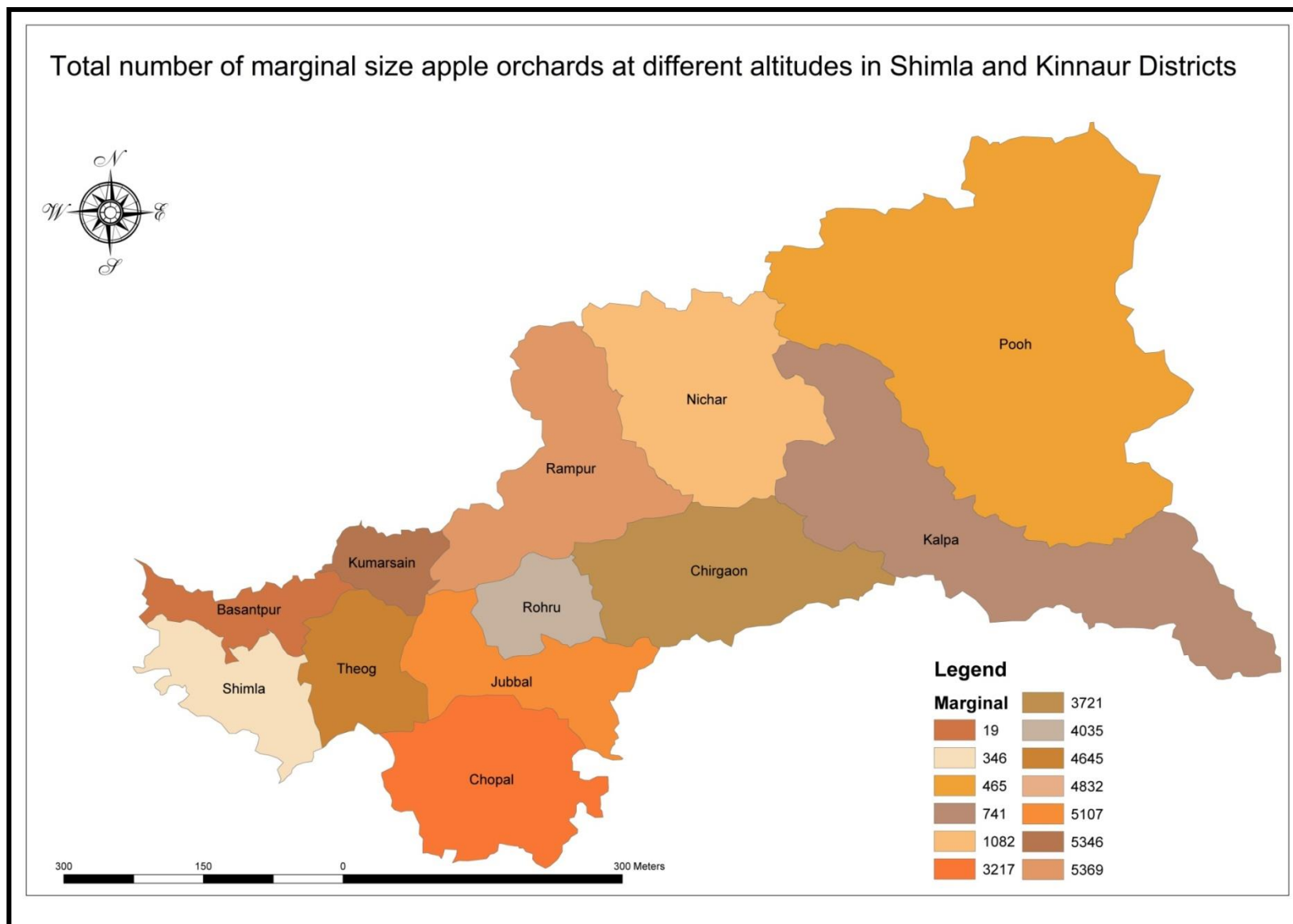


Figure 105

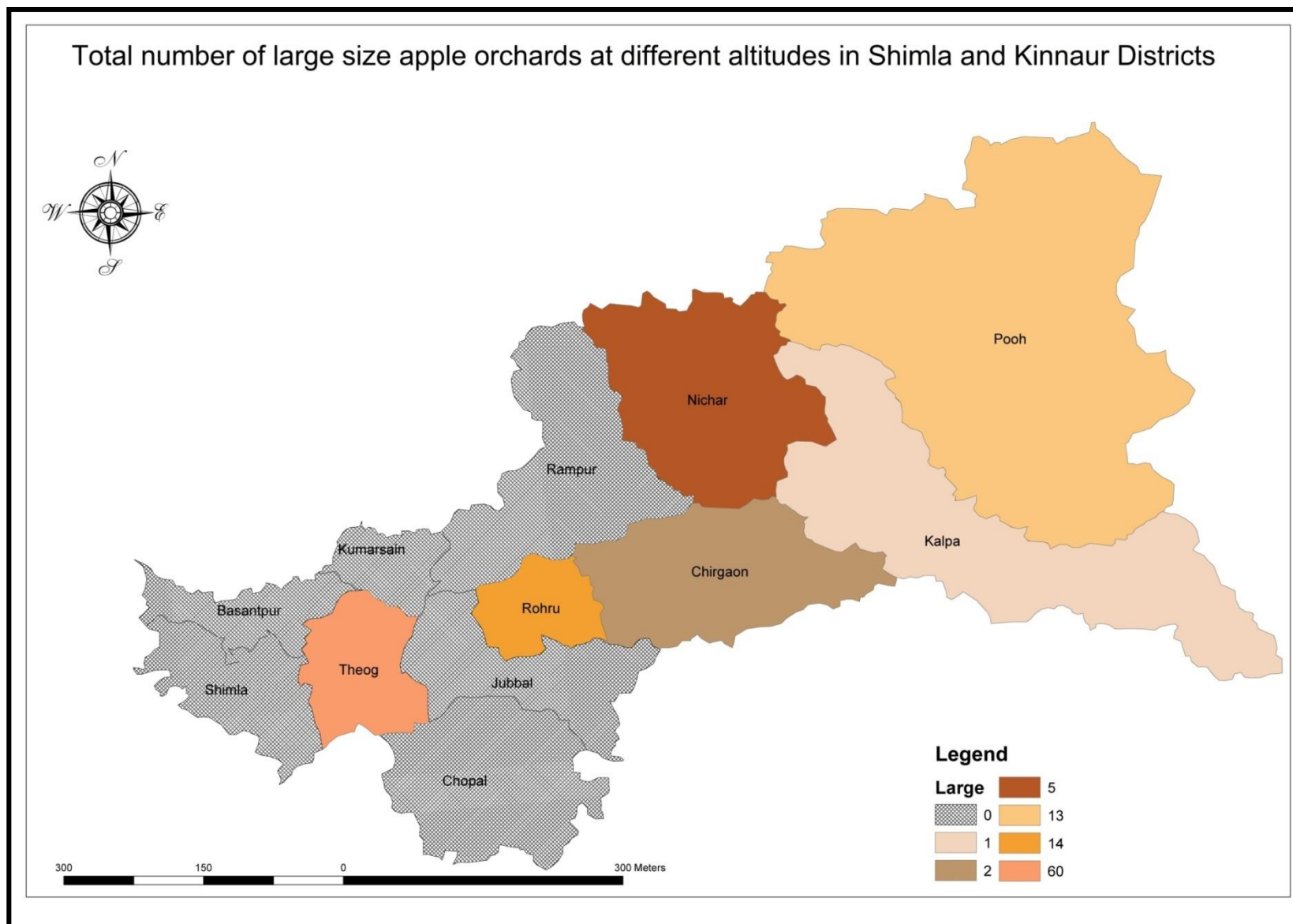


Figure 106

generate maps of apple crop quality parameters by punctual kriging with global variogram on a common grid (Manfriniet *al.*, 2012).

4.2.12 Socio-economic parameters

4.2.12.1 Total number of apple orchards of different sizes

4.2.12.1.1 Total number of small size apple orchards

Thematic map presented on small size apple orchard under Shimla and Kinnaur districts (Figure 103) depicts higher density of such orchards in majority of blocks of the former than the later. Map shows highest number of orchards in this category in Theog (2125), followed Rampur (1660), Rohru (1578), Kumarsain (1511), Jubbal (1451) and Chopal (1067) and Chirgaon (1190). Among different blocks of Kinnaur, Kalpa (1451) and Nichar (722) had higher number of orchards in small category.

4.2.12.1.2 Total number of medium size apple orchards

Thematic map in respect of medium sized apple orchards in Shimla and Kinnaur district (Figure 104) depicts their highest number in Theog (678) followed by Kotkhair (160) and Jubbal (130). Pooh block in Kinnaur had least number (34) of orchards in medium size category.

4.2.12.1.3 Total number of marginal size apple orchards

Thematic map (Figure 105) on marginal size of apple orchards in Shimla and Kinnaur district, depicts their highest number in Rampur (5369), followed by Kumarsain (5346) and Kotkhair (5107). Number of orchards in this category were however, the least (19) in Basantpur block of Shimla. Different blocks of Kinnaur also had sizable number [Kalpa (741), Nichar (1082) & Pooh (465)] of such orchards.

4.2.12.1.4 Total number of large size apple orchards

Thematic map (Figure 106) depicts that large sized apple orchards were highest in Theog (60) followed by Rohru (14) and Pooh (13). However, the

existence of large apple orchard in the remaining blocks were either negligible or missing.

4.2.12.2 Area under irrigated apple orchards of different sizes

4.2.12.2.1 Area under small size irrigated orchards

Thematic map (Figure 107) on area under small size irrigated orchards revealed that Pooh block in Kinnaur had the largest area (129 ha) of irrigated orchards of this category while, Kumarsain and Chirgaon in Shimla had very negligible area under irrigation of small apple orchard (1 ha). In Shimla district, Kotkhai, Chopal and Basantpur however, did not have small size irrigated orchard.

4.2.12.2.2 Area under medium size irrigated orchards

The maximum area of medium size irrigated orchards has been shown in Pooh (118 ha), followed by Shimla (104). Medium size apple orchards at rest of the locations either had negligible area under irrigation or all were unirrigated (Figure 108).

4.2.12.2.3 Area under marginal size irrigated orchards

Thematic map presented in Figure 109 revealed that irrigated area under marginal size orchards was higher at Kalpa (164 ha) and Pooh (155), whereas, it did not show any irrigated orchard in Shimla, Chirgaon and Basantpur blocks. In the remaining blocks, area under marginal size irrigated orchards ranged just between 2 – 24 hectares.

4.2.12.2.4 Area under large size irrigated orchards

The 88 hectares of large size irrigated orchards has been depicted in Pooh block, whereas, no area has been shown under large size irrigated orchard at rest of locations (Figure 110).

