RESEARCH ARTICLE

Altitudinal Shifting of Apple Orchards with Adaption of Changing Climate in the Alpine Himalaya

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Abstract

The impact of climate change is found to be the most significant for agricultural practices in the alpine regions of the world. Apple orchards of Kalpa, Indian Himalaya, are facing the same dilemma. The main objective of this work is to analyze the effect of climate variability on the location of apple orchards through the computation of spatio-temporal dynamics of snow cover area, vegetation cover area and land surface temperature using earth observation based multi-spectral data analysis. Using the above variables, we have delineated suitable zones for apple cultivation using the analytical hierarchy process method. The IMD data have been used for descriptive statistics, Mann–Kendall (MK) test and Sen's slope estimation to detect temporal trends in local climatic conditions since 1987. The result indicates a significant rise in annual and seasonal temperatures, especially during the winter and spring seasons, along with declining precipitation, which has been assessed with the help of farmers' opinions. Shifting of the apple orchards along with vegetation covers from lower to higher altitudes, in the study area, squeezed the suitable zone in the limited pockets.

Keywords Climatic variability · Alpine phenology · Earth observation · Altitudinal shifting · Apple suitable zone

Introduction

In recent times, climate change is being noticed all around the world through the rising of the earth's surface temperature by 0.74 °C from 1906 to 2005, and it could increase as much as 3.7–4.8 °C on average during the twenty-first century (Parry et al., 2007; Pachauri et al., 2014). Similarly, the mean surface air temperature has increased between 0.3 and 0.6 °C during the last 150 years (Jones et al., 1999), and it triggered a rapid decrease in snow cover area (SCA) during the summer, as well as spring season (Lemke et al., 2007). The mountain ecosystem is one of the most susceptible ecosystems affected by climate variability and its changes, which is already showing rampant impacts on the Himalayan ecosystem (Sahu et al., 2020). In the Northwest Himalayan region, it has increased by almost 1.6 °C (Bhutiyani et al., 2007). Recent studies indicate that surface temperature variation has amplified due to significant influence from topographic changes, which eventually lead to surface temperature evolution (Zhao et al., 2019), including the - Himalayan region (Shrestha and Aryal, 2011).

The snow cover all around the world has been affected due to climate change, global warming and land surface temperature change. There is no doubt that reductions in the snow and glacier cover will change the surface albedo, which in turn will increase the surface temperature of the earth (Zhao et al., 2019). Thus, the earth's radiation balance is affected by the surface condition of the snow cover itself (Cohen, 1994; Cohen & Entekhabi, 2001; Douville & Royer, 1996; Foster et al., 1996; Stieglitz et al., 2001; Yang et al., 1999). A decreasing trend has been noticed globally that the seasonally frozen area gets reduced by almost 7%, especially in the spring time. The depth of snow cover is also reduced by 0.3 m in the northern hemisphere (Lemke et al., 2007; Liang et al., 2016). Thus, an upward shift in altitude of the snowline and thinner snow cover in low and medium elevated locations for a shorter time period is noticed in various studies like Laternser & Schneebeli, 2003; López- Moreno, 2005; Mote et al., 2005; Verma et al., 2006; Basannagari & Kala, 2013; Rai et al., 2015, Sahu et al., 2020. If climatic factors such as temperature and precipitation change beyond the

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tolerance of species, then changes in the distribution of species are inevitable (Lynch and Lande, 1993). According to Parmesan and Yohe (2003), plant species are shifting their position attitudinally as a response to changing regional climate and increasing temperature (Sugiura et al., 2013). In Japan, a vertical biodiversity shift has also been reported by Sugiura and Yokozawa (2004).

As apple trees are very sensitive to fluctuations in temperature and climate variability, it requires certain climatic condition for obtaining the best production (Byrne & Bacon, 1992; Partap & Partap, 2002; Rana et al., 2012). But recently, warm winters are responsible for less productivity of the apples, as there is low snow accumulation, effecting induction of dormancy, bud breaking and flowering (Jindal et al., 2001). Owing to the prolonged delay of cold during winter months in the study area, the chilling requirements are greatly affected and bad quality apples are produced due to interrupted winter. Wrege et al. (2006) also advocated that, with the increment of a few degrees rise in temperature, there is a substantial decrease in the chilling hours; so the present weather conditions are not meeting enough chilling hours for the production of good-quality apples in the Kalpa region.

A plant's phenology in the active tectonic part of Himalaya largely depends on climate components (Guédon & Legave, 2008) along with the unique geo-hydrological set-up (Haque et al., 2020). Taste and texture of a fruit is reportedly being affected due to global warming (Sugiura et al., 2013). The apple orchards in the future will expand to other localities in Himachal Pradesh and may emerge as new apple destination, to get optimum climatic conditions for the growth of apples (Kumar et al., 2018).

The study area, Kalpa tehsil of Himachal Pradesh (Fig. 1) is one of the leading apple production centers of the Western Himalaya (Horticulture Statistics Division, 2015) where apple growth and production has directly linked, corresponded with climate components and its variability. Apple orchards in Kalpa account for 46 percent of its total geographical area and 76 percent of total fruit production (Development of Horticulture, 2014). Rana et al. (2013) and Sahu et al. (2020) have mentioned that changing climatic condition adversely affects apple productivity in the study area and lead to the change in livelihood and socio-economic conditions of local people. Thus, the present study focuses on how the climate change affects orchard farming in a micro scale alpine region, impacting the agricultural adaptation, shifting of orchards fields and vegetation pattern in the western Himalaya. During the early 1980's, apples were being cultivated at an altitude of 1200–1500 m (National Horticulture Board of India, 2012) in the western Himalaya. Increasing surface temperature since 1980 has led to orchards being shifted to 1500–2000 m altitudes (Kothawale & Kumar, 2005). This work tries to evaluate the nature of climatic variability in an alpine ecosystem at the micro level during last three decades; and its impact on orchard locations, by utilizing both statistical as well as earth observation tools. And finally an apple suitability zone (ASZ) has been prepared for Kalpa Tehsil, Himachal Pradesh, India using the satellite data, temperature, precipitation, LST, SCA, VCA and the people's perception of social and economic factors.