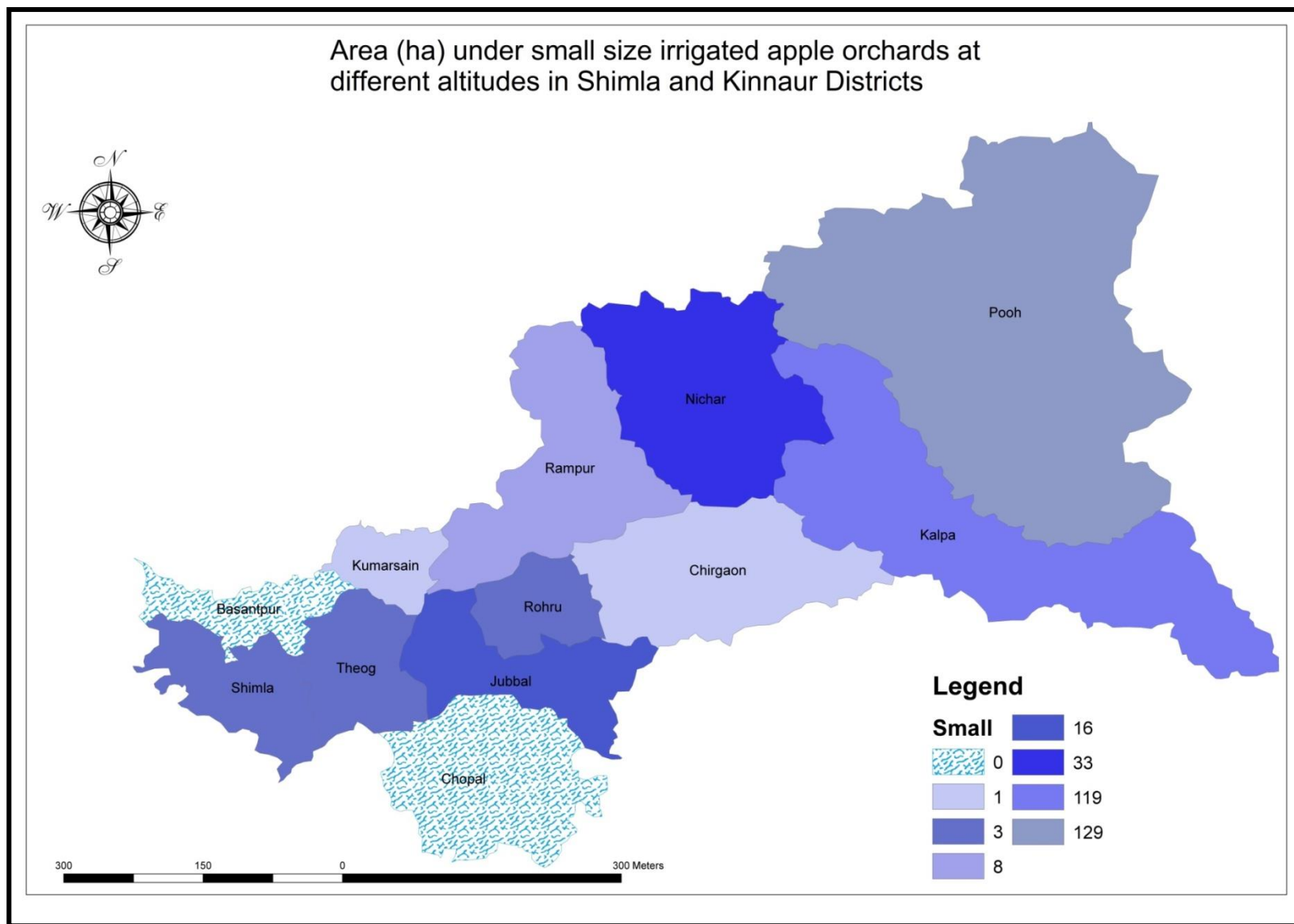


Figure 107

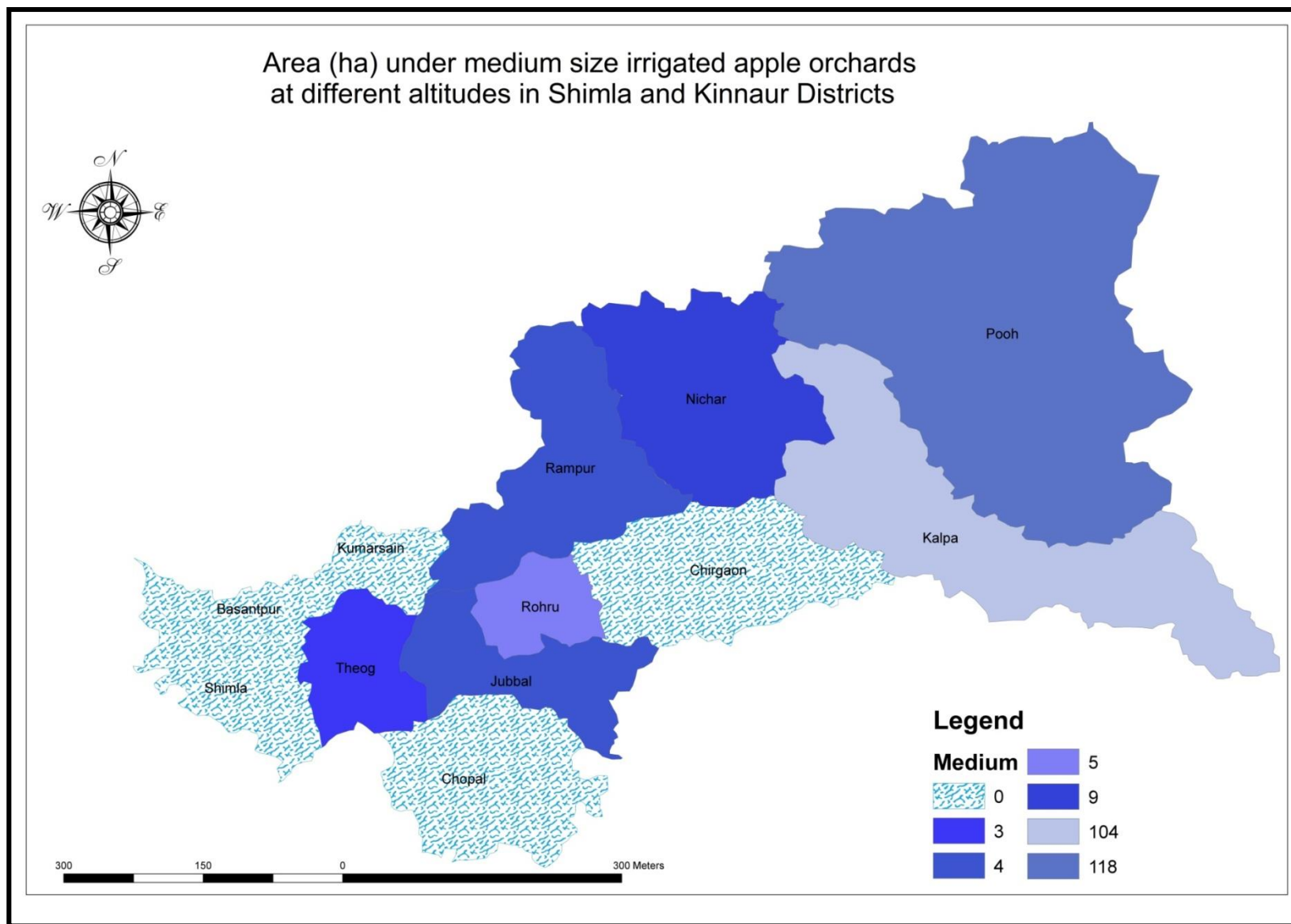


Figure 108

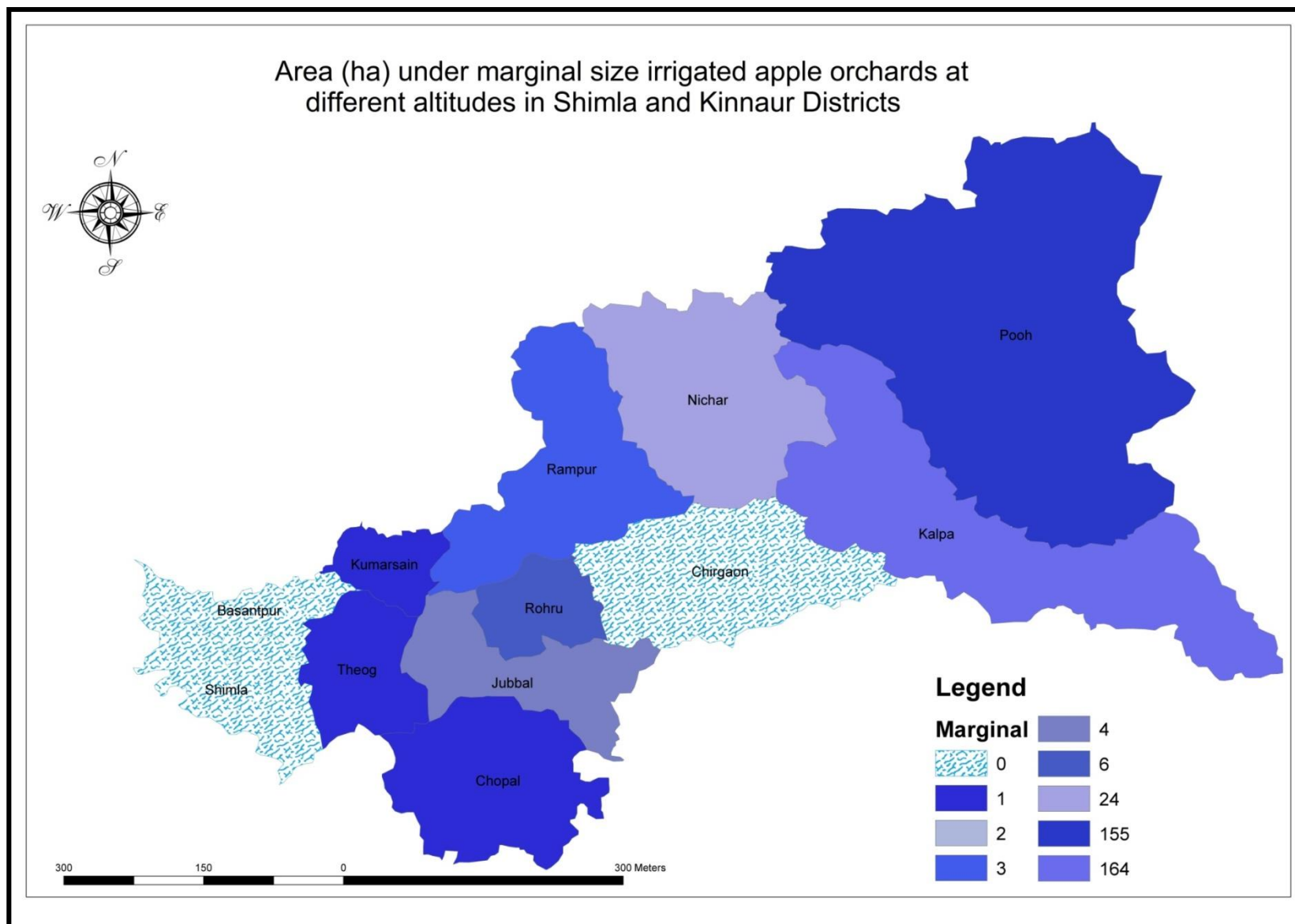


Figure 109

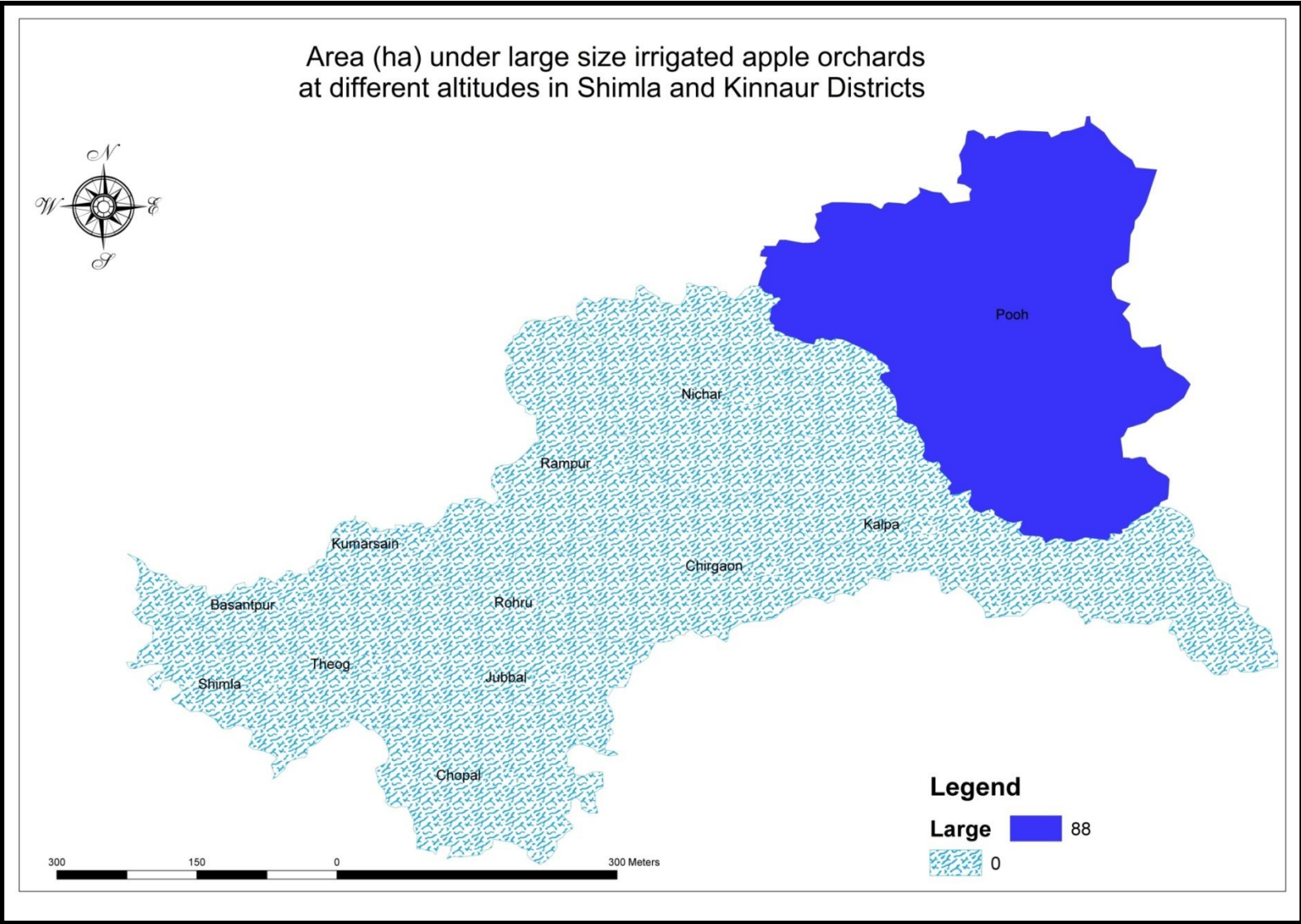


Figure 110

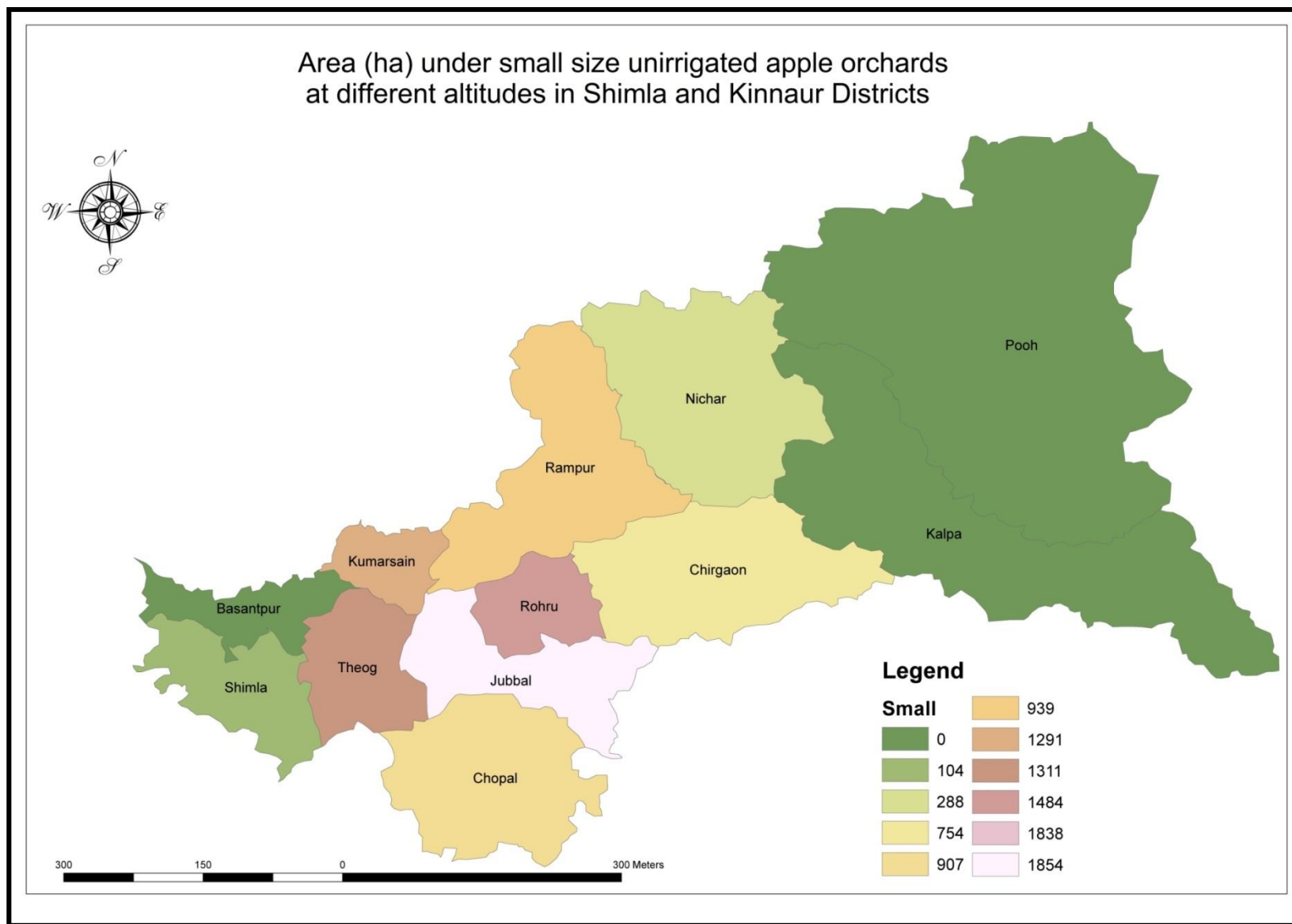


Figure 111

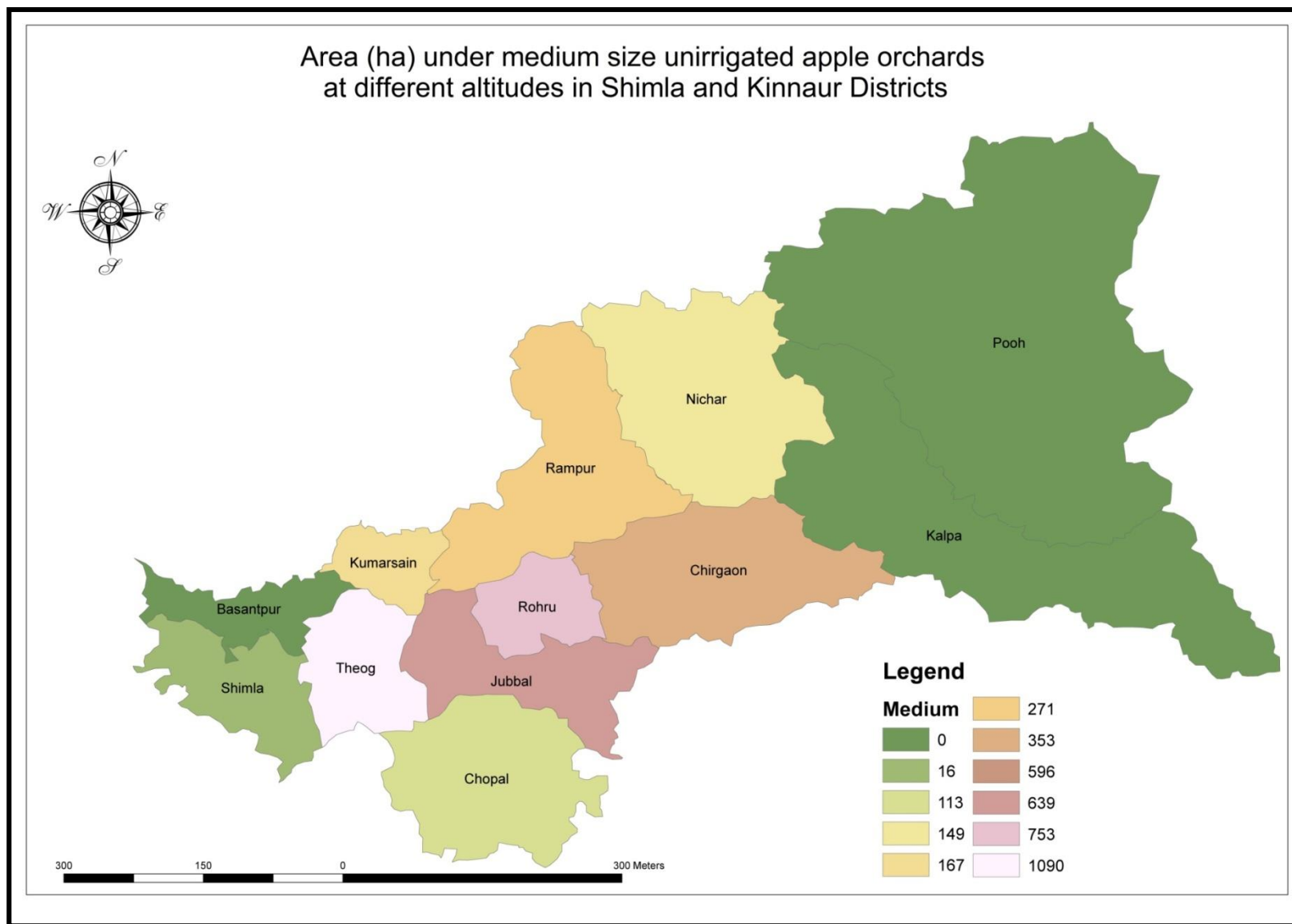


Figure 112

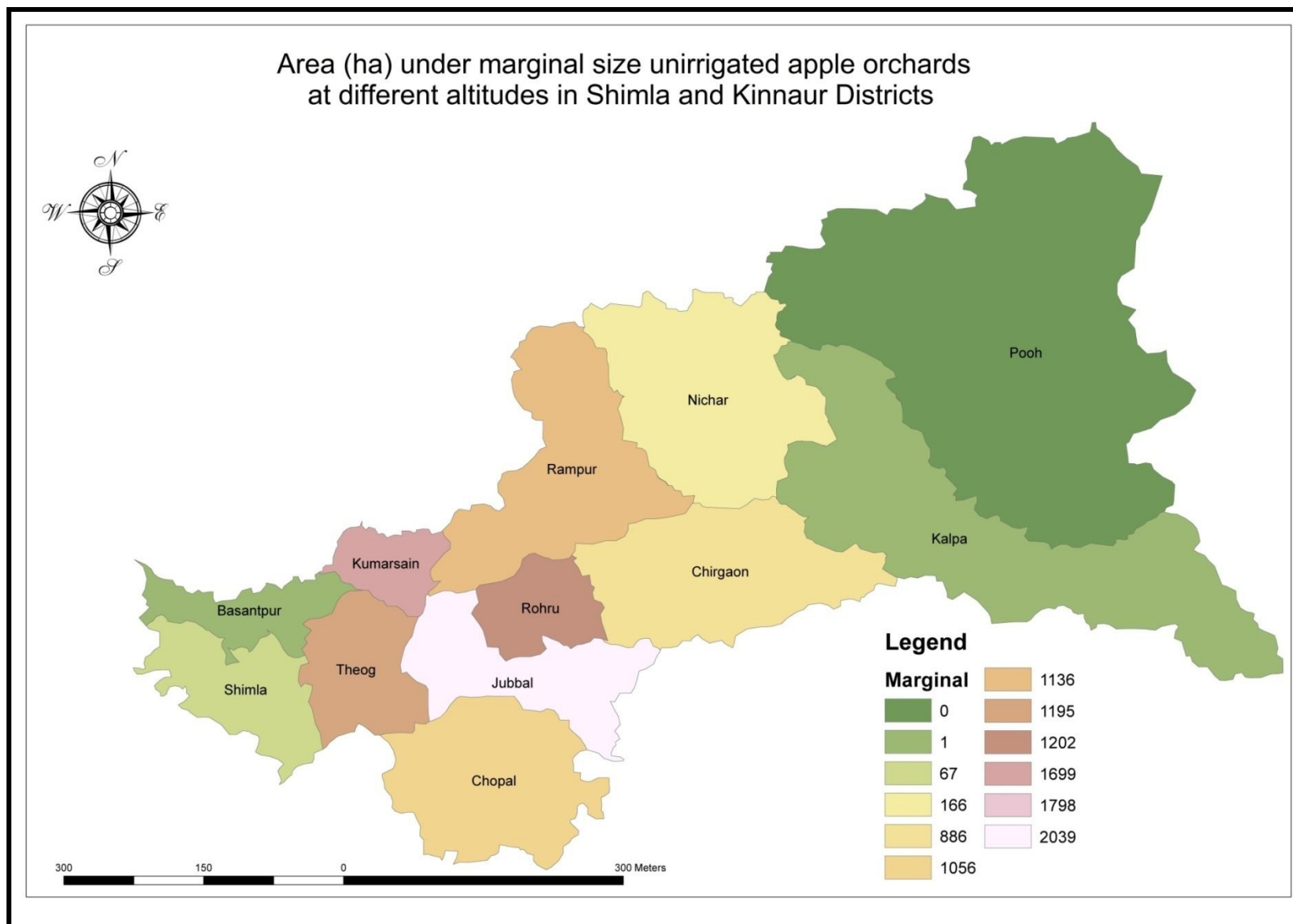


Figure 113

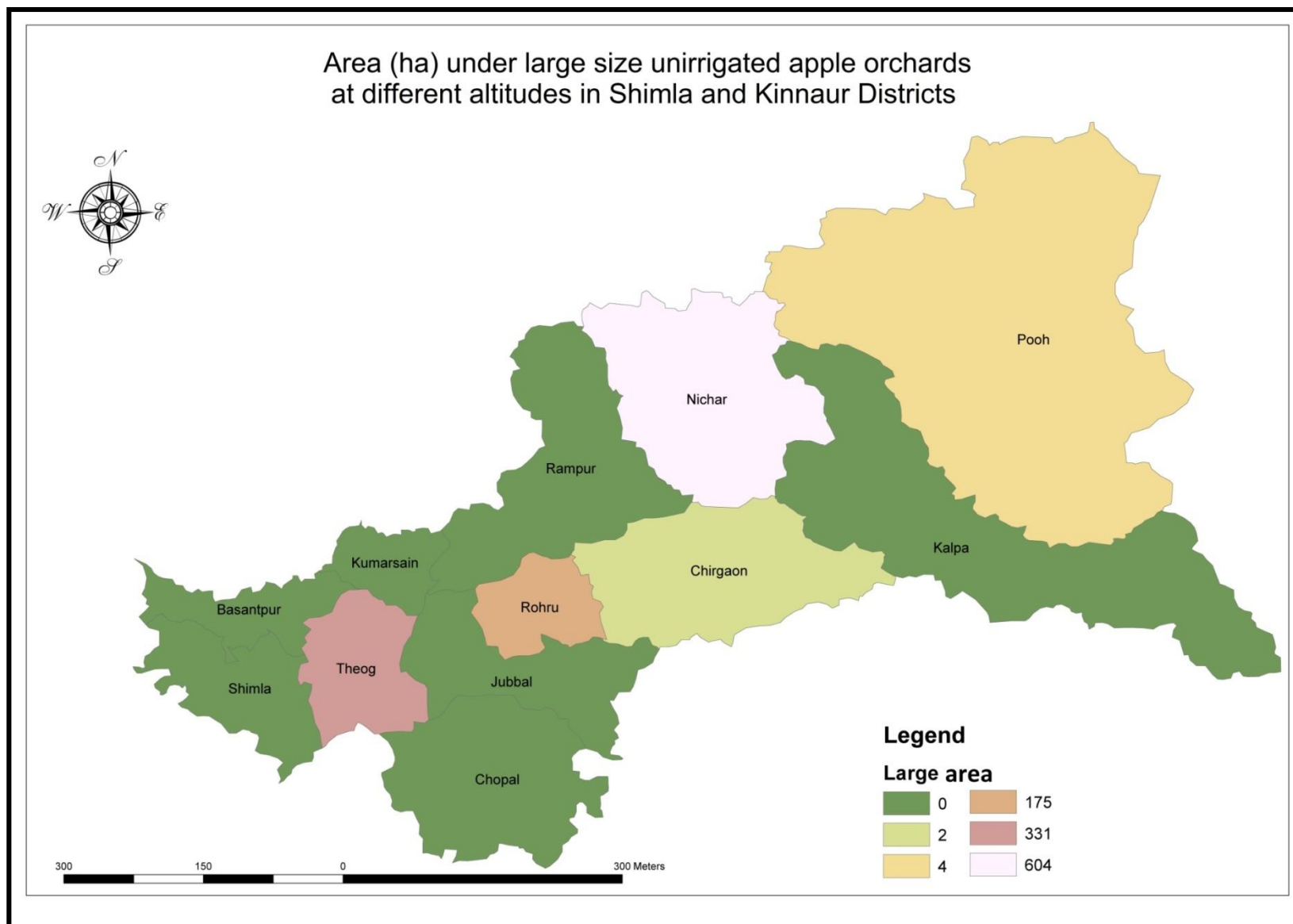


Figure 114

4.2.12.3 Area under unirrigated apple orchards of different sizes

4.2.12.3.1 Area under small size unirrigated orchard

Thematic map (Figure 111) with respect to area under small size unirrigated orchards revealed maximum area (1854 ha) in Kotkhai, followed by Jubbal (1838 ha) whereas, in this respect the minimum area was recorded in Shimla (104 ha). It is quite clear in the map that large area under small size orchards in Shimla district were largely unirrigated. On the contrary, none of the small size orchards in different blocks of Kinnaur lacked irrigation.

4.2.12.3.2 Area under medium size unirrigated orchard

Thematic map (Figure 112) presented on area under medium size unirrigated orchards revealed that maximum area i.e. 1090 ha was found in Theog followed by Rohru (753 ha) while, minimum area was recorded in Shimla (16 ha). It is clear in the map that Pooh and Basantpur blocks of Kinnaur and Shimla districts, respectively having no area under medium size unirrigated orchard.

4.2.12.3.3 Area under marginal size unirrigated orchard

Thematic map presented on area under marginal size unirrigated orchards (Figure 113) revealed that maximum area has been occupied in Kotkhai (2039 ha) followed by Jubbal (1798 ha). Pooh, Kalpa and Basantpur blocks having either negligible or no unirrigated area under orchards of this category.

4.2.12.3.4 Area under large size unirrigated orchards

The area under large size unirrigated orchards presented in Figure 114 revealed that the maximum area was found in Nichar (604 ha) followed by Pooh (331 ha) and Rohru (175 ha). Kalpa, Shimla, Kumarsain, Rampur, Kotkhai, Chopal, Jubbal and Basantpur blocks however, had no unirrigated large size orchard, and Chirgaon in Shimla had just 2 hectare area under such orchards without irrigation.

4.2.13 Hot spot analysis of altitude in Shimla and Kinnaur districts

For obtaining suitable elevation for apple cultivation, hot spot analysis for elevation GiZ score model was applied in the study area. As per the conclusion of the results for slope suitability (Figure 115), Kalpa block in Kinnaur district, Rohru, Jubbal, Shimla blocks in Shimla district were identified to the most suitable. Further, analysis of terrain for finding the most optimum elevation hot spot analysis with GiZ score was once again used for analysing parameter. According to the model results, Kalpa and Pooh are having most suitable elevation. But combining both the results of slope and elevation in model by super imposing both the results, Kalpa was identified yielding most suitable result of slope and elevation.

4.2.14 Hot spot analysis of slope in Shimla and Kinnaur Districts

For analysis of slopes, elevation found in the study area was taken as the base element and degree of slope as the inspecting element. When the data of both the parameters were provided to the model it gave the areas for GiZ score which enumerated them into hot spot zones for suitable slope in the study area and it was found that Kalpa, Rohru, Jubbal and Shimla as the Hot spot zones with optimum Giz score indicating the suitable slope of degree for suitable area for apple production (Figure 116). In the present study geo statistics (hot spot analysis) were used to optimise the appropriate slope for apple cultivation. Panagopoulos *et al.* (2007) also applied the geographical information system (GIS) and geo statistics to generate information that can be used to optimised the slope of kiwifruit production.

4.2.15 Hot Spot analysis of air temperature in Shimla and Kinnaur districts

By providing the air temperature data and elevation data for the model spherical study for suitability analysis, it was found that Kalpa situated at the altitude of 2780 meters above the mean sea level with -2.58 to -1.96 standard deviation had the most suitable air temperature conditions for apple cultivations, during the study. Rest of the blocks however, also showed the favourable zones having GiZ score with -1.65 standard deviation (Figure 117).