Data used and Methodology

Data Consideration for the Study

Data have been provided by India Meteorological Department (IMD), and this is an observed station data for Kalpa meteorological Station, Kinnaur, Himachal Pradesh, since 1987. Here, the annual and seasonal average, maximum, minimum temperature and precipitation data over a period of 31 years (1987–2018) have been used for descriptive analysis; along with Mann–Kendall (MK) test and Sen's slope estimation have been done using XLSTAT Software, to understand the spatio-temporal trends of the alpine climate of the study area. Many researchers and practitioners like Mann, 1945; Sen, 1968; Yue & Wang, 2004; Negi et al., 2013; Soltani et al., 2013; Mishra et al., 2014, etc., have used the nonparametric tests for trend analysis of climatic variables. The northern meteorological season has been adopted here for meteorological explanation to build seasonal information and further analysis, where September to November is considered as autumn, December to February as winter, March to May as spring and June–July as summer. The reason for doing so is to corroborate it with weather parameters for growth stages and growing periods of apple, namely (i) *dormant stage* (December to March); (ii) *flowering and fruit-set stage* (April to May); (iii) *growth and development stage* (June to September); and (iv) *pre-dormant stage* (October to November). This study involves the usage of earth observation images of two periods, i.e., late autumn (for the month of November, it depicts the snow free condition) and early spring (for the month of March, it exhumes the utmost snow-covered condition at the surface). The different sensors' output of Landsat satellite (Table 1) have been considered for analyzing the various variables, i.e., land surface temperature (LST), snow cover line (SCL), snow cover area (SCA), and vegetation covered area (VCA) of the study area. Since it is very difficult to get the cloud free data every year for a particular time period, we have chosen almost a decadal gap (10 years) cloud free data for the entire time period to show the overall spatio-temporal dynamics of these variables (i.e., LST, SCL, SCA and VCA). However, seasonal and annual climatic data have been used to understand the
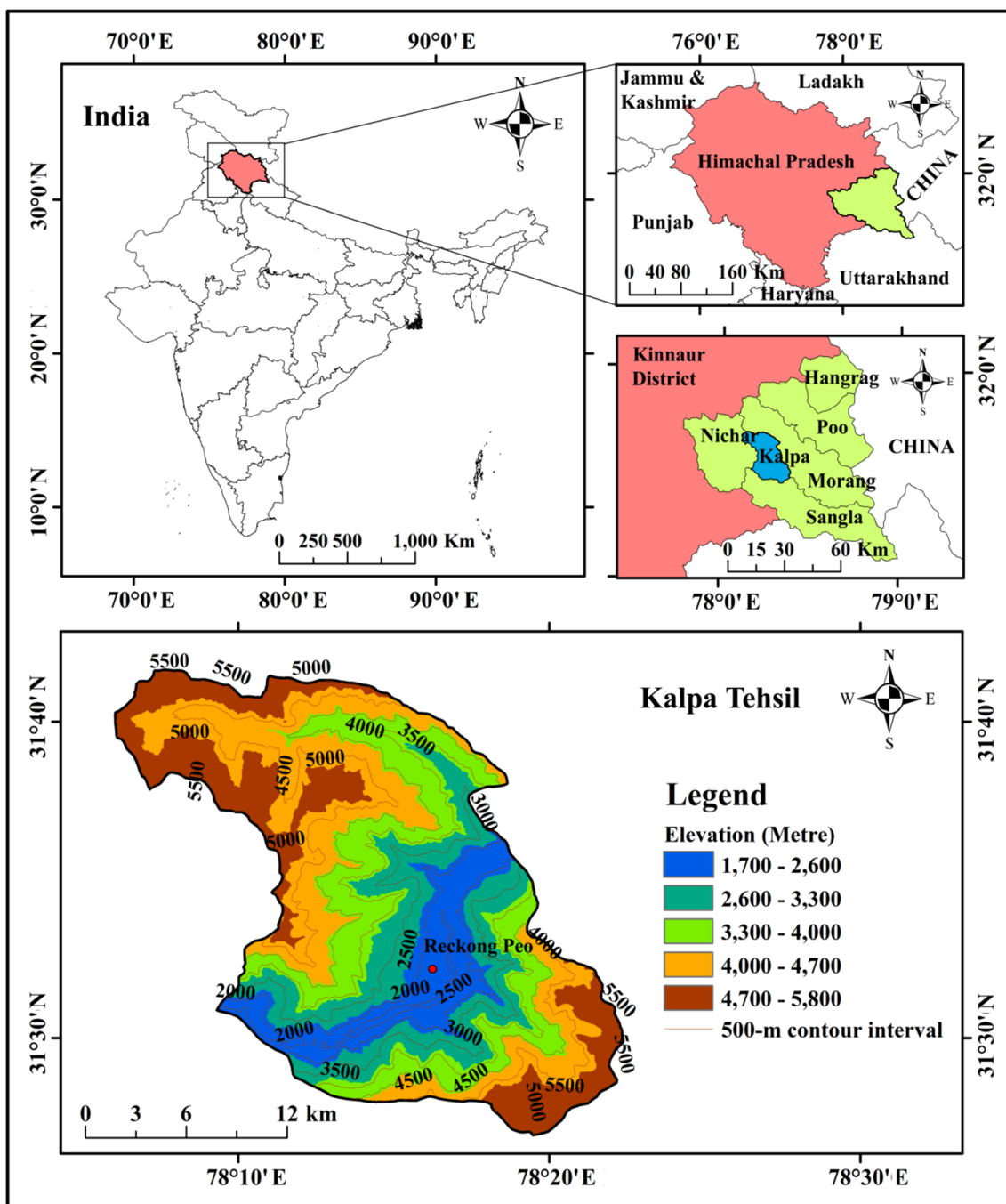
Fig. 1 Location of the study area (Kalpa Tehsil). *Source* Prepared by author, based on the atlas map and Aster DEM data using Arc GIS 10.3

trend of weather parameters every year. Here, remotely sensed data of 1994, 2004 and 2017 indicate late autumn period and images of 1995, 2005 and 2018 indicate the early spring period. There are different types of errors in both satellite and climatic data; thus, error correction is very much necessary before any analysis. To reduce such error in satellite data, various types of preprocessing methods like atmospheric correction, radiometric correction, geometric correction, and gap filling using scan line

error (SLE) method have been done using Arc-GIS software, whereas for IMD station data, missing values have been restored using the long-term mean method.

Kalpa tehsil had only one IMD station; thus, for validation of LST and preparation of rainfall distribution map, more grid points are needed. Therefore, grid data have been taken into consideration, where gauge-based global daily CPC (Climate Prediction Center) data of max and min temperature and precipitation data set have been used at

Table 1 Detail of Landsat satellite images used in the study

Satellite and sensor	Acquisition date	Spatial resolution	Band number	Spectral range (μm)	Datum and projection	Data source
Landsat 5, TM	01-11-1994	30 m	B1	0.45–0.52	WGS 84 and UTM	https://landsat.usgs.gov
			B2	0.52–0.60		
			B3	0.63–0.69		
			B4	0.76–0.90		
			B5	1.55–1.75		
	09-03-1995		B6	10.4.–12.50		
Landsat 7, ETM	04-11-2004		B7	2.08–2.35		
	12-03-2005		B9	1.36–1.39		
Landsat 8, OLI	31-10-2017		B10	10.30–11.30		
	08-03-2018		B11	11.50–12.50		
ASTER Global DEM V-2	October, 2011		–	–		

0.5×0.5 grid resolutions (https://psl.noaa.gov/data/gridded/index.html). The data set also being used by National Oceanic and Atmospheric Administration (NOAA/CPC) for verification, this is a global GTS (Global Telecommunication System) data and is gridded using the Shepard Algorithm with consideration of orographic effects. More importantly, this data set can also be applied to monitor surface air temperature variations over global land routinely or to verify the performance of model simulation and prediction (Fan and Van den Dool, 2008). In order to validate the LST, gauge-based observed grid data were corroborated with satellite derived LST which showed a good positive correlation between them.

Climatic Trend and Variability Analysis

In this study, both parametric and nonparametric analysis techniques have been used to analyze the temperature and precipitation data. The variability within the climatic data has been computed using Eq. 1.

The statistical distribution of climatic data is examined by the following equation (Eq. 1)

$$\text{CV} = \frac{\sigma}{\mu} \times 100 \qquad (1)$$

where CV indicates the coefficient of variation, σ stands for standard deviation, and μ denotes mean; where the higher CV value indicates higher variability and vice versa.

As the normality and homogeneity of time series data may be adversely affected by the outlier and missing data in parametric test, nonparametric technique has been used here according to the MK test and Sen's slope estimators to identify the recent trend of temperature and precipitation (Mann, 1945; Sen, 1968). To project the trend in a time series data without specifying whether the trend is linear or nonlinear, MK is more suitable and widely used for meteorological data as it has non-normal distribution, outlier and missing characteristics (Yue et al., 2002).

The trend of the recent temperature and precipitation has been done using MK nonparametric test, where MK Statistics 'S' is computed as

$$\sum_{i=1}^{n-1} \sum_{j=i+1}^{n} \text{sgn}(x_j - x_i) \qquad (2)$$

where xj and xi are the sequential data and n is the length of the data set

$$\text{sgn}(t) = \begin{cases} 1, & \text{For } t > 0 \\ 0, & \text{For } t = 0 \\ -1, & \text{For } t < 0 \end{cases} \qquad (3)$$

The value of 'S' indicates the trend of the data set, a positive value indicates a rising trend, and a negative value indicates a falling trend. The Mann–Kendall test has documented that when the observation is more than 10 ($n \geq 10$), the test statistics is approximately normally distributed with the mean and $E(S)$ become (0) (Kendall, 1975). In this case, variance statistics is as follows:

$$\text{Var}(S) = \frac{n(n-1)(2n+5) - \sum_{i=1}^{m} t_i(t_i - 1)(2t_i + 5)}{18} \qquad (4)$$

where 'n' is the number of the observation and ti are the ties of the sample time series. The standardized test statistics Z_{MK} is computed as follows:

$$Z_{MK} = \begin{cases} \dfrac{S-1}{\sqrt{\mathrm{Var}(S)}}, & \text{For } S > 0 \\ 0, & \text{For } S = 0 \\ \dfrac{S+1}{\sqrt{\mathrm{Var}(S)}}, & \text{For } S < 0 \end{cases} \qquad (5)$$

where Z_{MK} follows a normal distribution, a positive Z_{MK} depicts an upward trend and a negative Z_{MK} depicts a downward trend for the period, respectively.