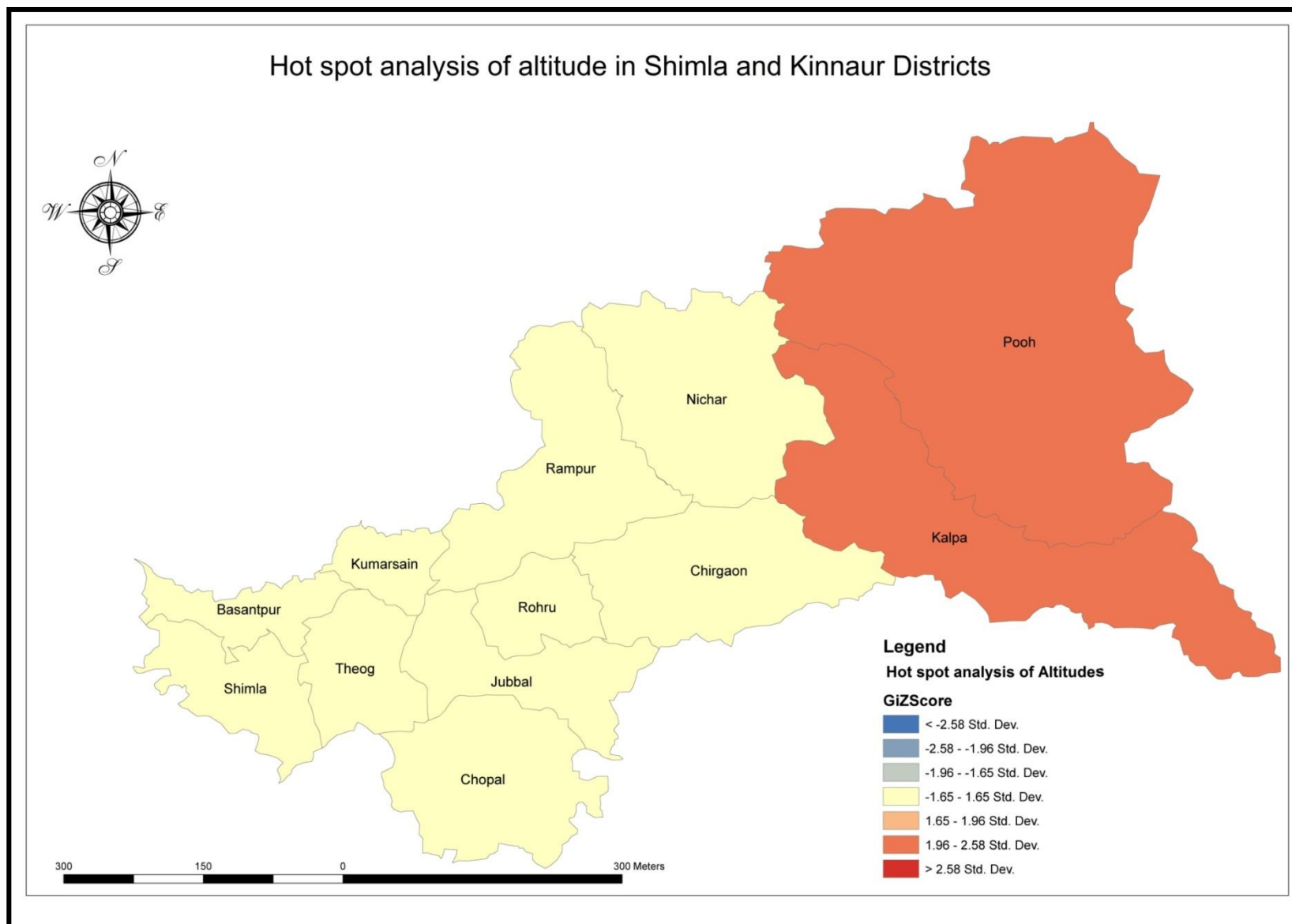


Figure 115

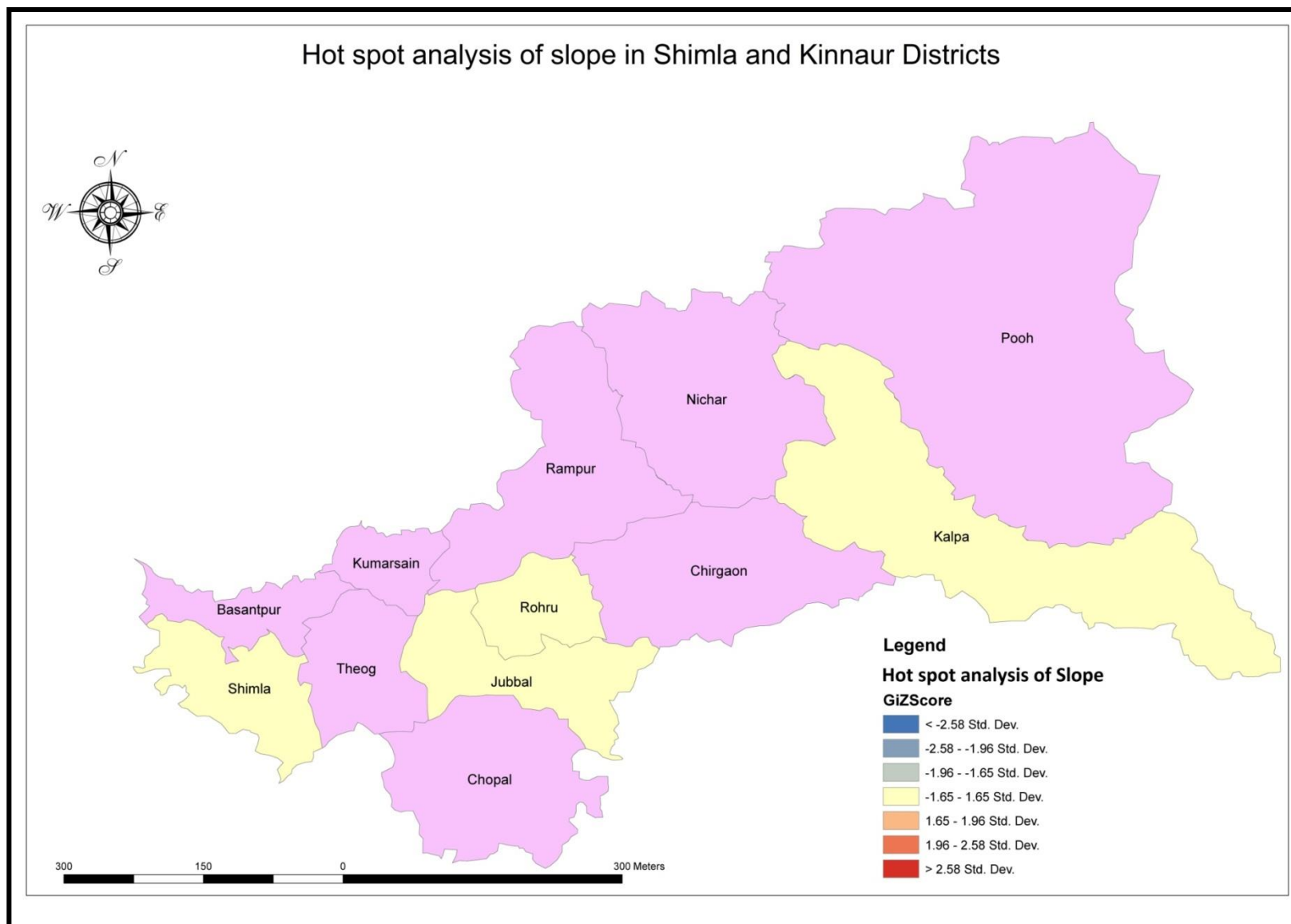


Figure 116

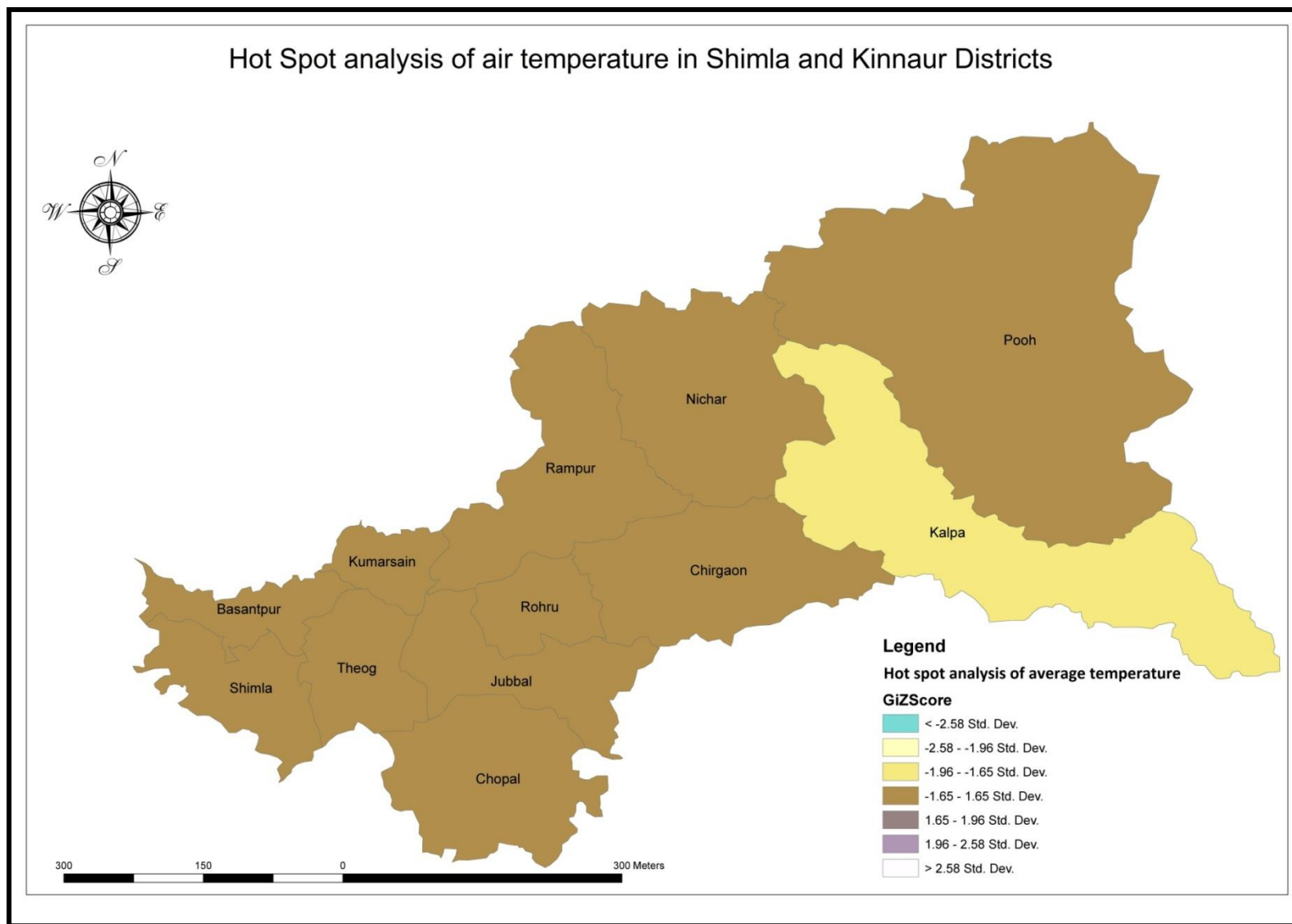


Figure 117

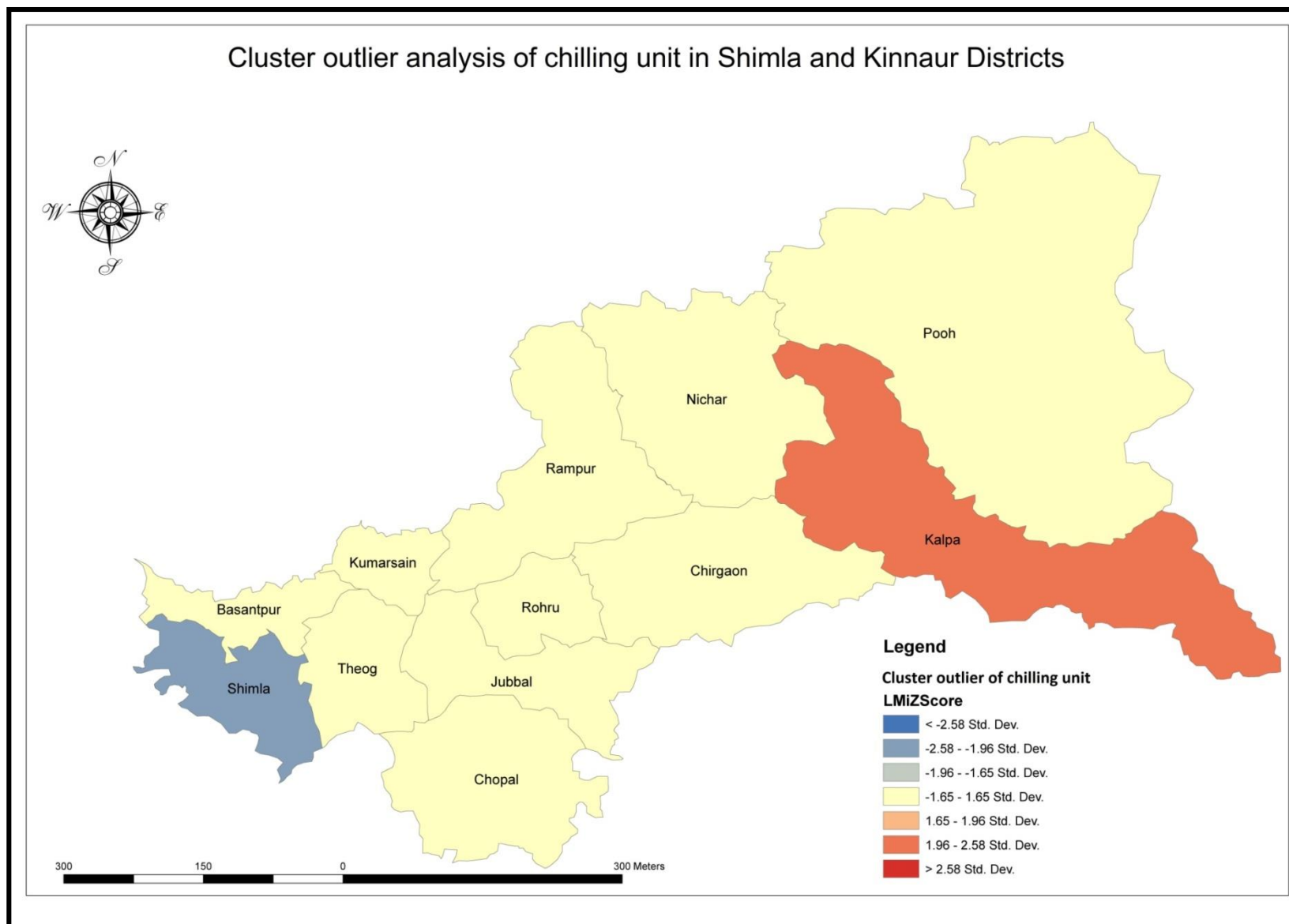


Figure 118

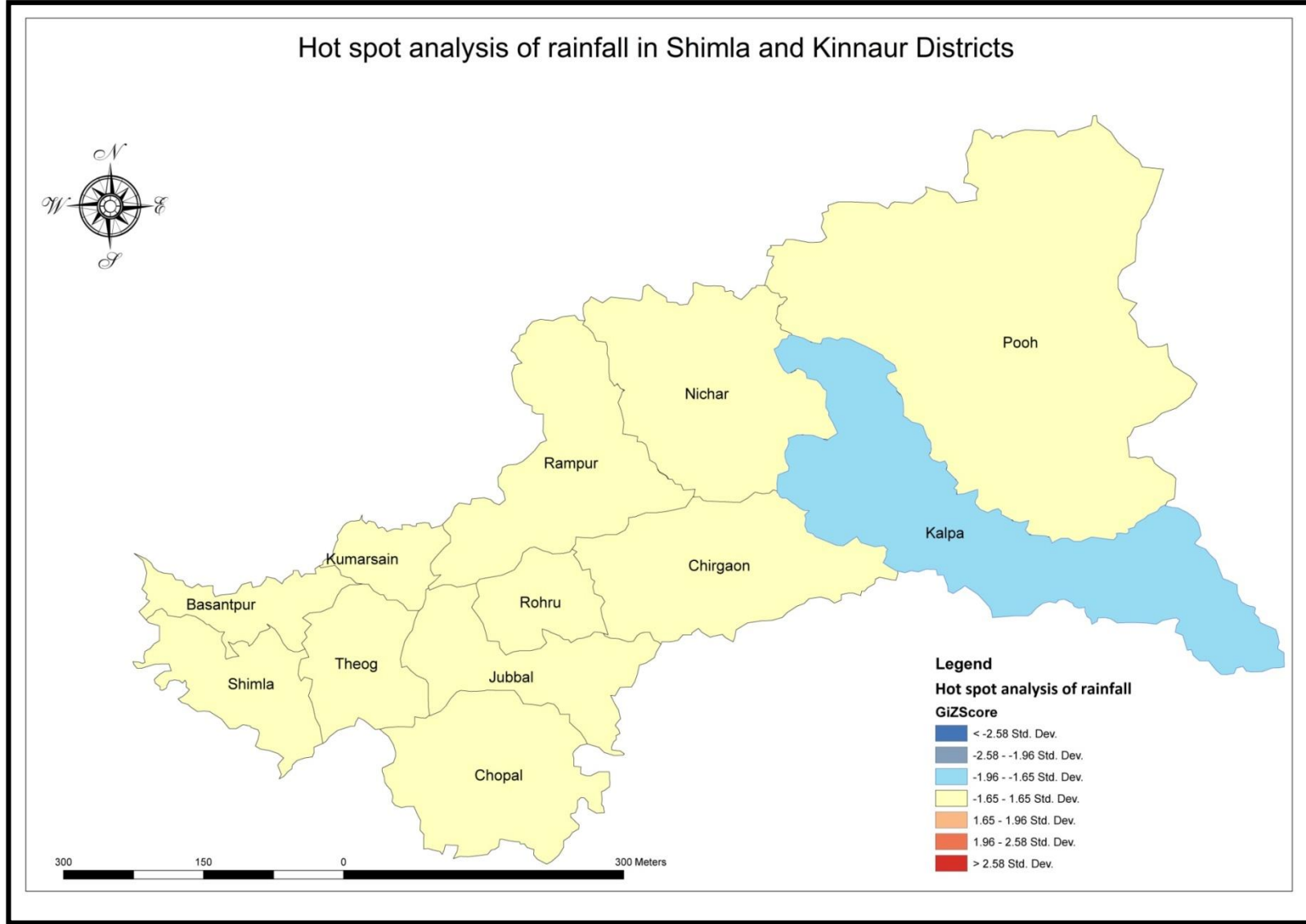


Figure 119

4.2.16 Cluster outlier analysis of chilling units in Shimla and Kinnaur Districts

In the thematic map (Figure 118) chilling units were considered as the analytical parameter and elevation (altitude) as base parameter, and after feeding the data in model calculator parameter, the model calculated the cluster of the chilling points in its optimum results. In the present study, according to cluster outlier analysis which was performed in GIS, Kalpa and Shimla blocks were found the most suitable for meeting chilling requirement of 'Starking Delicious' apple. Chilling units suitability in rest of the blocks however, has been depicted as average. Panda *et al.* (2010) also developed the GIS spatial model using various fruit crop characteristics such as chilling hours to determine the best sites for growing blueberry in Georgia, US. Wreg *et al.*, (2010) performed simulations to assess the effect of increasing minimum air temperature on the chilling hours of temperate fruit crops and used the generated model into geographical information system (GIS) to create regression equation. Accordingly these data were used to generate maps with the help of GIS of actual chilling hours.

4.2.17 Hot spot analysis of rainfall in Shimla and Kinnaur districts

By incorporation of the rainfall data of two consecutive years in model calculator, all the locations except Kalpa in Kinnaur, with -1.65 standard deviation were found more suitable for apple cultivation. Kalpa with GiZ score of -1.96 to -1.65 standard deviation was however, found to be fairly suitable, according to Hot spot analysis of rainfall (Figure 119).

4.2.18 Geographically weighted regression model for apple suitability in Shimla and Kinnaur districts

After analyzing of various parameters and suitability characteristics of apple, it has been concluded the following checklist and comparative study of the aspects mentioned below should be considered to conduct suitability analysis of land/area/zone for optimum cultivation of apple.

These parameters include climate variables namely, temperature, chilling units, rainfall, altitude, slope, aspect. Depending on the depiction of these parameters over the area of 415.25 sq/km in Shimla and Kinnaur districts, the total study area is divided into three zones, the best suitable zone, fairly suitable zone, and not suitable (Figure 120). When the available data was conceptualized in GIS platform, several models like high/low clustering (GEits-Ord General G), multi distance clustering analysis (Ripleys K Functions), clustering and outlier analysis (Anrelin local muransal), Hot spot analysis (Gets Ord G) and geographically weighted regression were used for characterization of location suitability.

The suitability map (Figure 120) of apple for Shimla and Kinnaur districts was obtained after running the geographically weighted regression model. The highly suitable areas includes Shimla, Kmarsain, Kalpa and Pooh blocks where the temperature and altitude was found to be in the exact optimum range and this area is about 211.79 sq km. In case of fairly suitable zone, there is moderate correspondence between climatic conditions and requirement of apple in these areas compared to best suitable zone. This zone includes Theog, Chopal, Jubbal, Rohru, Chirgaon and Nichar blocks with an area of 157.18 sq km. However, unsuitable zone considered as areas that are not suitable for apple because of non-compatibility between prevailing climatic requirement of apple. The zone includes Basantpur and Rampur with an area of 47.26 sq km. Wu-Ren *et al.*, (2009) established land suitability maps with the use of GIS for fruit crops, which were classified as suitable, sub suitable, possible area and unsuitable area on the basis of annual air temperature. In the present study, annual temperature was incorporated in regression model in GIS system as one of the major variable for locating the best suitable zone, fairly suitable zone, and not suitable in Shimla and Kinnaur districts. Wei-Wu *et al.* (2011) in a site specific management of citrus used the geographical information system to investigate the potential growing areas for citrus on the basis of topography and climate in the area. In the present study topography (slope, aspect and altitude) and climate factors were analysed in GIS system to locate the distinct zones of suitability. The weighted overly method used for climate parameters and topographic parameters to locate the appropriate locations for apple cultivations in this study was also carried out by Dhama *et al.* (2012) to find out

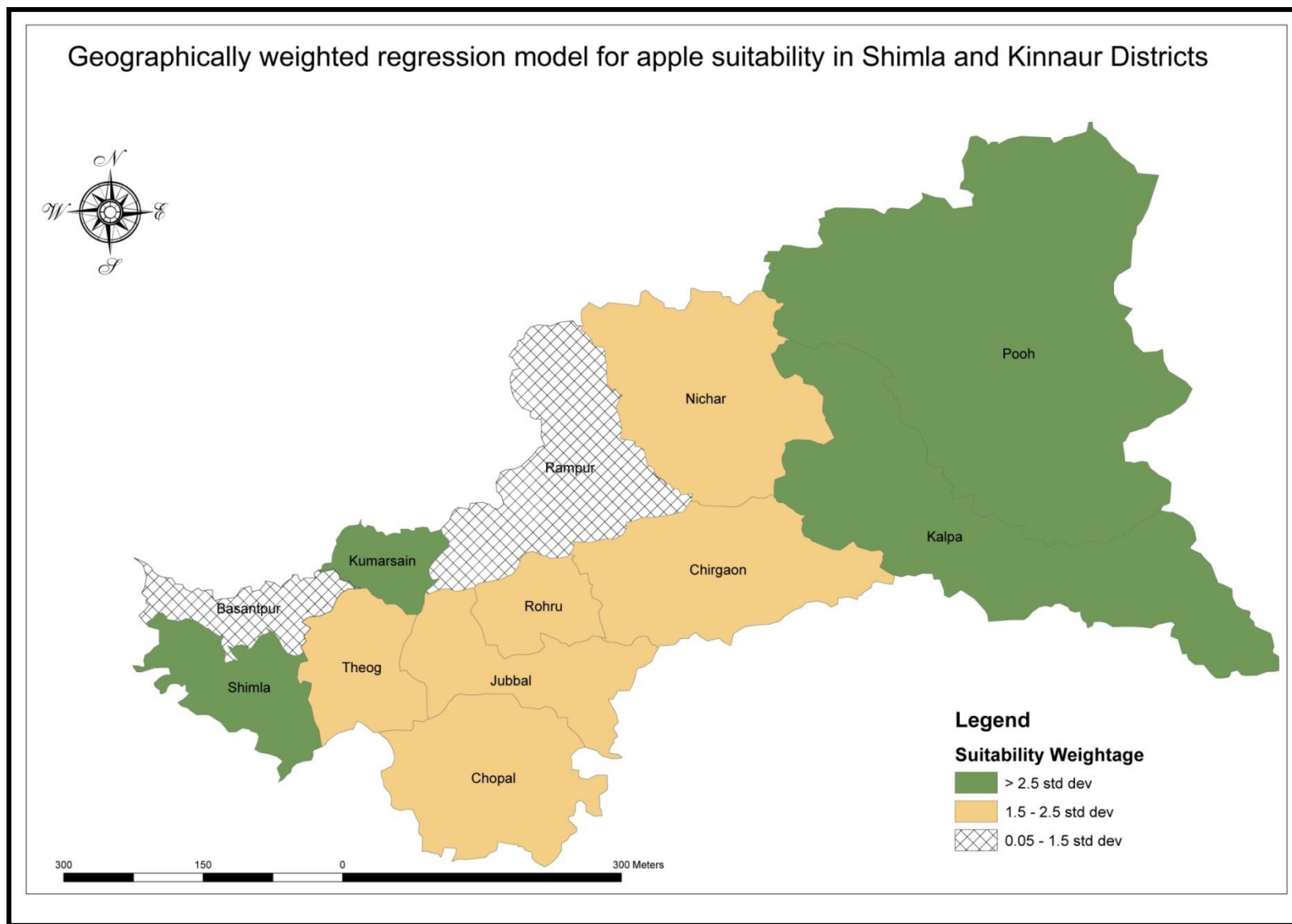


Figure 120

suitability analysis for apple and pear in Uttarakhand by using climatic parameters of Uttarakhand *viz.* precipitation and temperature, topographic parameters to generate the suitability maps. Mitra *et al.*, (1991) identified the best suitable apple growing area on the basis of high correspondence between climatic conditions of the area and the climatic requirements of apple, i.e. temperature, altitude, aspect, slope, rainfall and chilling hours.

***Summary and
Conclusion***



Chapter-5

SUMMARY AND CONCLUSION

The present investigation entitled “Geographical Information System based assessment of location suitability for apple (*Malus × domestica* Borkh) production” was carried out in the Department of Fruit Science, Dr Y S Parmar University of Horticulture and Forestry, Nauni, Solan, Himachal Pradesh, during the years 2012-14. The salient findings of the investigation are summarized as follows:

- 5.1** During the course of study, the maximum temperature decreased linearly with the corresponding increase in altitude. It was recorded highest at the lower altitude of Kotkhai (24.26°C), which was however, statistically at par with the higher altitude of Rohru and its average value was observed significantly lowest (14.34°C) at the higher altitude of Kinnaur (Kalpa).
- 5.2** The minimum average temperature was recorded significantly lowest (3.73°C) at higher altitudes of Kinnaur (Kalpa). It was recorded highest (14.06°C) at higher altitude of Kotkhai, which was however, statistically comparable to lower altitude of Kotkhai and both the locations in Rohru.
- 5.3** During 2012-13, the onset of chilling unit initiation was recorded earliest (Oct. 5) at higher altitude of Kotkhai, followed by Kalpa (Oct. 7). However, the chilling unit initiation was registered furthest at Mashobra (Oct. 22). In 2013-14, the chilling unit initiation recorded earliest (Oct.9) at lower altitude of Rohru and latest (Oct. 27) at Mashobra.
- 5.4** During 2012-13, the completion of rest was recorded earliest (Feb. 10, 2013) at higher altitude of Kotkhai, followed by Mashobra (Feb. 14) however, it occurred in the last (March 31) at Kalpa. In 2013-14, the date of rest completion varied from February 12 to April 6, 2014 at different locations.

The earliest date pertained jointly to higher altitudes of Rohru and Kotkhai and the latest date to Kalpa.

- 5.5** During 2012-13, the time of completion of chilling unit accumulation was noticed earliest on 5th March at lower altitude of Kotkhai, which extended up to 24th April, 2013 at Reckong Peo. During 2013-14, the chilling period ended earliest at lower altitude of Kotkhai on 7th March, 2014 and extended up to 29th April at Kalpa.
- 5.6** During 2012-13, the duration for the completion of rest period was recorded longest (175 days) at Kalpa and shortest (115 days) at Mashobra. In the year 2013-14, apple trees had taken the maximum time for rest completion at Kalpa (178 days), whereas, those at Mashobra took minimum time (114 days) for rest completion.
- 5.7** The maximum chilling duration (195 days) was noted jointly at Kalpa and Reckong Peo and the minimum chilling duration (140 days) was experienced at lower altitude of Kotkhai, during 2012-13. The chilling period extended from 140 days at lower altitude of Kotkhai to 201 days at Kalpa, in year 2013-14.
- 5.8** In the year 2012-13, total effective chilling unit accumulation (ECU) during the chilling period (chilling unit initiation to the end of ECU accumulation) varied from 1526 CU at higher altitude of Kinnaur (Kalpa) to 1898 CU at lower altitude of Kotkhai, as per the Richardson's "Utah Chill Model". According to 'North Carolina model', the maximum chilling units were noted at higher altitude of Kotkhai (2498 CU) and the minimum (1466 CU) at Kalpa (higher altitude of Kinnaur). In the year 2013-14, total effective chilling unit (ECU) accumulation during the chilling period varied from 1415 CU at Kalpa to 1942 CU at lower altitude of Kotkhai, as per the Richardson's "Utah Model". According to 'North Carolina model', the maximum chilling unit was noted at higher altitude of Kotkhai (2508 CU) and the minimum CU (1367) at Kalpa.

5.9 According to Utah Model, ECU accumulations during peak winters of the year 2012-13 were significantly highest at Mashobra (1306 CU) and lowest (419 CU) at Kalpa (higher altitude of Kinnaur). As per 'North Carolina model', during peak winter, significantly higher chilling unit were noted at Mashobra (1358 CU) than all other locations. According to Utah Model, ECU accumulation during peak winters of 2013-14 was significantly higher at Mashobra (1209 CU) than all other locations, and it was found to be least (337 CU) at Kalpa. As per 'North Carolina model', the maximum ECU during peak period were noted at Mashobra (1277 CU), whereas, the minimum chilling units (315 CU) were recorded at Kalpa.

5.10 During 2012-13, GDH°C accumulations during the chilling unit initiation to rest completion was found significantly higher at lower altitude of Rohru (16584 GDH°C) in comparison to all other locations whereas, the least GDH accumulation (14896 GDH°C) was observed at Reckong Peo (lower altitude of Kinnaur). In year 2013-14, the GDH accumulation between the chilling unit initiation to rest completion was computed significantly higher at lower altitude of Rohru (16032 GDH°C) in comparison to all other locations, while it was observed to be least (14982 GDH°C) at Reckong Peo.

5.11 During the peak winter of 2012-13, the GDH°C was recorded highest (5894) at lower altitude of Kotkhai and the lowest (2479) at Kalpa (higher altitude of Kinnaur). During peak winter of 2013-14, higher GDH accumulation was recorded at lower and higher altitude of Kotkhai (5988 GDH°C and 5951 GDH°C, respectively), however, this value was noted significantly least (2591 GDH°C) at Kalpa.

5.12 During the period of the rest completion to full bloom stage, the maximum GHD accumulation (8219 GDH°C) corresponded to lower altitude of Kotkhai while, the minimum accumulations (4951 GDH°C) pertained to Kalpa (higher altitude of Kinnaur), in year 2012-13. Whereas, during 2013-14, the maximum GDH between the period of rest completion to full bloom stage was recorded in respect of lower altitude of Kotkhai (8362 GDH°C) and this value was computed minimum (4893 GDH°C) for Kalpa location.

- 5.13** The earliest full bloom time was noted at lower altitude of Kotkhai (March 18 & 07 in 2013 & 2014, respectively) whereas, the time of full bloom was noticed furthest at Kalpa (May 4 & 6 in 2013 & 2014, respectively) during the course of study.
- 5.14** Rainfall was recorded significantly lower at both the locations of district Kinnaur (65.64 & 71.02cm at Reckong Peo & Kalpa, respectively) in comparison to all the locations of district Shimla (96.11-125.00 cm). In Shimla district, the maximum rainfall was recorded at Mashobra whereas, lower altitude of Rohru recorded lesser rainfall as compare to other locations of study area in the district.
- 5.15** During the year 2013, soil moisture level was observed lowest (18.80%) between green tip to pink bud stage and highest (37.95%) at pre harvest stage. During the year 2014, the average soil moisture content gradually increased from green tip stage (19.65%) to pre harvest stage (37.28%). Among locations, soil moisture level was observed highest at Kalpa (36.67 & 37.75% in 2013 & 2014, respectively) and the lowest at lower altitude of Kotkhai (16.57 & 16.33 % in 2013 & 2014, respectively).
- 5.16** During the year 2013, mean soil temperature increased gradually from green tip stage (12.79 & 12.84°C in 2013 & 2014, respectively) to pre harvest stage (28.24 & 27.23°C in 2013 & 2014, respectively). Among locations, mean soil temperature during the growing period was observed highest at Kalpa in the year 2013 (22.14°C) and at Reckong Peo (21.54°C) in the year 2014. However, minimum soil temperature (17.65°C) was observed at Mashobra in both years.
- 5.17** The maximum tree height (6.63 m) was observed at higher altitude of Kotkhai, which was however, found to be statistically at par with Mashobra and higher altitude of Rohru. Apple trees at Kalpa attained the minimum height (5.00 m), which in this respect were however, at par with those at Reckong Peo. The tree spread was significantly higher at higher altitude of Kotkhai (4.98 m) than all other locations except, higher altitude of Rohru

(4.70 m) and Mashobra (4.59 m). Tree spread was however, found to be least (4.11 m) at both the locations of Kinnaur, which was at par with Mashobra and higher altitudes of Kotkhai and Rohru.

5.18 During 2012-13, the earliest bud swell time was noticed at lower altitude of Kotkhai, (26 Feb.) and it was observed in the last at Kalpa (5th April). In year 2013-14, the bud swell was again observed earliest (1st March) at lower altitude of Kotkhai, however, it got much delayed at Kalpa (7th April).

5.19 During year 2012-13, green tip in apple appeared earliest at lower altitude of Kotkhai on (5th March) however, this stage got much delayed at Kalpa (13th March). During 2013-14, green tip stage was noticed earliest (10th March) at lower altitude of Kotkhai and in the last (17th April) at Kalpa.

5.20 During the year 2012-13, appearance of pink buds were first noticed at lower altitude of Kotkhai (9th march), however, this stage occurred furthest at Kalpa (21st April). During the year 2013-14, pink buds first became visible at lower altitude of Kotkhai (14th March), however, this stage got much delayed at Kalpa (24th April).