The magnitude of trend (Ti in Eq. 6) among the climatic variables has been computed using the Sen's slope (1968).

$$T_i = \frac{Xj - Xk}{j - k} \text{ for } i = 1, 2, 3, ...N \qquad (6)$$

where Xj and Xk are the data values for j and k times of a period where $j > k$. the slope is estimated for each observation. Median (Eq. 7) is computed from N observations of the slope to estimate the Sen's Slope estimator is

$$Q_i = T_{\frac{N+1}{2}} \text{ for } N \text{ is odd}$$
$$Q_i = \frac{1}{2}\left(T_{\frac{N}{2}} T_{\frac{N+1}{2}}\right) \text{ for } N \text{ is even} \qquad (7)$$

When the N Slope observations are odd, the Sen's estimator is computed as $Q\text{med} = (N + 1)/2$ and for even time of observation the slope estimate is $Q\text{med} = [(N/2) + ((N + 2)/2)]/2$. The positive or negative slope Qi is obtained as an upward means increasing or downward means decreasing trend.

Multispectral Images Analysis

To determine the spatiality of surface temperature, vegetation cover, and snow fed area, multispectral Landsat images have been used incorporating suitable indices like land surface temperature (LST), normalized difference vegetation index (NDVI), and normalized difference snow index (NDSI). LST is an inseparable component of the radiative transfer equation for space borne thermal infrared (TIR) sensor (Li et al., 2013). It helps in critically characterizing the climate system, as well as, its uncertainty both in a regional and global scale (Mannstein, 1987). It is used to estimate crop yield using triangular scatters of LST and vegetation index (Holzman et al., 2014). NDSI is a spectral ratio (Townshend & Tucker, 1984; Tucker, 1979, 1986) that takes advantage of the spectral differences of snow in short-wave infrared (SWIR) and visible spectral bands (green) to identify snow versus other features (Nolin & Liang, 2000). Since the accuracy of LST is very much necessary for various applications, the validation techniques have been applied here to reduce its uncertainty, where the result of the LST has been validated with CPC observed grid temperature data. As a part of the suitability analysis for apple orchards, the analytic hierarchy process (AHP) also has been adopted here. Eventually, all the steps and methodologies have been shown using a flow diagram in Fig. 2.

Estimation of LST and VCA

In this study, the TIR band (i.e., band 6 for both TM and ETM, band 10 for OLI sensor data) was used to estimate brightness temperature (BT). Red and NIR bands (i.e., bands 3, 4 for both TM and ETM, bands 4, 5 for OLI) were used to calculate the NDVI. Other necessary information presented in the metadata of satellite images were systematically used for farther calculation. Estimation of LST is a complex process, and it is cataloged in Table S1. After applying the above-mentioned efforts, an LST raster map has been produced to get the area under different LST classes, then different polygon layers for each class are created using ArcGIS software. The process is also same for VCA calculation, creating a polygon layer for each class from the NDVI raster map. And finally, the area is calculated using the field calculator in attribute table.

Assessing the Variability of SCL and SCA

When working with SCA and SCL, remotely sensed data are extremely valuable to study its spatial and temporal variability. The NDSI has been incorporated for two separate time periods: one for before the onset of snowfall (i.e., late autumn) and other after snowfall (early spring) so that in the final output one can get a clearer idea regarding the magnitude of snow line that has shifted over times. To segregate snow-covered from the non-snow-covered areas, the NDSI was estimated using green and shortwave infrared (SWIR) band (band 2, 5 for TM and band 3, 6 for OLI sensor) by the following equation (after Hall et al, 2002)

$$NDSI = \frac{\text{Green} - \text{SWIR}}{\text{Green} + \text{SWIR}} \qquad (8)$$

The NDSI-based raster data of different years were then reclassified into two classes, i.e., snow cover and non-snow cover using Hall et al. (1998) that suggested NDSI threshold value (i.e., > 0.40). Here, we have considered cloud free scene having less than 5% coverage. To get the snow-covered and non-snow-covered area from the NDSI raster image, authors have created a polygon layer from the reclassified NDSI raster and calculated the area. In order to draw the total shifting of snow line, a shape file was created and lines were digitized for different years (1994, 1995, 2017 and 2018) depicting the actual shifting of snow cover area between the first and last years. To estimate the height, vector files of snow lines of all year's data were overlaid on the digital elevation output (30 m resolution ASTER Global DEM v2 data set). A point shape file has
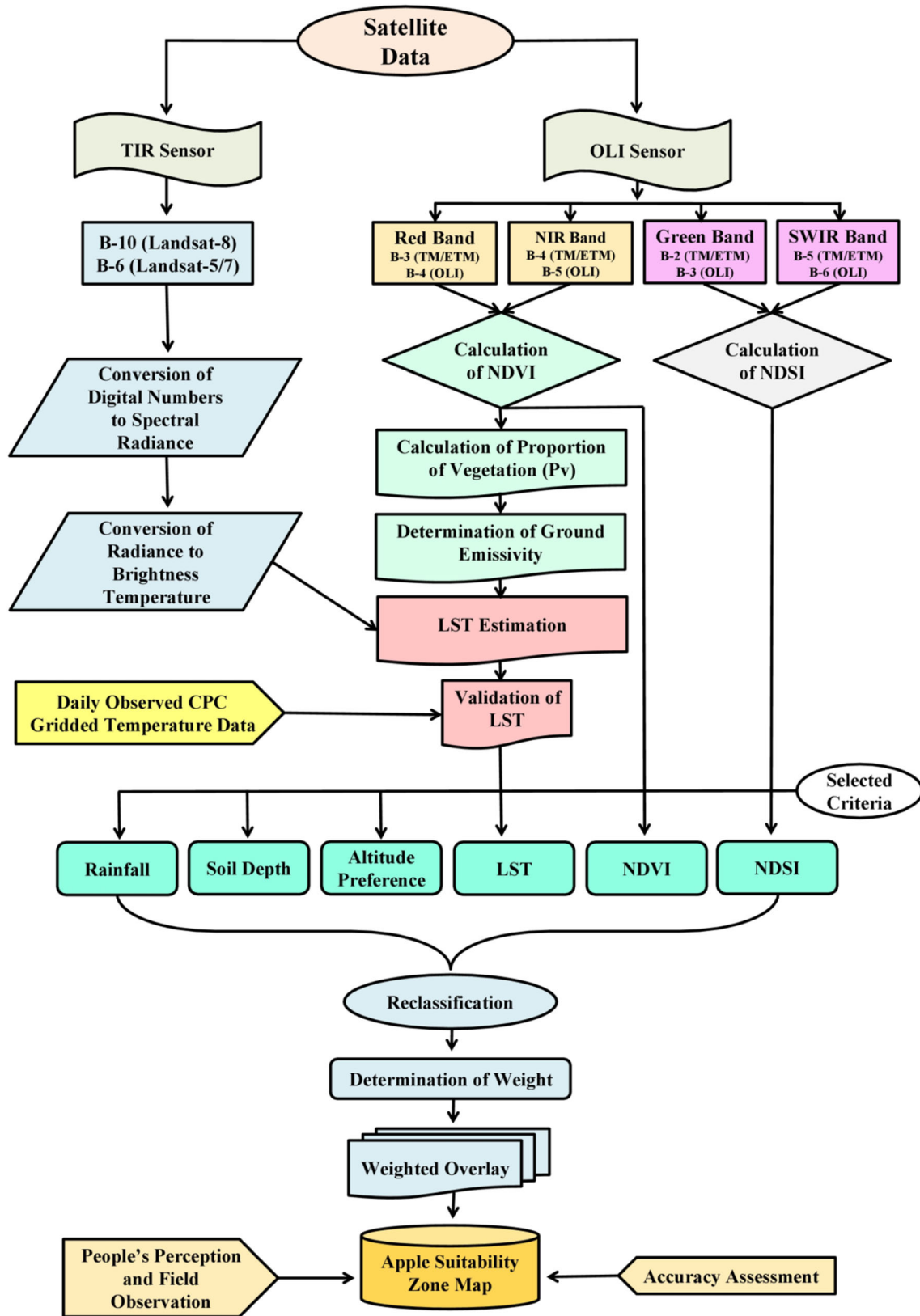
Fig. 2 Schematic representation of the general methodologies for multispectral image analysis

Table 2 Pair-wise comparison matrix for AHP

Criteria	Rainfall	Soil depth	LST	NDSI	NDVI	Altitude preference	Criteria weight
Rainfall	1	3	0.2	5	4	6	0.20974542
Soil depth	0.33	1	0.14	3	2	4	0.10824878
LST	5	7	1	8	7	8	0.50999802
NDSI	0.2	0.33	0.12	1	0.33	2	0.04571292
NDVI	0.25	0.5	0.14	3	1	5	0.0943716
Altitude preference	0.17	0.25	0.12	0.5	0.2	1	0.03192327

Maximum eigenvalue (λ max) = 6.453

$n = 6$

Consistency index (CI) = (λ max $- n$)/($n - 1$) = 0.09056

Random index (RI) = 1.24; consistency ratio (CR) = CI/RI = 0.07303

been created in ArcGIS using Arc-catalogue. Keeping the snapping mode on, further digitization was done to delineate the snowline of the year 1994 and finally digitized points data were masked by the mask function from ASTER GDEM output. So that each points bears some height and then those points were exported into the Microsoft excel sheet to estimate the average height. The same process was repeated for the years 1995, 2017 and 2018 to estimate the snow line height. Finally, all SCL of different years has been superimposed on the DEM output of the study area to visualize the shifting of SCL and SCA.