5.21 During 2013-14, date of anthesis was first recorded at lower altitude of Kotkhai (14th March), however, it got delayed till 10th April at Reckong Peo and 30th April at Kalpa. During 2013-14, time of anthesis was recorded earliest at lower altitude of Kotkhai (17th March) and furthest at Kalpa (30th April).

5.22 During 2012-13, apple trees at lower altitude of Kotkhai were first to come into full bloom (18th March), whereas those at Kalpa experienced this stage in the last (4th May). During 2013-14, full bloom in apple occurred first at lower altitude of Kotkhai (21st March) however, it got much delayed at Kalpa (6th May).

5.23 During 2012-13, date of petal fall was recorded earliest (26th March) at lower altitude of Kotkhai and latest (13th May) at Kalpa. During 2013-14, this stage was again observed earliest at lower altitude of Kotkhai (28th March) and furthest (13th May) at Kalpa.

- 5.24** The duration of flowering was observed minimum (16 days) at lower altitude of Kotkhai and maximum (25 days) at Kalpa, during 2012-13. In 2013-14, the minimum duration of flowering was observed at lower altitude of Kotkhai (16 days) whereas, it was registered maximum (23 days) at Kalpa.
- 5.25** The flowering intensity was recorded significantly higher at Kalpa (27.59 %) than all other locations except, Reckong Peo. The lowest flowering intensity (14.20 %) was observed at lower altitude of Kotkhai.
- 5.26** The maximum fruit set (75.19 %) was recorded at higher altitude of Kinnaur (Kalpa), however it was observed minimum (51.63 %) at lower altitude of Kotkhai.
- 5.27** The higher altitude of Kinnaur (Kalpa) registered the maximum average fruit yield (119.60 kg tree⁻¹), which was however, statistically at par with Mashobra and Reckong Peo. The minimum fruit yield was recorded at lower altitude of Kotkhai (103.37 kg tree⁻¹).
- 5.28** The productivity was recorded significantly higher at Kalpa (33.22 tones ha⁻¹) in comparison to all other locations except, Reckong Peo (32.00 tones ha⁻¹) whereas, the minimum productivity was recorded at lower altitude of Kotkhai (18.38 tones ha⁻¹).
- 5.29** The fruit length was observed significantly greatest (75.52 mm) at higher altitude of Kinnaur (Kalpa), however, it was found to be least (61.26 mm) at lower altitude at Kotkhai. The average fruit length at Mashobra and higher altitude of Rohru were in the intermediate range.
- 5.30** Significantly higher fruit diameter was recorded at Kalpa (76.70 mm) in comparison to all other locations except, Reckong Peo (73.98 mm). Whereas, average fruit diameter was found to be minimum (66.92 mm) at lower altitude of Kotkhai.
- 5.31** The fruit length/diameter ratio was observed significantly highest at Kalpa (0.98 %) and lowest at lower altitude of Kotkhai (0.92 %).

- 5.32** The fruit weight was significantly greatest at Kalpa (221.65 g), however, it was recorded significantly least at lower altitude of Kotkhai (136.89 g).
- 5.33** Fruits with more red colour (RED GROUP CARD 45 A) were observed at higher altitude of Kinnaur (Kalpa) during both the years. However, the fruits of lower altitude of Kotkhai developed lesser color on their surface (RED GROUP CARD 43 C & RED GROUP CARD 47 D during 2013 & 2014, respectively).
- 5.34** The highest TSS (15.28 °Brix) was recorded in fruits from higher altitude of Kinnaur (Kalpa), which was however, statistically at par with Mashobra and Reckong Peo. Fruits from lower altitude of Kotkhai had lowest TSS content (13.36 °Brix).
- 5.35** Titratable acidity in fruits was recorded significantly higher in the fruits of lower altitude of Kotkhai (0.53 %) in comparison to those from all other locations and lowest fruit acid content (0.35 %) was noted at higher altitude of Kinnaur (Kalpa).
- 5.36** The maximum fruit TSS/ acid ratio (43.91 %) was recorded at Kalpa, which was however, comparable to Reckong Peo. Fruits from lower altitude of Kotkhai were most inferior (25.06 %) in this quality attribute.
- 5.37** Fruit total sugar content was recorded significantly higher at Kalpa (14.01 %) than all other locations except, Reckong Peo, however, it was observed to be significantly lower at both the locations of Kotkhai (8.78 & 9.76% at lower & higher altitude, respectively) in comparison to all other locations.
- 5.38** The reducing sugar in fruits was recorded significantly higher (7.56%) at Kalpa than all other locations except, Reckong Peo. Fruits from lower altitude of Kotkhai registered least value of this attributes (4.49 %), which in this respect were however, comparable with those at higher altitude of Kotkhai (5.04 %).
- 5.39** Fruit non-reducing sugar (6.43%) level was significantly greater at higher altitude of Kinnaur (Kalpa) than all other locations except, Reckong Peo. Significantly lower non-reducing sugar was found in fruits from lower altitude

of Kotkhai (4.26 %) than all other locations except, higher altitude of Kotkhai (4.73 %).

5.40 During 2012-13, apple production had significantly positive correlation with rest period and also with the chilling period. During the chilling period, apple production however, had significantly negative correlation with chilling units ($r=-0.88$), whether computed according to Utah chill model or North Carolina chilling units model ($r=-0.78$). During peak winter, apple production registered negative but non-significant correlation with Utah chill model chilling units ($r=-0.74$) and also with North Carolina chilling units model ($r=-0.70$). During 2013-14, the correlation between apple production and time for rest period was found to be positive but non-significant ($r=0.74$). Whereas, significant and positive correlation ($r=0.91$) was observed between apple production and time requirement for chilling period. The production of apple had significantly negative correlation ($r=-0.95$) with Utah Model chilling units while, negative but non-significant correlation ($r=-0.72$) was found in between apple production and North Carolina chilling unit model, during the chilling period. During peak winter, significant negative correlation ($r=-0.76$) was found between apple production and Utah Model chilling units whereas, according to North Carolina model apple production indicated negative but non-significant correlation ($r=-0.70$) with chilling units.

5.41 The correlation between apple production and $\text{GDH}^{\circ}\text{C}$ accumulation during chilling initiation to rest completion during 2012-13 was found to be negative but non-significant ($r=-0.60$). However, the negative and significant correlation ($r=-0.97$) was observed between apple production and $\text{GDH}^{\circ}\text{C}$ accumulation during peak winter. Whereas, significantly negative correlation ($r=-0.86$) was found between apple production and $\text{GDH}^{\circ}\text{C}$ accumulation throughout the period of rest completion to full bloom. In the year 2013-14, the negative and non-significant association ($r=-0.43$) was observed between apple production and $\text{GDH}^{\circ}\text{C}$ accumulation during chilling initiation to rest completion, indicating that there was no effect of $\text{GDH}^{\circ}\text{C}$ accumulation during the period of chilling initiation to rest completion on the apple production. During peak

winter, negative and significant correlation ($r = -0.96$) was observed between apple production and GDH°C accumulation. Significant negative correlation ($r = -0.85$) was found between apple production and GDH°C accumulation throughout the period of rest completion to full bloom.

- 5.42** Correlations between altitudes and different quality parameters implied that with the increase in altitude, the yield, fruit length, length/diameter ratio, fruit weight, TSS, total sugar, reducing sugar and non-reducing sugar contents and TSS/acid ratio increased, and the acidity decreased in the apple fruits. The fruit diameter was however, found to have positive but non-significant association with different altitudes.
- 5.43** Correlations of temperature with flowering intensity, fruit set, fruit yield and productivity of apple implied that the increase the maximum and minimum temperature decreased the flowering intensity, fruit set, fruit yield and productivity.
- 5.44** The thematic layer for UV index indicates that there was a direct relationship of UV index with the altitudes in Shimla and Kinnaur districts during both the years *i.e.* UV index increased with the increase in altitude.
- 5.45** The thematic layer for solar influx depicts its highest values during green tip to pink bud stage at all the locations, which however, declined gradually up to pre harvest stage, during both the years.
- 5.46** The thematic layer for canopy temperature indicates its lowest values during green tip to pink bud stage at all the locations, which however, increased gradually up to pre harvest stage, during both the years.
- 5.47** In the present study, according to cluster outlier analysis performed in GIS for chilling units suitability, Kalpa and Shimla blocks were found most suitable for meeting chilling requirement of ‘Starking Delicious’ apple. Chilling units’ suitability in rest of the blocks has however, been projection as average.

5.48 According to hot spot analysis for suitable slope in the study area, it was found that Kalpa, Rohru, Jubbal and Shimla as the hot spot zones with optimum GiZ score, indicating the desirable degree of slope for apple production.

5.49 According to the GiZ score model, Kalpa and Pooh are having most suitable elevation. But combining both the results of slope and elevation in model by super imposing both the results, Kalpa was identified yielding most suitable result of slope and elevation.

5.50 The suitability map of apple for Shimla and Kinnaur districts was obtained after running the geographically weighted regression model. The highly suitable areas includes Shimla, Kumarsain, Kalpa and Pooh blocks, where the temperature and altitude was found to be in the exact optimum range and this area is about 211.79 sq km. In case of fairly suitable zone, there was moderate correspondence between climatic conditions and requirement of apple in these areas compared to best suitable zone. This zone includes Theog, Chopal, Jubbal, Rohru, Chirgaon and Nichar blocks with an area of 157.18 sq km. However, unsuitable zone considered as areas that are not suitable for apple because of non-compatibility between prevailing climatic requirements of apple. This zone includes Basantpur and Rampur covering an area of 47.26 sq km.

CONCLUSIONS

Based on these studies, Kalpa has been identified as the most suitable location for apple cultivation as it has most appropriate altitude of fulfilling of chilling requirements and optimum environmental conditions (air temperature, solar influx, UV index, soil moisture and temperature) during flowering and fruit development for the production of quality fruits. Assured irrigation at this location, nullified the scarcity of required amount of rainfall. Environmental conditions at higher altitudes of Kotkhai, Rohru, Mashobra and Reckong Peo were in the optimum range during growing season and these were identified as suitable locations, however, at lower altitudes of Kotkhai and Rohru optimum environmental conditions did not prevail during winter, flowering, fruit set and fruit development period thereby resulting in lower yield and inferior quality

fruits and these were found unsuitable for “Delicious” apple production. The study highlighted that location mapping of apple and characterization of growth environment of apple orchards can be successfully achieved through the approach of Geo-statistical technique with the supplement of field survey. Spectral response of apple orchards can be modelled easily with the help of field survey to find out the areal extent of apple production areas. The digital elevation model of ASTER data has been found very convenient to relate the growing environment of apple orchards with terrain parameters. It shows that the growing environment of apple has shifted towards upper areas due to changes in the nature of environment.

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Appendices



APPENDIX-1

Experiment-1: Effects of environmental factors on production and quality of apple cv. Starking Delicious

ANOVA for Plant height (Table 14)

Source of variation	df	2012-13		2013-14		Pooled	
		MSS	Cal F	MSS	Cal F	MSS	Cal F
Treatments (7)	6	1.89	7.35	1.63	4.50	1.75	10.80
Replications (5)	4	1.79	6.98	1.38	3.79	1.57	9.71
Error	24	0.26		0.36		0.16	
Total	34						

ANOVA for Plant spread (Table 14)

Source of variation	df	20112-13		2013-14		Pooled	
		MSS	Cal F	MSS	Cal F	MSS	Cal F
Treatments (7)	6	0.55	2.51	1.33	2.35	0.50	3.61
Replications (5)	4	1.52	7.02	2.73	4.82	1.52	10.98
Error	24	0.22		0.57		0.14	
Total	34						

ANOVA for flowering intensity (Table 17)

Source of variation	df	2012-13		2013-14		Pooled	
		MSS	Cal F	MSS	Cal F	MSS	Cal F
Treatments (7)	6	59.03	11.27	73.97	12.22	65.56	11.68
Replications (5)	4	7.31	1.40	8.32	1.37	7.76	1.38
Error	24	5.24		6.06		5.61	
Total	34						

ANOVA for fruit set (Table 18)

Source of variation	df	2012-13		2013-14		Pooled	
		MSS	Cal F	MSS	Cal F	MSS	Cal F
Treatments (7)	6	388.75	23.56	281.88	20.37	331.49	29.17
Replications (5)	4	113.90	6.90	136.83	9.89	118.42	10.42
Error	24	16.50		13.84		11.37	
Total	34						

ANOVA for fruit yield (Table 19)

Source of variation	df	2012-13		2013-14		Pooled	
		MSS	Cal F	MSS	Cal F	MSS	Cal F
Treatments (7)	6	163.83	0.82	146.51	0.74	153.90	0.77
Replications (5)	4	84.40	0.42	84.40	0.42	84.40	0.42
Error	24	199.26		199.26		199.26	
Total	34						

ANOVA for productivity (Table 20)

Source of variation	df	2012-13		2013-14		Pooled	
		MSS	Cal F	MSS	Cal F	MSS	Cal F
Treatments (7)	6	231.43	111.00	201.85	107.39	216.35	109.21
Replications (5)	4	3.98	1.91	3.96	2.11	3.97	2.00
Error	24	2.08		1.88		1.98	
Total	34						

ANOVA for fruit length (Table 21)

Source of variation	df	2012-13		2013-14		Pooled	
		MSS	Cal F	MSS	Cal F	MSS	Cal F
Treatments (7)	6	183.86	22.75	78.60	8.38	124.08	29.63
Replications (5)	4	22.08	2.73	7.44	0.79	13.45	3.21
Error	24	8.08		9.38		4.19	
Total	34						

ANOVA for fruit diameter (Table 22)

Source of variation	df	2012-13		2013-14		Pooled	
		MSS	Cal F	MSS	Cal F	MSS	Cal F
Treatments (7)	6	41.89	7.32	123.84	11.98	72.89	33.83
Replications (5)	4	20.72	3.62	1.89	0.18	7.44	3.45
Error	24	5.72		10.33		2.15	
Total	34						

ANOVA for length/diameter ratio (Table 23)

Source of variation	df	2012-13		2013-14		Pooled	
		MSS	Cal F	MSS	Cal F	MSS	Cal F
Treatments (7)	6	0.12	17.91	0.02	1.08	0.02	3.08
Replications (5)	4	0.01	1.53	0.01	0.35	0.00	0.60
Error	24	0.01		0.02		0.01	
Total	34						

ANOVA for fruit weight (Table 24)

Source of variation	df	2012-13		2013-14		Pooled	
		MSS	Cal F	MSS	Cal F	MSS	Cal F
Treatments (7)	6	4963.34	670.89	4864.29	682.13	4796.08	3873.17
Replications (5)	4	274.36	37.09	120.79	16.94	174.86	141.21
Error	24	7.40		7.13		1.24	
Total	34						

ANOVA for TSS (Table 26)

Source of variation	df	2012-13		2013-14		Pooled	
		MSS	Cal F	MSS	Cal F	MSS	Cal F
Treatments (7)	6	1.78	3.66	3.60	7.38	2.59	5.30
Replications (5)	4	2.11	4.32	2.11	4.32	2.11	4.32
Error	24	0.49		0.49		0.49	
Total	34						

ANOVA for acidity (Table 27)

Source of variation	df	2012-13		2013-14		Pooled	
		MSS	Cal F	MSS	Cal F	MSS	Cal F
Treatments (7)	6	0.49	8.75	0.29	5.27	0.37	7.50
Replications (5)	4	0.05	0.81	0.04	0.73	0.01	0.15
Error	24	0.06		0.05		0.05	
Total	34						

ANOVA for TSS/acid ratio (Table 28)

Source of variation	df	2012-13		2013-14		Pooled	
		MSS	Cal F	MSS	Cal F	MSS	Cal F
Treatments (7)	6	104.29	8.98	61.27	9.96	79.97	10.02
Replications (5)	4	13.57	1.17	7.82	1.27	5.97	0.75
Error	24	11.61		6.15		7.98	
Total	34						

ANOVA for total sugar (Table 29)

Source of variation	df	2012-13		2013-14		Pooled	
		MSS	Cal F	MSS	Cal F	MSS	Cal F
Treatments (7)	6	14.00	39.21	13.87	37.28	13.93	38.21
Replications (5)	4	0.70	1.96	0.73	1.95	0.71	1.96
Error	24	0.36		0.37		0.36	
Total	34						

ANOVA for reducing sugars (Table 30)

Source of variation	df	2012-13		2013-14		Pooled	
		MSS	Cal F	MSS	Cal F	MSS	Cal F
Treatments (7)	6	8.07	21.06	11.31	25.97	9.52	23.38
Replications (5)	4	0.46	1.21	0.51	1.17	0.48	1.19
Error	24	0.38		0.44		0.41	
Total	34						

ANOVA for non-reducing sugars (Table 31)

Source of variation	df	2012-13		2013-14		Pooled	
		MSS	Cal F	MSS	Cal F	MSS	Cal F
Treatments (7)	6	5.12	10.63	3.69	8.22	4.35	9.35
Replications (5)	4	0.60	1.25	0.56	1.25	0.58	1.25
Error	24	0.48		0.45		0.46	
Total	34						

ANOVA for Soil pH (Table 38)

Source of variation	df	Soil pH	
		MSS	Cal F
Treatments (7)	6	1.62	22.60
Replications (5)	4	0.65	9.04
Error	24	0.07	
Total	34		

The soil texture at different location of Shimla and Kinnaur districts

Location	Replication	Textural compositions of soil (%)			Textural class
		Sand	Silt	Clay	
Mashobra					
	1	58.7	20.6	20.7	sandy clay loam
	2	60.5	18.2	21.3	sandy clay loam
	3	69.5	17.8	12.7	sandy loam
	4	62.7	19.7	17.6	sandy clay loam
	5	55.9	22.3	21.8	sandy clay loam
	Mean	61.46	19.72	18.82	
Kotkhai (E1)					
	1	58.5	25.7	15.8	sandy loam
	2	62.5	22.7	14.8	sandy loam
	3	69.8	17.7	12.5	sandy loam
	4	66.1	20.3	13.6	sandy loam
	5	62.5	22.8	14.7	sandy loam
	Mean	63.88	21.84	14.28	
Kotkhai (E2)					
	1	58.4	23.8	17.8	sandy clay loam
	2	61.7	23.5	14.8	sandy loam
	3	65.8	21.7	12.5	sandy loam
	4	70.2	18.5	11.3	sandy loam
	5	67.1	19.6	13.3	sandy loam
	Mean	64.64	21.42	13.94	
Rohru (E1)					
	1	55.9	28.5	15.6	sandy loam
	2	62.5	24.6	12.9	sandy loam
	3	56.8	29.7	13.5	sandy loam
	4	62.8	25.6	11.6	sandy loam
	5	65.4	24.3	10.3	sandy loam
	Mean	60.68	26.54	12.78	
Rohru (E2)					
	1	57.8	27.7	14.5	sandy loam
	2	56.4	31.2	12.4	sandy loam
	3	65.5	21.8	12.7	sandy loam
	4	59.8	24.4	15.8	sandy loam
	5	63.7	24.4	11.9	sandy loam
	Mean	60.64	25.9	13.46	
Kalpa					
	1	60.9	22.3	16.5	sandy loam
	2	55.9	22.1	21.8	sandy loam
	3	62.5	17.9	19.4	sandy clay loam
	4	63.8	23.3	13.2	sandy loam
	5	61.5	25.4	13	sandy loam
	Mean	60.92	22.2	16.78	
Reckong Peo					
	1	62.3	24.2	13.5	sandy loam
	2	61.3	22.7	16	sandy loam
	3	57.4	25.4	17.2	sandy clay loam
	4	63.1	23.2	13.7	sandy loam
	5	59.9	20.3	19.8	sandy clay loam
	Mean	60.8	23.16	16.04	

APPENDIX-II

Maximum temperature 2012-13

Blocks	January	February	March	April	May	June	July	August	September	October	November	December	Annual average
Rampur	12.67	13.56	23.17	30.12	36.08	34.75	33.05	29.64	26.76	25.23	19.67	19.53	25.35
Chirgaon	9.07	10.25	18.12	27.97	21.36	31.85	30.71	26.77	24.23	21.53	15.80	15.76	21.12
Chopal	8.07	7.40	15.36	21.88	23.21	24.55	24.92	23.79	23.58	23.42	18.15	13.83	19.01
Kumarsain	4.29	1.94	9.73	16.55	18.23	19.67	22.29	21.00	20.94	17.99	14.17	9.40	14.68
Theog	9.07	10.25	18.12	27.97	21.36	31.85	30.71	26.77	24.23	21.53	15.80	15.76	21.12
Basantpur	12.67	13.56	23.17	30.12	36.08	34.75	33.05	29.64	26.76	25.23	19.67	19.53	25.35
Shimla	9.72	11.22	16.72	19.44	28.95	30.92	29.56	24.86	22.79	18.33	14.38	12.34	9.72
Pooh	4.29	1.94	9.73	16.55	18.23	19.67	22.29	21.00	20.94	17.99	14.17	9.40	14.68
Nichar	9.07	10.25	18.12	27.97	21.36	31.85	30.71	26.77	24.23	21.53	15.80	15.76	21.12
Rohru	14.86	13.09	15.61	23.48	28.58	27.92	29.11	27.31	27.58	26.59	22.82	18.74	22.97
Jubbal	9.07	10.25	18.12	27.97	21.36	31.85	30.71	26.77	24.23	21.53	15.80	15.76	21.12
Kalpa	4.29	1.94	9.73	16.55	18.23	19.67	22.29	21.00	20.94	17.99	14.17	9.40	14.68

Maximum temperature 2013-14

Blocks	January	February	March	April	May	June	July	August	September	October	November	December	Annual average
Rampur	11.21	12.09	18.33	23.47	33.18	33.94	32.66	28.36	25.74	24.06	17.93	17.12	23.17
Chirgaon	10.03	11.36	17.39	22.63	32.22	33.13	31.56	27.43	24.56	22.59	17.09	16.23	22.18
Chopal	8.72	7.42	15.40	21.93	23.24	24.61	25.01	23.83	23.62	23.47	18.39	13.96	19.13
Kumarsain	4.46	4.34	8.83	15.25	12.58	17.93	21.55	21.10	18.30	19.19	14.04	10.31	13.99
Theog	10.03	11.36	17.39	22.63	32.22	33.13	31.56	27.43	24.56	22.59	17.09	16.23	22.18
Basantpur	11.21	12.09	18.33	23.47	33.18	33.94	32.66	28.36	25.74	24.06	17.93	17.12	23.17
Shimla	9.80	10.26	14.28	19.58	31.07	32.14	29.94	26.31	22.97	18.82	16.13	12.38	20.31
Pooh	4.46	4.34	8.83	15.25	12.58	17.93	21.55	21.10	18.30	19.19	14.04	10.31	13.99
Nichar	10.03	11.36	17.39	22.63	32.22	33.13	31.56	27.43	24.56	22.59	17.09	16.23	22.18
Rohru	16.15	14.61	17.87	21.33	29.62	28.51	29.86	27.49	27.77	27.12	23.37	19.22	23.58
Jubbal	10.03	11.36	17.39	22.63	32.22	33.13	31.56	27.43	24.56	22.59	17.09	16.23	22.18
Kalpa	4.46	4.34	8.83	15.25	12.58	17.93	21.55	21.10	18.30	19.19	14.04	10.31	13.99

Minimum temperature- 2012-13

Blocks	January	February	March	April	May	June	July	August	September	October	November	December	Annual average
Rampur	6.37	7.29	10.74	12.42	18.65	31.14	23.31	21.97	19.44	17.52	10.72	8.29	15.66
Chirgaon	5.26	6.36	9.92	11.36	17.38	29.95	22.24	21.08	18.74	16.12	9.41	7.22	14.59
Chopal	1.63	-0.78	3.72	6.57	8.49	8.53	8.87	9.11	9.36	9.68	4.12	1.66	5.91
Kumarsain	-1.08	-1.20	2.75	2.69	5.26	5.73	9.00	7.77	8.50	6.85	0.86	-1.36	3.81
Theog	5.26	6.36	9.92	11.36	17.38	29.95	22.24	21.08	18.74	16.12	9.41	7.22	14.59
Basantpur	6.37	7.29	10.74	12.42	18.65	31.14	23.31	21.97	19.44	17.52	10.72	8.29	15.66
Shimla	0.40	0.10	3.68	7.15	16.21	26.73	19.74	20.04	16.89	9.32	4.82	1.69	10.56
Pooh	-1.08	-1.20	2.75	2.69	5.26	5.73	9.00	7.77	8.50	6.85	0.86	-1.36	3.81
Nichar	5.26	6.36	9.92	11.36	17.38	29.95	22.24	21.08	18.74	16.12	9.41	7.22	14.59
Rohru	2.08	1.95	4.94	8.30	14.08	17.58	19.32	18.70	15.22	12.87	6.27	3.84	10.43
Jubbals	5.26	6.36	9.92	11.36	17.38	29.95	22.24	21.08	18.74	16.12	9.41	7.22	14.59
Kalpa	-1.08	-1.20	2.75	2.69	5.26	5.73	9.00	7.77	8.50	6.85	0.86	-1.36	3.81

ix

Minimum temperature- 2013-14

Blocks	January	February	March	April	May	June	July	August	September	October	November	December	Annual average
Rampur	6.78	7.45	11.51	12.75	19.34	30.84	24.79	23.24	20.19	16.63	10.88	8.49	16.07
Chirgaon	4.19	5.33	8.82	10.52	16.15	29.02	21.08	20.40	17.58	14.81	8.33	6.06	13.52
Chopal	1.57	-0.66	3.69	6.49	8.22	8.46	8.74	9.03	9.27	9.60	3.81	1.41	5.80
Kumarsain	-1.56	-1.79	1.72	3.53	5.62	6.17	9.58	9.29	6.07	5.42	0.57	-0.98	3.64
Theog	4.19	5.33	8.82	10.52	16.15	29.02	21.08	20.40	17.58	14.81	8.33	6.06	13.52
Basantpur	6.78	7.45	11.51	12.75	19.34	30.84	24.79	23.24	20.19	16.63	10.88	8.49	16.07
Shimla	1.05	0.24	5.54	7.73	12.56	26.67	19.88	16.95	13.06	7.40	3.79	2.24	9.76
Pooh	-1.56	-1.79	1.72	3.53	5.62	6.17	9.58	9.29	6.07	5.42	0.57	-0.98	3.64
Nichar	4.19	5.33	8.82	10.52	16.15	29.02	21.08	20.40	17.58	14.81	8.33	6.06	13.52
Rohru	1.92	1.64	4.72	9.27	13.79	17.02	18.87	18.31	14.73	12.44	5.85	3.29	10.15
Jubbals	4.19	5.33	8.82	10.52	16.15	29.02	21.08	20.40	17.58	14.81	8.33	6.06	13.52
Kalpa	-1.56	-1.79	1.72	3.53	5.62	6.17	9.58	9.29	6.07	5.42	0.57	-0.98	3.64

Rainfall 2012-13

Blocks	January	February	March	April	May	June	July	August	September	October	November	December	Annual average
Rampur	83	75	86	47	68	95	263	189	146	44	16	38	95.83
Chirgaon	86	77	93	57	72	106	334	270	170	58	16	37	114.67
Chopal	108	80	106	81	86	28	68	56	73	49	19	43	66.42
Kumarsain	107	83	109	82	87	33	89	79	84	51	19	44	72.25
Theog	86	77	93	57	72	106	334	270	170	58	16	37	114.67
Basantpur	83	75	86	47	68	95	263	189	146	44	16	38	95.83
Shimla	67	60	73	49	69	170	423	334	179	47	15	29	126.25
Pooh	107	83	109	82	87	33	89	79	84	51	19	44	72.25
Nichar	86	77	93	57	72	106	334	270	170	58	16	37	114.67
Rohru	97	88	98	62	78	84	258	226	159	55	17	51	106.08
Jubbal	86	77	93	57	72	106	334	270	170	58	16	37	114.67
Kalpa	107	83	109	82	87	33	89	79	84	51	19	44	72.25

x

Rainfall 2013-14

Blocks	January	February	March	April	May	June	July	August	September	October	November	December	Annual average
Rampur	82	78	83	45	68	94	268	184	145	48	19	43	96.38
Chirgaon	85	73	95	54	72	102	330	265	168	56	14	35	112.45
Chopal	112	75	99	76	83	23	67	56	73	53	15	46	64.85
Kumarsain	109	79	103	77	85	32	87	75	83	44	21	43	69.79
Theog	85	73	95	54	72	102	330	265	168	56	14	35	112.45
Basantpur	82	78	83	45	68	94	268	184	145	48	19	43	96.38
Shimla	67	57	72	44	66	165	421	331	175	46	16	25	123.75
Pooh	109	79	103	77	85	32	87	75	83	44	21	43	69.79
Nichar	85	73	95	54	72	102	330	265	168	56	14	35	112.45
Rohru	95	85	94	61	78	83	255	222	156	55	16	50	104.15
Jubbal	85	73	95	54	72	102	330	265	168	56	14	35	112.45
Kalpa	109	79	103	77	85	32	87	75	83	44	21	43	69.79

Elevation angle 2012-13

Blocks	January	February	March	April	May	June	July	August	September	October	November	December	Annual average
Rampur	12.45	16.69	23.85	31.90	37.31	38.18	36.17	33.13	28.96	24.41	18.30	13.34	26.22
Chirgaon	12.88	17.12	24.28	32.33	37.74	38.61	36.6	33.56	29.39	24.84	18.73	13.77	26.65
Chopal	13.16	17.49	24.73	32.87	38.37	39.27	37.32	34.35	30.48	25.19	18.98	14	27.18
Kumarsain	13.15	17.47	24.71	32.85	38.35	39.25	37.3	34.33	30.46	25.18	18.97	13.99	27.17
Theog	12.88	17.12	24.28	32.33	37.74	38.61	36.6	33.56	29.39	24.84	18.73	13.77	26.65
Basantpur	12.45	16.69	23.85	31.90	37.31	38.18	36.17	33.13	28.96	24.41	18.30	13.34	26.22
Shimla	12.66	16.88	24.02	32.06	37.48	38.34	36.4	33.49	29.75	24.6	18.5	13.55	26.48
Pooh	13.15	17.47	24.71	32.85	38.35	39.25	37.3	34.33	30.46	25.18	18.97	13.99	27.17
Nichar	12.88	17.12	24.28	32.33	37.74	38.61	36.6	33.56	29.39	24.84	18.73	13.77	26.65
Rohru	12.98	17.25	24.42	32.49	37.93	38.8	36.86	33.93	30.15	21.63	18.82	13.86	26.59
Jubbal	12.88	17.12	24.28	32.33	37.74	38.61	36.6	33.56	29.39	24.84	18.73	13.77	26.65
Kalpa	13.15	17.47	24.71	32.85	38.35	39.25	37.3	34.33	30.46	25.18	18.97	13.99	27.17

ix.