Altitudinal Shifting of Apple Orchards

Monitoring the altitudinal shifting of apple orchards needs careful investigation and analysis of the remotely sensed data in different years. Here, data of 1994, 2004 and 2017 (late autumn period/before the onset of snowfall) have been considered for the analysis. The presence of a minimum amount of snowfall over the ground and clear sky helped us to identify and distinguish apple orchards from other types of vegetation using the effects on tone, size, texture, shadow, pattern and site-association with respect to their surroundings. A patch of apple orchards has been identified and a polygon layer was created from Google Earth pro. It is a Geo-Browser which accesses various meta-data like aerial, satellite, other geographical data from the internet, and it also used elevation information from NASA's Shuttle Radar Topography Mission (SRTM) to represent the Earth as a 3D globe (Pandya et al., 2017). This is user-friendly software, and it allows us better spatial resolution (15 m) and high-quality visualizing effect using aerial view. Hence, orchards were easily identified from other trees, but it is more difficult to do by using Landsat data. With the help of the Google Earth time slider function, layers of apple orchards were created for snow free late autumn period in 1994, 2004 and 2017. Subsequently, all the layers were overlapped to show the shifting during the last three decades. The validation of altitudinal shifting

of orchards was assessed empirically based on the perception of local farmers using detailed and structured questionnaires. For this purpose, total 92 farmers were interviewed in December, 2018 (see Table S9).

Suitability Zone Analysis for Apple Orchards

Saaty (1977, 1980) developed one of the multiple criteria decision-making methods called AHP. It is a method that uses consistency, deriving priorities among criteria and alternatives, simplifies preference ratings among decision criteria using pair-wise comparisons (Gayen et al., 2020; Mishra et al., 2020). It provides best alternatives for severe situations and problems of land management, using a mathematical method that establishes a hierarchical model for it (Cengiz and Akbulak, 2009; Malczewski, 2006; Roig-Tierno, et al. 2013; Saaty, 2001, Gayen & Haque, 2022). The three significant steps for generating AHP is, firstly, for each hierarchical level, a pair-wise comparison matrix is generated (Table 2) with the standard weights of the criteria, and the consistency ratio (CR) calculation (Malczewski, 1999; Madrigal-Martínez and PugaCalderón, 2018). The CR coefficient should be less than 0.1, indicating the overall consistency of the pair-wise comparison matrix (Park et al. 2011). When CR is ≤ 0.10, it shows that the pair-wise comparison matrix has an acceptable consistency and when CR is ≥ 0.10, it indicates that pair-wise consistency has inadequate consistency. When CR is above 0.10, to reduce inconsistency, the judgments are re-examined (Chakraborty and Banik 2006; Chen et al. 2010). In this study, the lambda (λ) was 6.453, consistency index (CI) = 0.09056, $n = 6$, and random index (RI) = 1.24. The calculated CR value was 0.07303, which indicates that the pair-wise comparison matrix was overall consistent for the study.

After that, the classes and value ranges of the selected evaluation criteria for the apple suitability zone assessment (Table 3) were determined, based on a review of relevant literature along with personal interviews with the District

Table 3 Weights and scores of criteria and their sub-criteria

Criteria	Weight	Influence (%)	Sub-criterion (with ranges)	Score	Data sources
LST	0.51	51	Very Low (< − 10)	2	Landsat data, Source: https://earthexplorer.usgs.gov/
			Low (− 10 to 0)	3	
			Moderate (0–10)	8	
			High (10–20)	7	
			Very High (> 20)	4	
Rainfall (mm)	0.21	21	Very Low (< 580)	2	CPC global daily precipitation data, Source: https://psl.noaa.gov/data/gridded/data.cpc.globalprecip.html
			Low (580–610)	3	
			Moderate (610–640)	5	
			High (640–670)	6	
			Very High (> 670)	7	
Soil depth (grid-wise fraction area)	0.11	11	Very Low (< 2400)	3	NRSC/ISRO Open data, Source: https://bhuvan-app3.nrsc.gov.in/data/download/index.php
			Low (2400–4200)	4	
			Moderate (4200–6000)	5	
			High (6000–7800)	6	
			Very High (> 7800)	7	
NDVI	0.09	9	Very Low (< 0.05)	1	Landsat data, Source: https://earthexplorer.usgs.gov/
			Low (0.05–0.25)	3	
			Moderate (0.25–0.4)	7	
			High (0.4–0.55)	8	
			Very High (> 0.55)	6	
NDSI	0.05	5	Very Low (< − 0.2)	6	Landsat data, Source: https://earthexplorer.usgs.gov/
			Low (− 0.2 to 0.1)	7	
			Moderate (0.1–0.4)	8	
			High (0.4–0.7)	2	
			Very High (> 0.7)	1	
Altitude preference (meter)	0.03	3	Very Low (< 2000)	3	ASTER Global Digital Elevation Model data, Source: https://earthexplorer.usgs.gov/
			Low (2000–2500)	5	
			Moderate (2500–3000)	7	
			High (3000–3500)	8	
			Very High (> 3500)	2	

Horticulture Officer, horticulturists, farm managers, and local farmers conducted in December, 2018, by following the method suggested by Madrigal-Martínez and Pug-aCalderón (2018); Manandhar et al. (2014). Finally, the weighted overlay analysis (WOA) was applied to generate the apple suitability zone map. The individual suitability maps of the selected criteria were classified into five levels of suitability classes and weighted by their importance, using a numerical scale for comparison developed by Saaty (2001). Finally, all the layers were overlaid by recognizing cell values to the same scale, giving a weight value to the individual criterion, and integrating the weight cell values together as given below:

$$ASZ = \sum_{i=1}^{n} W_i X_i \qquad (9)$$

where ASZ indicates the total ASZ score, W_i denotes the weight of ASZ criteria, X_i indicates the sub-criteria score of i ASZ criteria, and n represents a total number of ASZ criteria (Cengiz and Akbulak 2009; Pramanik 2016). Using the above method, the apple suitability zones (ASZ) map was made in ArcGIS software.

Result and Discussion

It is noticed that there are regional imprints of increasing temperature and less precipitation due to the effect of global warming leading to altitudinal shifting of LST and less snow fall in lower elevated areas. This study experiences new encroachment of orchards toward areas where earlier permanent snow cover was found.

Relationship of Climatic Variables with Apple Cultivation in Kalpa

Temporal Variation of Temperature and its Trend

In this study (Table S2), season-wise average maximum temperature for the past three decades in winter period has the highest variability (23.55%) followed by spring and autumn, whereas in summer it is least variable (2.51%) and it is also quite less fluctuating in annual dimension (5.43%). Thus, it reveals that the maximum temperature in winter and spring is not consistent in this region (Fig. S1). The changes of minimum temperatures in this study area are highly variable; the most variability is observed in winter and least in the summer season (Fig. S2). It is highly varied from one year to another years, and it creates problems for the optimum growth of apple production. The MK test and Sen's slope estimation of the past 31 years clearly show a positive trend in winter (0.057 °C/years),

spring (0.109 °C/years) and autumn. Similarly, the annual maximum temperature indicates significant rising trends at a rate of 0.047 °C per year (Fig. 3a). The MK and Sen's slope results in Table S3 clearly indicate that there is a negative trend in winter and autumn seasons; the annual minimum temperature also sowing negative trend at − 0.0022 °C/ year, but these all are statistically insignificant (Fig. 3b).

High temperature during winter season is considered as a negative factor for apple cultivators. An increase in surface temperature during the summer, as well as in the winter season, affects the growth of apples and directly influences the number of chilling hours. Inter-annual variation in effective chill unit shows a decreasing trend from 1978 to 2013. Due to this, the shift in zones of apple orchards toward higher elevation was marginal during the 1970–80, but the rate of shifting toward higher altitudes increased drastically during 2000–2013 (Singh and Patel, 2017). The rise of minimum temperature during the winter season becomes negative for apple cultivation because it reduces apple production and quality. Apple production needs winter with high chilling hours, during its dormant periods, but the gradual increase of maximum temperature during winter seasons leads to the warming of surface temperature. This in turn leads to the number of chilling hours being diminished, which is greatly affecting apple production (Basannagari & Kala, 2013).
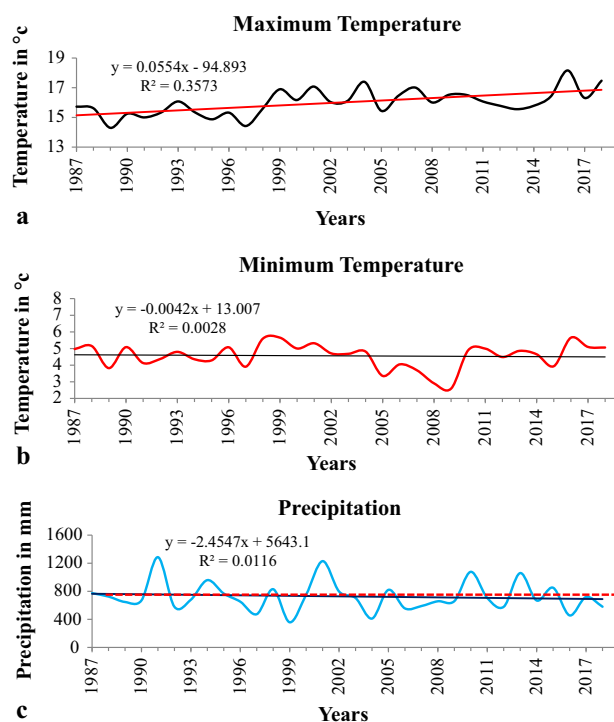

Fig. 3 Annual variation and trend of **a** maximum temperature, **b** minimum temperature and **c** mean precipitation from 1987 to 2018 in Kalpa tehsil, Kinnaur District, Himachal Pradesh

During the period of pre-dormant, dormant and flowering period of apples, high variability of minimum temperature leads to improper development of the fruit and hence decreased the production. The flowering, fruit settings, healthy growth of apple orchards are affected due to the rise in minimum temperature in spring time leading to increase in defrost activities and faster melting of accumulated snow which becomes responsible for less production of apples. The annual minimum temperature also indicates a statistically insignificant negative trend, decreasing at a very slow rate. Variation in climatic conditions produces diseases in apple (scrub diseases, premature defoliation, alternaria, and alternaria alternata) in the study area, sometimes even leading to endemics, when an optimum favorable condition for these disease proliferation is experienced (Jangra & Sharma, 2010).

Temporal Variation and Trend of Precipitation

The precipitation, including both rainfall and snow fall for the last three decades, varies from 40.67% in winter to 82.13% in autumn (Table S4 and Fig. S3). The annual average precipitation in Kalpa is 727.53 mm with 29.35% annual variability. The MK and Sen's slope estimation indicates there is a slightly decreasing trend in precipitation during winter and spring seasons at a rate of -0.2357 mm/year and -1.7338 mm/year, respectively, and almost -2.034 mm/year decreasing trend in annual average precipitation in last three decades (Fig. 3c).

Precipitation during winter and spring seasons is crucial for apple orchards in Kalpa, as it requires attaining the chilling requirements for producing good apples during this period. Snow also acts as manure, which is essential for apple cultivation (Sen et al., 2015). Decreasing precipitation in winter and spring months produces a moisture deficit and a drought-like situation and negatively affects the growth and fruit production in apple orchards (Sen et al., 2015). Decreased volume of snowfall and rainfall in winter, spring and summer seasons has led to drought-like conditions creating moisture stress, leading to trees not flowering properly (Singh et al., 2016). Sometimes due to climate variability, winters remain warm and dry, but during spring, spring frosts occur leading to frost injury, causing damage to the flowers and leading to poor fruit set. These result in low retention of fruit and poor yields (Awasthi et al. 2001); hailstorms are also experienced, due to high fluctuation in weather and climate, which can lead to significant damage to the flowers and fruits, at various stages of growth. Hail directly damage plantations, which reduces the fruit set for the next season (Abbott, 1984).
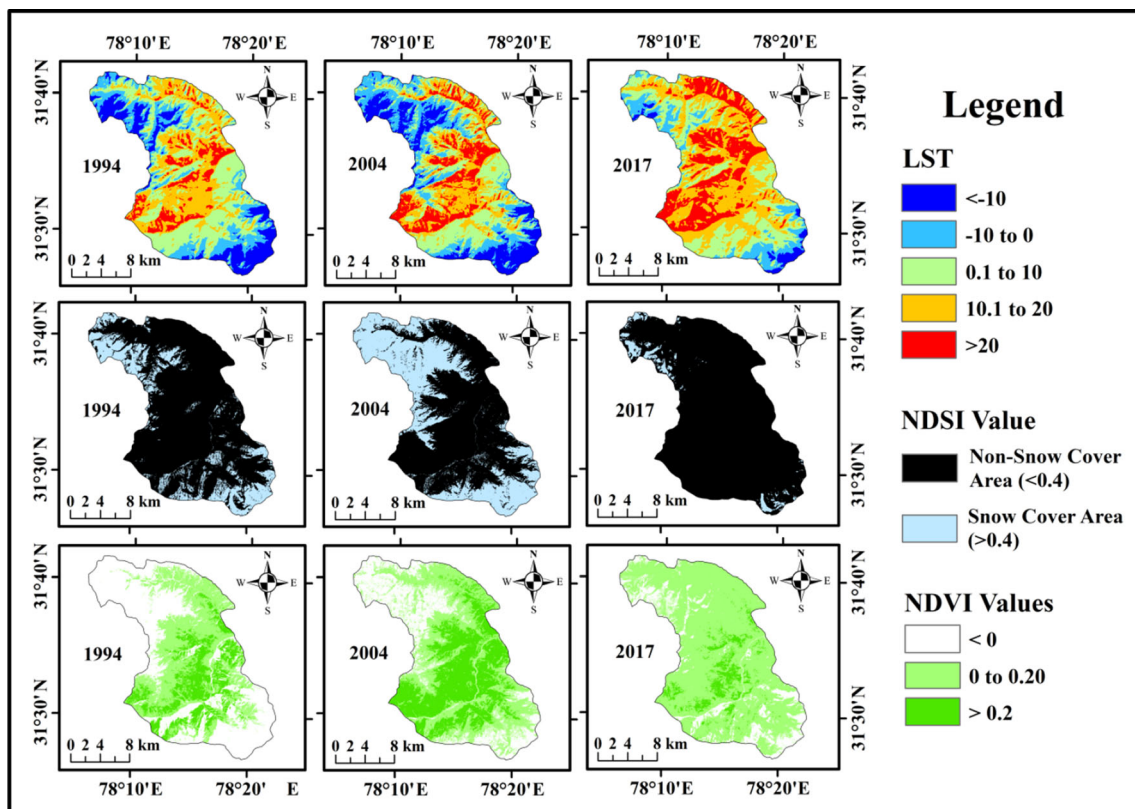