Elevation angle 2013-14

Blocks	January	February	March	April	May	June	July	August	September	October	November	December	Annual average
Rampur	12.37	16.57	23.38	31.77	37.22	38.11	36.19	33.28	31.20	24.39	18.24	13.30	26.34
Chirgaon	12.87	17.07	23.88	32.27	37.72	38.61	36.69	33.78	31.7	24.89	18.74	13.8	26.84
Chopal	13.15	17.33	24.66	32.82	38.35	39.27	37.34	34.37	30.51	25.24	19.03	14.03	27.18
Kumarsain	13.13	17.42	24.64	32.8	38.33	39.26	37.32	34.35	30.5	25.22	19.02	14.02	27.17
Theog	12.87	17.07	23.88	32.27	37.72	38.61	36.69	33.78	31.7	24.89	18.74	13.8	26.84
Basantpur	12.37	16.57	23.38	31.77	37.22	38.11	36.19	33.28	31.20	24.39	18.24	13.30	26.34
Shimla	12.64	16.83	23.95	32.01	37.45	38.34	36.59	33.52	29.78	24.49	16.89	13.58	26.34
Pooh	13.13	17.42	24.64	32.8	38.33	39.26	37.32	34.35	30.5	25.22	19.02	14.02	27.17
Nichar	12.87	17.07	23.88	32.27	37.72	38.61	36.69	33.78	31.7	24.89	18.74	13.8	26.84
Rohru	12.97	17.20	24.35	32.43	37.90	38.80	36.87	33.96	30.19	25.01	18.87	13.89	26.87
Jubbal	12.87	17.07	23.88	32.27	37.72	38.61	36.69	33.78	31.7	24.89	18.74	13.8	26.84
Kalpa	13.13	17.42	24.64	32.8	38.33	39.26	37.32	34.35	30.5	25.22	19.02	14.02	27.17

Azimuth angle 2012-13

Blocks	January	February	March	April	May	June	July	August	September	October	November	December	Annual average
Rampur	122.87	115.72	107.73	98.17	88.32	82.84	85.08	94.00	106.75	117.10	124.96	126.96	105.88
Chirgaon	123.96	116.81	108.82	99.26	89.41	83.93	86.17	95.09	107.84	118.19	126.05	128.05	106.97
Chopal	124.5	117.4	109.47	99.98	90.13	84.61	86.66	95.11	107.15	118.88	126.67	128.61	107.43
Kumarsain	124.48	117.39	109.46	101.63	90.1	84.59	86.65	95.1	107.13	118.86	126.66	128.59	107.55
Theog	123.96	116.81	108.82	99.26	89.41	83.93	86.17	95.09	107.84	118.19	126.05	128.05	106.97
Basantpur	122.87	115.72	107.73	98.17	88.32	82.84	85.08	94.00	106.75	117.10	124.96	126.96	105.88
Shimla	123.76	116.62	108.62	99.08	90.11	83.8	85.52	94.25	106.23	294.81	125.84	127.85	121.37
Pooh	124.48	117.39	109.46	101.63	90.1	84.59	86.65	95.1	107.13	118.86	126.66	128.59	107.55
Nichar	123.96	116.81	108.82	99.26	89.41	83.93	86.17	95.09	107.84	118.19	126.05	128.05	106.97
Rohru	124.11	116.97	108.99	99.45	89.58	84.1	86.15	94.59	106.61	118.37	126.22	128.2	106.95
Jubbal	123.96	116.81	108.82	99.26	89.41	83.93	86.17	95.09	107.84	118.19	126.05	128.05	106.97
Kalpa	124.48	117.39	109.46	101.63	90.1	84.59	86.65	95.1	107.13	118.86	126.66	128.59	107.55

ix

Azimuth angle 2013-14

Blocks	January	February	March	April	May	June	July	August	September	October	November	December	Annual average
Rampur	124.81	117.68	109.81	100.14	90.27	84.75	86.74	95.13	107.13	118.90	126.81	128.86	107.59
Chirgaon	124.01	116.88	109.01	99.34	89.47	83.95	85.94	94.33	106.33	118.1	126.01	128.06	106.79
Chopal	124.55	117.47	109.55	100.06	90.17	84.62	86.61	95.02	107.05	118.8	126.63	128.62	107.43
Kumarsain	124.53	117.45	109.53	100.04	90.16	84.61	86.6	95.01	107.03	118.78	126.62	128.6	107.41
Theog	124.01	116.88	109.01	99.34	89.47	83.95	85.94	94.33	106.33	118.1	126.01	128.06	106.79
Basantpur	124.81	117.68	109.81	100.14	90.27	84.75	86.74	95.13	107.13	118.90	126.81	128.86	107.59
Shimla	123.82	116.69	108.7	99.16	89.32	83.82	85.81	94.16	106.13	117.89	125.8	127.86	106.60
Pooh	124.53	117.45	109.53	100.04	90.16	84.61	86.6	95.01	107.03	118.78	126.62	128.6	107.41
Nichar	124.01	116.88	109.01	99.34	89.47	83.95	85.94	94.33	106.33	118.1	126.01	128.06	106.79
Rohru	124.16	117.04	109.06	99.52	89.64	84.11	86.11	94.5	106.51	118.29	126.18	128.21	106.94
Jubbal	124.01	116.88	109.01	99.34	89.47	83.95	85.94	94.33	106.33	118.1	126.01	128.06	106.79
Kalpa	124.53	117.45	109.53	100.04	90.16	84.61	86.6	95.01	107.03	118.78	126.62	128.6	107.41

UV index 2012-13

Blocks	January	February	March	April	May	June	July	August	September	October	November	December	Annual average
Rampur	11.20	11.10	15.00	20.00	21.80	20.70	17.30	16.10	15.20	14.30	13.40	10.10	15.52
Chirgaon	12.30	12.20	16.10	21.10	22.90	21.80	18.40	17.20	16.30	15.40	14.50	11.20	16.62
Chopal	19.50	19.70	19.70	20.50	23.60	26.50	24.70	23.60	26.40	28.90	25.20	19.80	23.18
Kumarsain	29.50	26.50	28.80	28.80	32.00	32.60	32.50	30.20	34.20	35.90	32.40	25.90	30.77
Theog	12.30	12.20	16.10	21.10	22.90	21.80	18.40	17.20	16.30	15.40	14.50	11.20	16.62
Basantpur	11.20	11.10	15.00	20.00	21.80	20.70	17.30	16.10	15.20	14.30	13.40	10.10	15.52
Shimla	17.50	15.10	17.90	21.10	21.30	19.70	17.10	16.60	18.20	18.90	19.40	16.50	18.28
Pooh	29.50	26.50	28.80	28.80	32.00	32.60	32.50	30.20	34.20	35.90	32.40	25.90	30.77
Nichar	12.30	12.20	16.10	21.10	22.90	21.80	18.40	17.20	16.30	15.40	14.50	11.20	16.62
Rohru	19.20	13.50	16.30	21.10	21.60	18.70	13.70	13.20	16.50	18.80	22.40	18.50	17.79
Jubbals	12.30	12.20	16.10	21.10	22.90	21.80	18.40	17.20	16.30	15.40	14.50	11.20	16.62
Kalpa	29.50	26.50	28.80	28.80	32.00	32.60	32.50	30.20	34.20	35.90	32.40	25.90	30.77

UV index 2013-14

Blocks	January	February	March	April	May	June	July	August	September	October	November	December	Annual average
Rampur	10.50	10.40	14.30	19.30	21.10	20.20	16.60	15.20	14.30	13.60	12.40	9.70	14.80
Chirgaon	11.70	11.60	15.50	20.50	22.30	21.20	17.80	16.40	15.50	14.80	13.40	10.60	15.94
Chopal	18.70	18.90	18.90	19.20	22.80	25.70	23.90	22.80	25.60	28.10	24.30	19.00	22.33
Kumarsain	28.00	25.00	27.30	27.30	30.50	31.10	31.00	28.70	32.70	34.40	30.90	24.40	29.28
Theog	11.70	11.60	15.50	20.50	22.30	21.20	17.80	16.40	15.50	14.80	13.40	10.60	15.94
Basantpur	10.50	10.40	14.30	19.30	21.10	20.20	16.60	15.20	14.30	13.60	12.40	9.70	14.80
Shimla	16.60	14.20	17.00	20.20	20.40	18.80	16.20	15.70	17.30	18.00	18.50	15.60	17.38
Pooh	28.00	25.00	27.30	27.30	30.50	31.10	31.00	28.70	32.70	34.40	30.90	24.40	29.28
Nichar	11.70	11.60	15.50	20.50	22.30	21.20	17.80	16.40	15.50	14.80	13.40	10.60	15.94
Rohru	18.50	12.80	15.60	20.40	20.90	18.00	13.00	12.50	15.80	18.10	21.70	17.30	17.05
Jubbals	11.70	11.60	15.50	20.50	22.30	21.20	17.80	16.40	15.50	14.80	13.40	10.60	15.94
Kalpa	28.00	25.00	27.30	27.30	30.50	31.10	31.00	28.70	32.70	34.40	30.90	24.40	29.28

Solar influx 2013

Locations	Solar influx				
	Green tip-pink bud	Flowering -fruit set	Walnut	Fruit development	Pre-harvest
Rampur	63.48	54.66	48.42	36.31	50.02
Chirgaon	65.58	49.54	51.97	50.11	45.87
Chopal	77.97	74.05	69.45	65.9	56.82
Kumarsain	76.3	67.95	63.99	51.44	49.66
Theog	65.58	49.54	51.97	50.11	45.87
Basantpur	63.48	54.66	48.42	36.31	50.02
Shimla	71.08	69.2	58.23	55.78	47.95
Pooh	76.3	67.95	63.99	51.44	49.66
Nichar	65.58	49.54	51.97	50.11	45.87
Rohru	73.32	61.02	55.41	54.72	50.58
Jubbal	65.58	49.54	51.97	50.11	45.87
Kalpa	76.3	67.95	63.99	51.44	49.66

Solar influx 2014

Locations	Solar influx				
	Green tip-pink bud	Flowering -fruit set	Walnut	Fruit development	Pre-harvest
Rampur	86.47	76.88	67.78	58.66	50.89
Chirgaon	86.63	75.73	68.02	60.10	50.89
Chopal	87.83	80.82	74.80	68.58	62.12
Kumarsain	90.91	83.19	76.42	69.64	63.53
Theog	86.63	75.73	68.02	60.10	50.89
Basantpur	86.47	76.88	67.78	58.66	50.89
Shimla	78.05	72.60	67.63	59.68	50.64
Pooh	90.91	83.19	76.42	69.64	63.53
Nichar	86.63	75.73	68.02	60.10	50.89
Rohru	90.13	81.32	72.51	62.77	54.14
Jubbal	86.63	75.73	68.02	60.10	50.89
Kalpa	90.91	83.19	76.42	69.64	63.53

Canopy temperature 2013

Locations	Canopy temperature				
	Green tip-pink bud	Flowering -fruit set	Walnut	Fruit development	Pre-harvest
Rampur	18.05	22.80	23.30	23.70	26.76
Chirgaon	15.32	21.40	22.90	23.50	25.09
Chopal	21.54	24.82	22.22	22.32	19.22
Kumarsain	18.93	20.16	21.11	23.84	19.64
Theog	15.32	21.40	22.90	23.50	25.09
Basantpur	18.05	22.80	23.30	23.70	26.76
Shimla	22.67	25.60	25.70	23.70	25.00
Pooh	18.93	20.16	21.11	23.84	19.64
Nichar	15.32	21.40	22.90	23.50	25.09
Rohru	19.80	19.00	26.50	25.00	24.52
Jubbals	15.32	21.40	22.90	23.50	25.09
Kalpa	18.93	20.16	21.11	23.84	19.64

Canopy temperature 2014

Locations	Canopy temperature				
	Green tip-pink bud	Flowering -fruit set	Walnut	Fruit development	Pre-harvest
Rampur	21.63	23.82	26.04	25.22	21.14
Chirgaon	20.60	24.32	25.85	24.69	21.37
Chopal	20.59	23.30	25.50	26.12	25.67
Kumarsain	15.82	18.60	22.48	23.34	25.01
Theog	20.60	24.32	25.85	24.69	21.37
Basantpur	21.63	23.82	26.04	25.22	21.14
Shimla	17.91	19.68	25.07	24.07	24.71
Pooh	15.82	18.60	22.48	23.34	25.01
Nichar	20.60	24.32	25.85	24.69	21.37
Rohru	19.95	22.06	25.25	24.39	23.85
Jubbals	20.60	24.32	25.85	24.69	21.37
Kalpa	15.82	18.60	22.48	23.34	25.01

Estimated irrigated and un-irrigated area under apple cultivation

Kinnaur	No. of Holdings (Orchards)				Irrigated Area (Hectares)				Un-irrigated Area (Hectares)			
	Small	Medium	Marginal	Large	Small	Medium	Marginal	Large	Small	Medium	Marginal	Large
Kalpa	159	42	741	1	119	104	164	Neg	0	Neg	1	0
Nichar	722	98	1082	5	33	9	24	0	288	149	166	604
Pooh	132	34	465	13	129	118	155	88	0	0	0	4
Shimla	No. of Holdings (Orchards)				Irrigated Area (Hectares)				Unirrigated Area (Hectares)			
	Small	Medium	Marginal	Large	Small	Medium	Marginal	Large	Small	Medium	Marginal	Large
Shimla	301	37	346	0	3	0	0	0	104	16	67	0
Theog	2125	678	4645	60	3	3	1	0	1311	1090	1195	331
Kumarsain	1511	87	5346	0	1	0	1	0	1291	167	1699	0
Rampur	1660	100	5369	0	8	4	3	0	939	271	1136	0
Rohru	1621	201	4035	14	3	5	6	0	1484	753	1202	175
Kotkhai	1578	160	5107	0	0	0	2	0	1854	639	2039	0
Chopal	1067	39	3217	0	0	0	1	0	907	113	1056	0
Jubbal	1451	130	4832	0	16	4	4	0	1838	596	1798	0
Chirgaon	1190	168	3721	2	1	0	0	0	754	353	886	2
Basantpur	3	0	19	0	0	0	0	0	Neg	0	1	0

Small (upto 1 ha), medium (1-2 ha), marginal (2-4 ha), large (>4ha)

Block name and area acquired by GIS software

Sr. No	Name	Area sq km
1	Rampur	36.34
2	Chirgaon	36.49
3	Chopal	30.65
4	Kumarsain	8.10
5	Theog	16.06
6	Basantpur	10.92
7	Shimla	16.91
8	Pooh	121.56
9	Nichar	41.43
10	Rohru	11.01
11	Jubbal	21.52
12	Kalpa	64.22

Abstract



**Dr. Y.S. Parmar University of Horticulture and Forestry,
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Department of Fruit Science

Title of Thesis	:	“Geographical Information System based assessment of location suitability for apple (<i>Malus× domestica</i> Borkh.) production”
Name of student	:	Chaitanya R. Belsare
Admission No.	:	H-2011-17-D
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Major Field	:	Fruit Science
Minor Field(s)	:	i) Plant Physiology
Degree Awarded	:	Ph.D (Fruit Science)
Number of pages in thesis	:	146+xvii
Number of words in abstract	:	321
Year of Award of Degree	:	2016

Abstract

The present investigation entitled “Geographical Information System based assessment of location suitability for apple (*Malus×domestica* Borkh.) production” was carried out at different locations and altitudes in district Shimla and Kinnaur during the years 2012 - 2014. The data on weather, geological, physical, production, quality, soil and socio-economic parameters were recorded. The result revealed that the temperature decreased linearly with the corresponding increase in altitude. Rainfall was recorded significantly lower at both the locations of district Kinnaur in comparison to all the locations of district Shimla. Depending upon the climatic variations at different locations during the course of study, dates of chilling unit initiation, rest completion, end of chilling period and full bloom stages of Starking Delicious apple showed discrepancy among the locations and between the years. According to present findings all the locations in Shimla and Kinnaur fulfilled the basic chilling requirement for apple. Different altitudes showed significant positive correlation with flowering intensity, fruit set, yield, productivity, fruit length, diameter, weight, TSS, TSS/acid ratio, sugars whereas, negative and significant association was found between altitudes and fruit acidity. Soil temperature and moisture increased with the progress in growth period and increase in altitudes. The suitability map of apple for Shimla and Kinnaur districts was obtained after running the geographically weighted regression model. The highly suitable areas includes Shimla, Kumarsain, Kalpa and Pooh blocks, where the temperature and altitudes were found to be in the exact optimum range and this area is about 211.79 sq km. In case of fairly suitable zone, there was moderate correspondence between climatic conditions and requirement of apple in these areas compared to best suitable zone. This zone includes Theog, Chopal, Jubbal, Rohru, Chirgaon and Nichar blocks with an area of 157.18 sq km. However, unsuitable zone considered as areas that are not suitable for apple because of non-compatibility between prevailing climatic requirements of apple. This zone includes Basantpur and Rampur covering an area of 47.26 sq km.

Signature of Major Advisor

Signature of Student

Countersigned

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