Fig. 4 Spatiotemporal changes in Land surface temperature (LST), normalized difference snow index (NDSI), normalized difference vegetation index (NDVI), in late autumn (Oct–Nov)
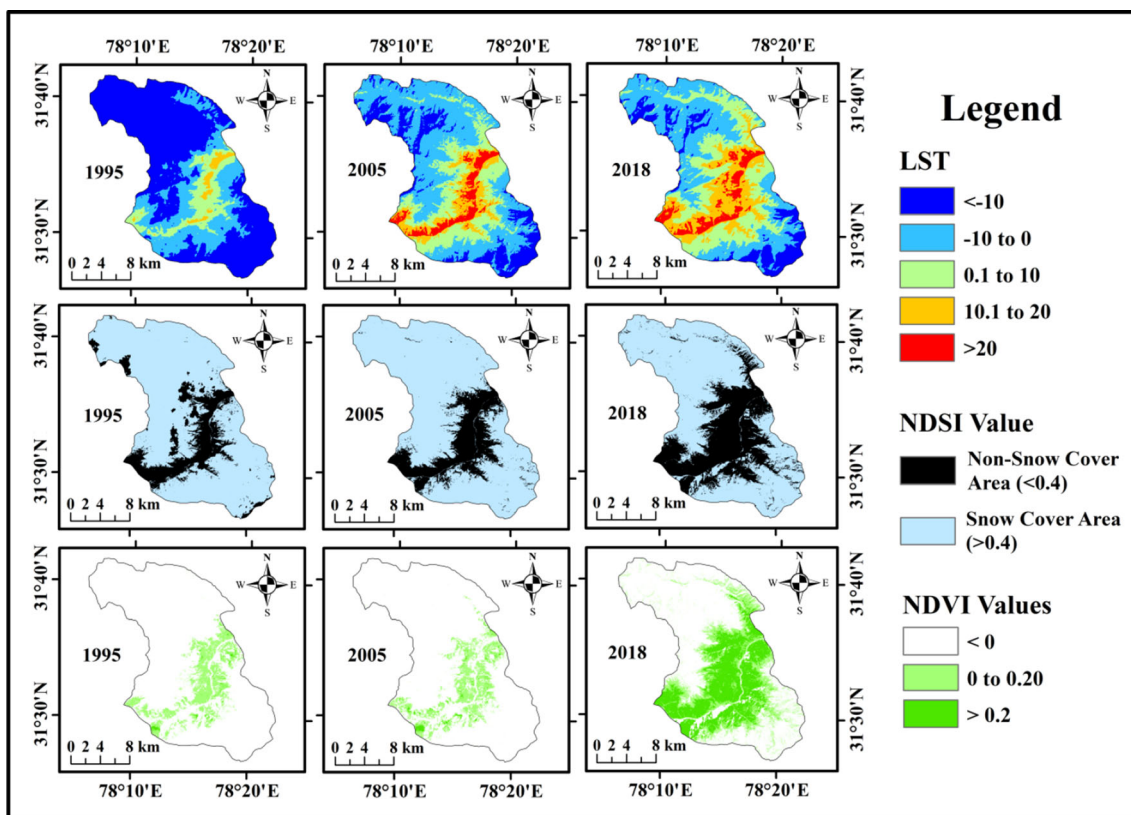
Fig. 5 Spatiotemporal changes in land surface temperature (LST), normalized difference snow index (NDSI), normalized difference vegetation index (NDVI), in early spring (March)
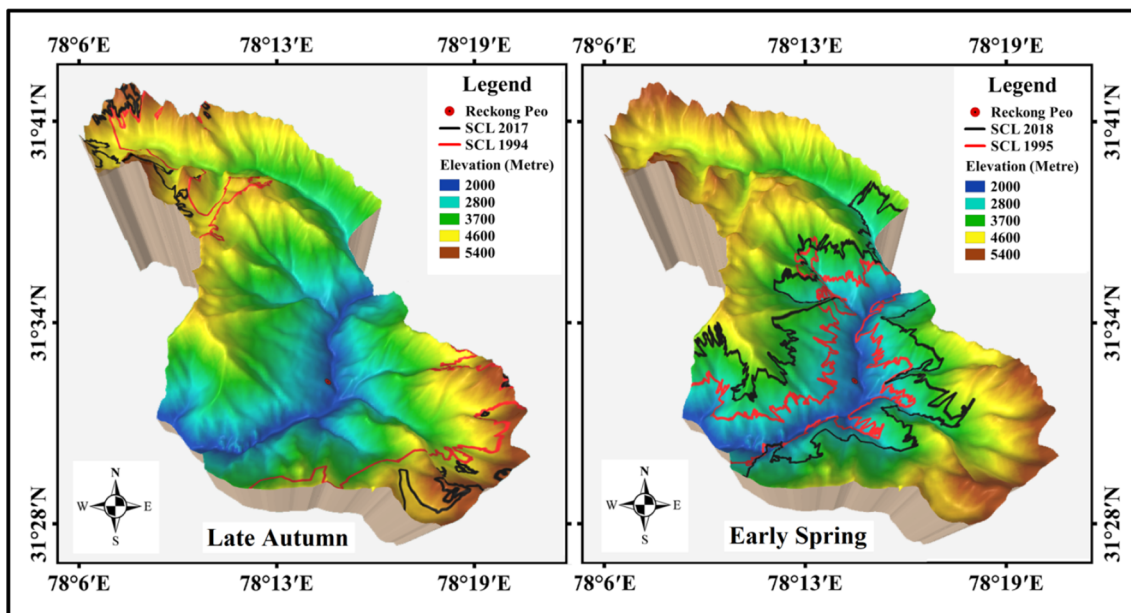

Fig. 6 Spatiotemporal change of snow cover line (SCL) in Kalpa Tehsil, Kinnaur District, H.P (1994–2018)

Cold waves and Western disturbances also have direct impacts on apple production in the northern Himalayas, as it affects the amount of rainfall and snowfall in this region (Gautam et al., 2003).
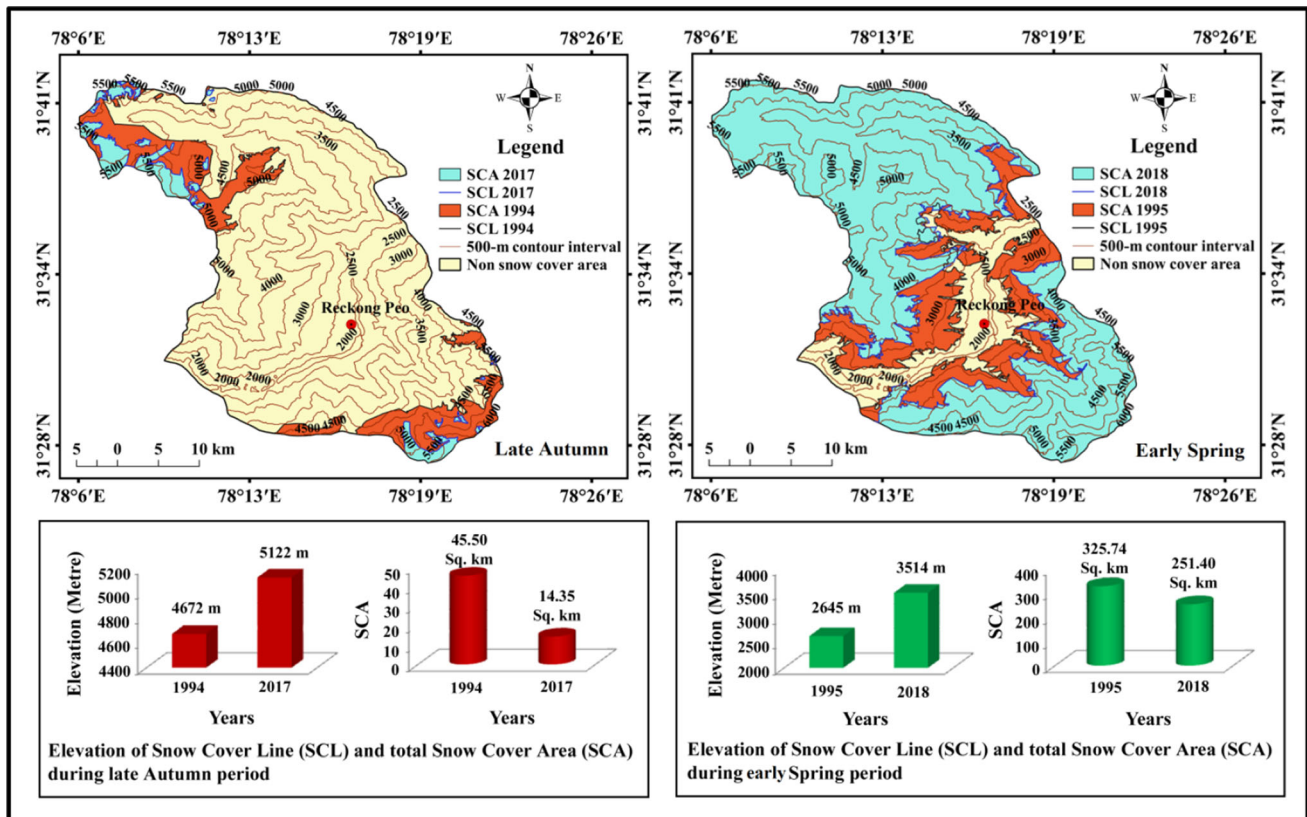
Fig. 7 Spatiotemporal changes in snow cover area (SCA) of Kalpa Tehsil, Kinnaur District, H.P (1994–2018)

Estimation of Climate Variability Through Multispectral Image Analysis

Spatiotemporal Changes of LST

Figures 4 and 5 show changes of LST before and after snowing period. Late autumn LST data of 1994, 2004 and 2017 were used to derive its scenario in the pre-snowing period. It is seen that area with LST above 20 °C have increased by almost 20 sq. km in 2004 and LST of areas below − 10 °C has increased by 19.46% from 1994 to 2004. This anomaly may be developed owing to heavy snowfall in the previous years. But, it is clearly seen that areas having LST between 10 and 20 °C have increased by almost 42.40% from 1994 to 2017 for the pre-snowing period. Areas having LST below − 10 °C got reduced by 79.88%. Even areas having LST between − 10 and 10 °C have also been significantly reduced, thereby depicting a receding snow cover due to a gradual increase in LST.

The early spring data show LST after the winter snowfall (Fig. 5). It is observed that there is a distinct reduction in areas having LST below − 10 °C (about 80.15%) from 1995 to 2018. In 1995, there is no such area to be found where the LST is above 2$\overset{\circ}{0}$C in the early spring, but it emerges slowly to 6.57 sq km. in 2018, proving that there is

an increase in LST condition during the post-snowing period. Areas having LST between 0 and 20 °C increased significantly from 1995 to 2018 by almost 16% (Table S5), which further prove that there is an increase in LST throughout the years. An area having a temperature below − 10 °C is greatly responsible for apple tree germination, growth and its production (Sahu et al., 2020; You et al., 2010), which is gradually decreasing in the lower altitudes of the Kalpa region. Previously mass of snow has accumulated throughout the winter months, with low temperatures creating long existence of chilling days. The maximum increase in LST was noticed in the lower altitudinal zones of the Kalpa area, and it is gradually increased toward the high altitudinal zones. The space borne LST provides a picture of the spatiotemporal behavior of the surface parameters and a significant means for the analysis of surface processes. This altitudinal shifting of LST clearly indicates that there is an increased surface temperature in the mountainous region which is responsible for snow line retreat. Thus, the cultivators are trying to overcome this changing climatic variability by shifting their apple orchards toward higher altitudes to get a good chilling and optimum environment for apple production.

Spatio-Temporal Changes of SCA and SCL

Snow cover extent has been mapped by NDSI which depicts changes in the snow-covered area of Kalpa in the intermediate period between 1994 and 2018 having pre- as well as post-snowing season. Area-altitude distribution influences snow accumulation which has changed significantly due to the increase of temperature and its variability. Over the western Himalaya, it is noted that the spring SCA has been reduced by a considerable amount and snow has been melting faster from winter to spring since 1993 (Kripalani et al., 2003). During the past decades, changes in the snow cover are found in quite a large extent. Figure 6 shows changes in the snow covered line over the past three decades in Kalpa Tehsil. It is found that a vast stretch of open field between the pre- and post-winter snowfall has been developed and areas of winter snow accumulation are treated as an attractive filed of new apple orchards and the fresh snow acts as a fertilizer for apple plants. There is a reduction of almost 68.46% of the area covered in snow during the pre-snowfall period from 1994 to 2017 (Table S6). As the years go by, the area covered by snow gets reduced and the snow cover line shifts toward higher slopes. SCA in the region is affected by the monotonous decrease of snowfall (Snehmani et al., 2016).

In 1994, snow cover line could be found at an elevation of around 4600 m, but in 2017 snow cover line could only be found at elevations above 5000 m. We can thereby say that the SCL has shifted about 600 m toward a higher altitude. Same condition has been observed in the post-snowfall period, the SCL shifted to higher altitudes from 2500 m in 1995 to almost 3500 m in 2018. But, we see that the shift in the SCL of the post-snowfall period is more drastic as the SCL shifted by almost 1000 m in the span of 23 years (Fig. 7).
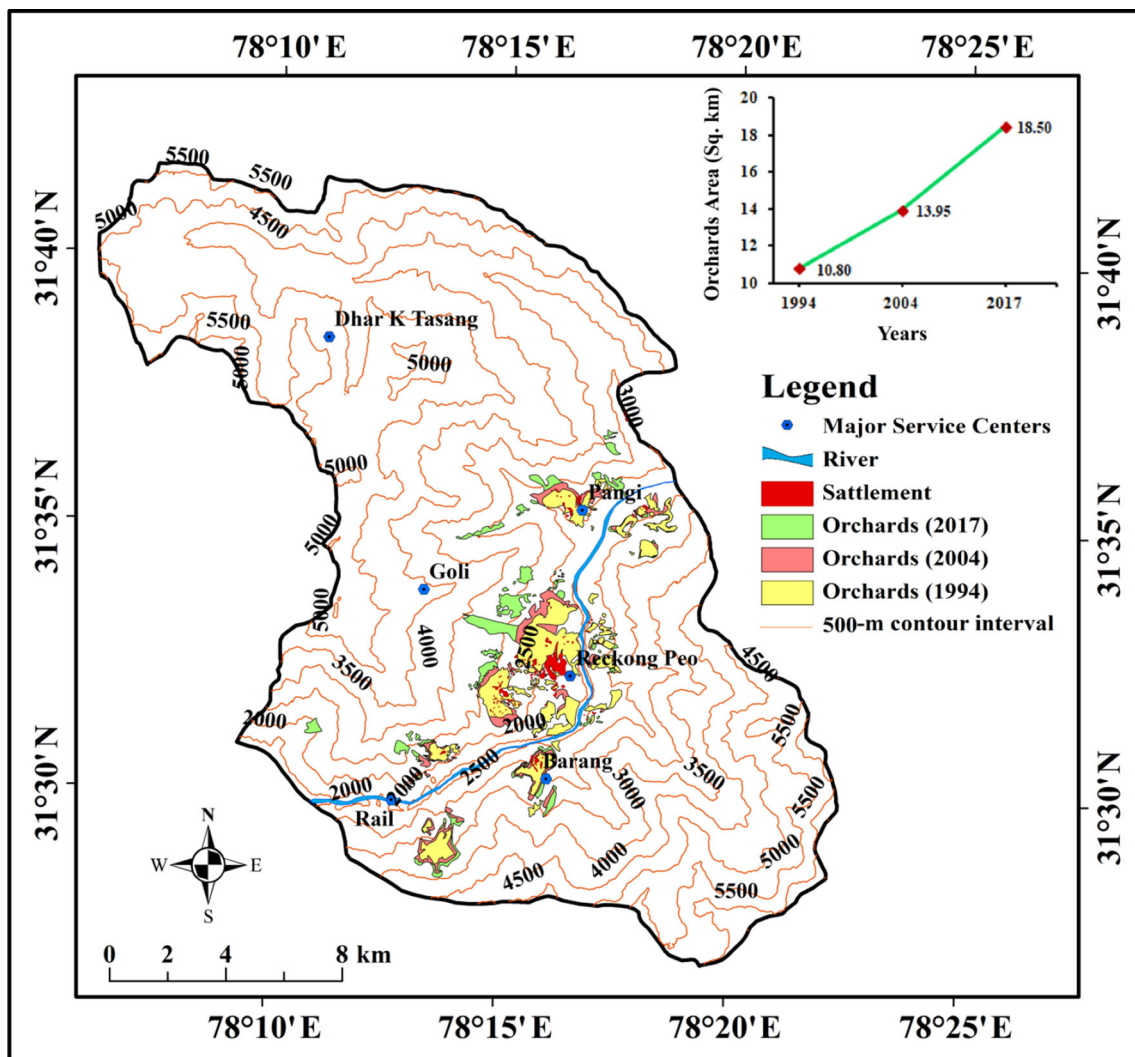

Fig. 8 Altitudinal shifts of apple orchards in Kalpa Tehsil, Kinnaur District, H.P (1994–2017)

From 1994 to 2004, before the onset of the snowing period there is an increase in the snow-covered area by more than 100 km^2. (45.499 km^2 in 1994 to 147.584 km2 in 2004, overall 224.35% increase); however, it diminished drastically in 2017 of October (due to the absence of cloud free data for the 1st week of November, 2017 we have used 31st October data) with hardly any snow-covered area in the whole region (only 14.347 sq. km, a decrease of 90.23% of the snow covered area), thereby indicating a rapid rate of snow melt of previously permanent snow-covered regions, making the whole area almost a non-snow-covered region, shown in Fig. 7. When we look at the consecutive maps of March 1995, 2005 and 2018 after the snowing season, we see that the area covered by snow continues to gradually decrease from 1995 to 2018, (more or less than 100 sq. km) (Table S6). The negative correlation observed between mean seasonal temperature and SCA indicates that if the temperature is more, it leads to less SCA and if the temperature is less, then the SCA is likely to be more. The trend of temperature and precipitation over the Western Himalaya between 1975 and 2006 has shown significant change (Dimri et al., 2008). In Western Himalaya, an increase of 2 °C temperature and a decreasing trend in winter precipitation are observed from data on long-term trends in seasonal (November–April) temperature and winter precipitation (Shekhar et al., 2010). The lower altitude areas, which previously experienced snow veil since early winter, now hardly have any imprints due to the rapid melting of snow for high temperature. This can harm the vegetation, as well as orchards due to such receding snow cover and shifting of snow cover line toward the higher altitudes.

Spatio-temporal Changes of VCA

Warming at the regional level has led to an upward shift of vegetation beyond tree lines throughout the alpine climatic provinces. This is also observed in high elevated areas of the Himalaya which are in direct contrast to that of the mountains in Europe (Gottfried et al., 2012; Gehrig-Fasel et al., 2007). The vegetation cover in Kalpa has been processed by NDVI to find the trend and pattern of VCA and how the VCA has changed through the decades (Figs. 4 and 5). Consecutive years are taken to show the difference in vegetation cover and its relation with climate by seasonal cycles. In consideration of late autumn, i.e., before the onset of the snowfall in 1994, 2004 and 2017, the total area under vegetation was estimated approx 206.802 sq. km, 282.093 sq. km and 326.069 sq. km, respectively (Table S7) (in consideration of moderate and dense vegetation). During the late autumn period, the canopy cover is more because of the monsoonal rain and low amounts of snowfall and warmer temperatures than in the post-snow fall period, i.e., early spring, when the non-canopy cover is more. Growth of high-altitude Himalayan vegetation is significantly controlled by precipitation, especially snowfall (Liang et al., 2014). When looking at the consecutive years (the after- snowfall periods, i.e., early spring), similar patterns of NDSI are found. Snow gradually covers less area from 1995 to 2018 (Fig. 5) producing bare ground. The non-vegetation zone recedes from 330 sq. km approx from 1995 to about 216 sq. km in 2018, thus, a 34.54% decrease in non-vegetation area. But the dense vegetation cover found at the lower altitudes has increased area to 96.066 sq. km in 2018 indicating a significant rise because of rapid increase in temperature, favoring the growth of vegetation in the early spring, and previously it was not possible. Similarly, moisture availability declines due to absence of springs and reduce of glacial at higher altitudinal area. From all these, we can deduce that the vegetation cover, snow cover and the land surface temperature are interlinked and correlated with each other.

This study finds the extension of apple orchards, and the new orchards are developed at the higher altitudes between 2500 and 4000 m (Fig. 8), as found in Reckong Peo, Barang, Pangi and Rail locality. Previously, the apple orchards could be found only at altitudes between 2000 and 2500 m producing good-quality apples in the 1990s and early 2000s. But, as climatic condition varies and became unsuitable for producing the best quality apples on down slope low elevated areas, farmers started continuously shifting up their farm land toward higher slopes as higher altitudes were becoming more suitable for apple cultivation. Similarly, many cultivators preferred to shift their orchards to the higher elevated areas, which were earlier unsuitable due to extremely low temperatures.

Scenario of Altitudinal Shifting in a Changing Climate

The area having LST more than 0 °C and SCA are deeply related for the pre- and post-snow cover period (November and March, respectively). Generally, a low amount of SCA has been depicted during the end of the summer season. Thus, in late autumn (pre-snow cover), the area having less than 0 °C LST is very limited. The snow-covered patches are found in small pockets (Fig. 7). The net SCA and LST are inversely related in the pre- and post-snowing period. The same condition is also found in post-snowing season (early spring), when low LST is experienced over the vast surface due to the dominancy of snow-covered area, which depicts a strong linear trend ($R^2 = 0.8628$) (Fig. S4a–h).

There is a moderate correlation between vegetation cover and LST (r-value 0.616), with a weak trend line ($R^2 = 0.379$), as the scatter plots are quite dispersed. This is due to various conditions, such as, having a rocky surface

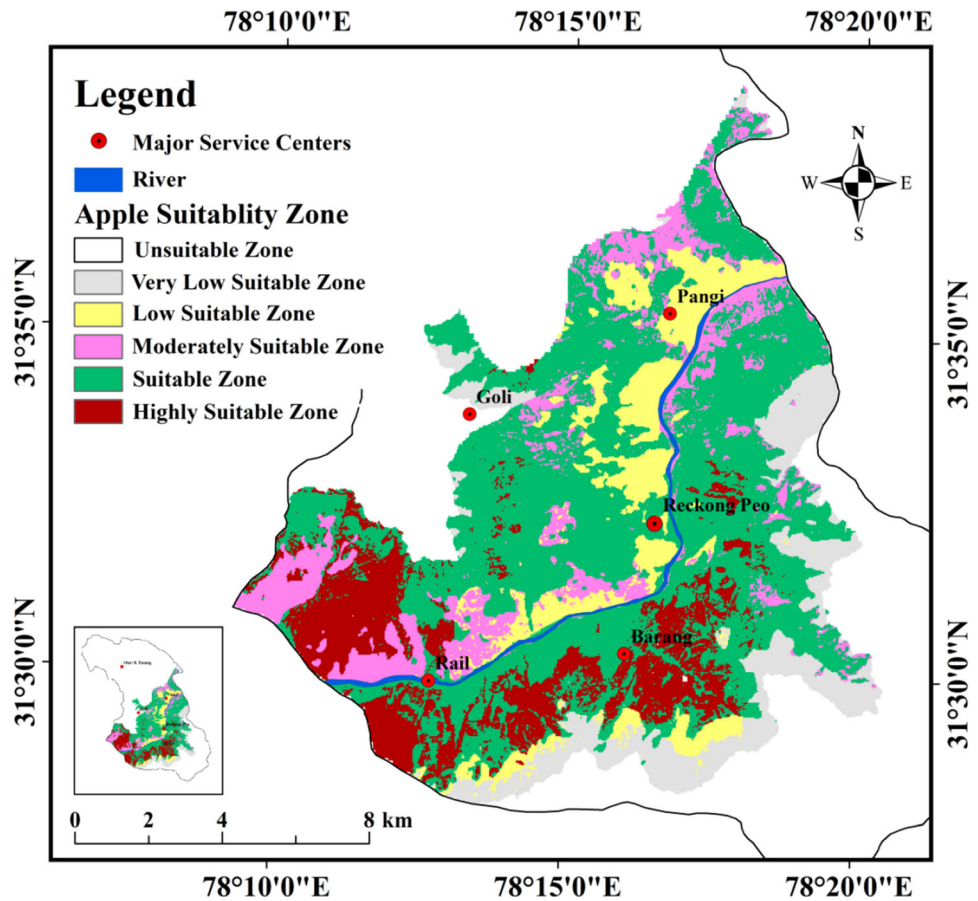**Fig. 9** AHP-based apple suitability zone (ASZ) map of Kalpa Tehsil, Kinnaur District, HP

Table 4 The area under different suitable classes

Apple suitable zone	Area (Sq. Km)	Area (%)
Unsuitable zone (UZ)	212.39	55.89
Very low suitable zone (VLSZ)	18.74	4.93
Low suitable zone (LSZ)	17.88	4.71
Moderately suitable zone (MSZ)	20.86	5.49
Suitable zone (SZ)	85.24	22.43
Highly suitable zone (HSZ)	24.89	6.55
Total	380	100

where vegetation cannot grow even though the LST is high, or the crops have already been harvested before the winter season, leaving barren lands. The post-snow fall period also shows a moderate correlation (r-value 0.761), along with a moderate trend line ($R^2 = 0.5798$). This may be due to the fact that the barren lands are covered with snow and the vegetation can be found in the lower altitudes where LST is greater than 0 °C. The vegetation cover area and snow-covered area are always inversely related for the pre- and post-snowing period. If there is permanent snow, most of the vegetation cannot grow freely. For the pre-snowfall

season, relationship between the vegetation cover area and the snow-covered area is slightly negative (r-value − 0.075) due to very less snow cover which also varies greatly each year. We can observe that there is a very weak trend line ($R^2 = 0.0056$), having a widely dispersed scatter plot. From this we cannot conclude that there is any strong relationship between the two variables or they affect each other in any way or not. But for the post-snow season, (Fig. S4h), we see a highly negative correlation (r-value − 0.947), as there is a lot of snow accumulated and most vegetation cannot grow in the winter snowing period. The scatters are close fit showing the presence of a strong trend line ($R^2 = 0.8975$) which thereby proves a definite inter-dependence between the vegetation cover area and the snow cover area.

Over the period of 1994, 2004, 2017, during late autumn, we see an increase in LST and a decrease in NDSI value. This may be due to global warming, the effect of urban activities in the down valley at Reckong Peo, transport emissions, etc., which create local warming, formulating warmer weather till the end of November. As a result, occurrence of snow fall and lower temperature gets reduced during winter months. Snow melt water increases soil-moisture capacities, which freeze during the winter
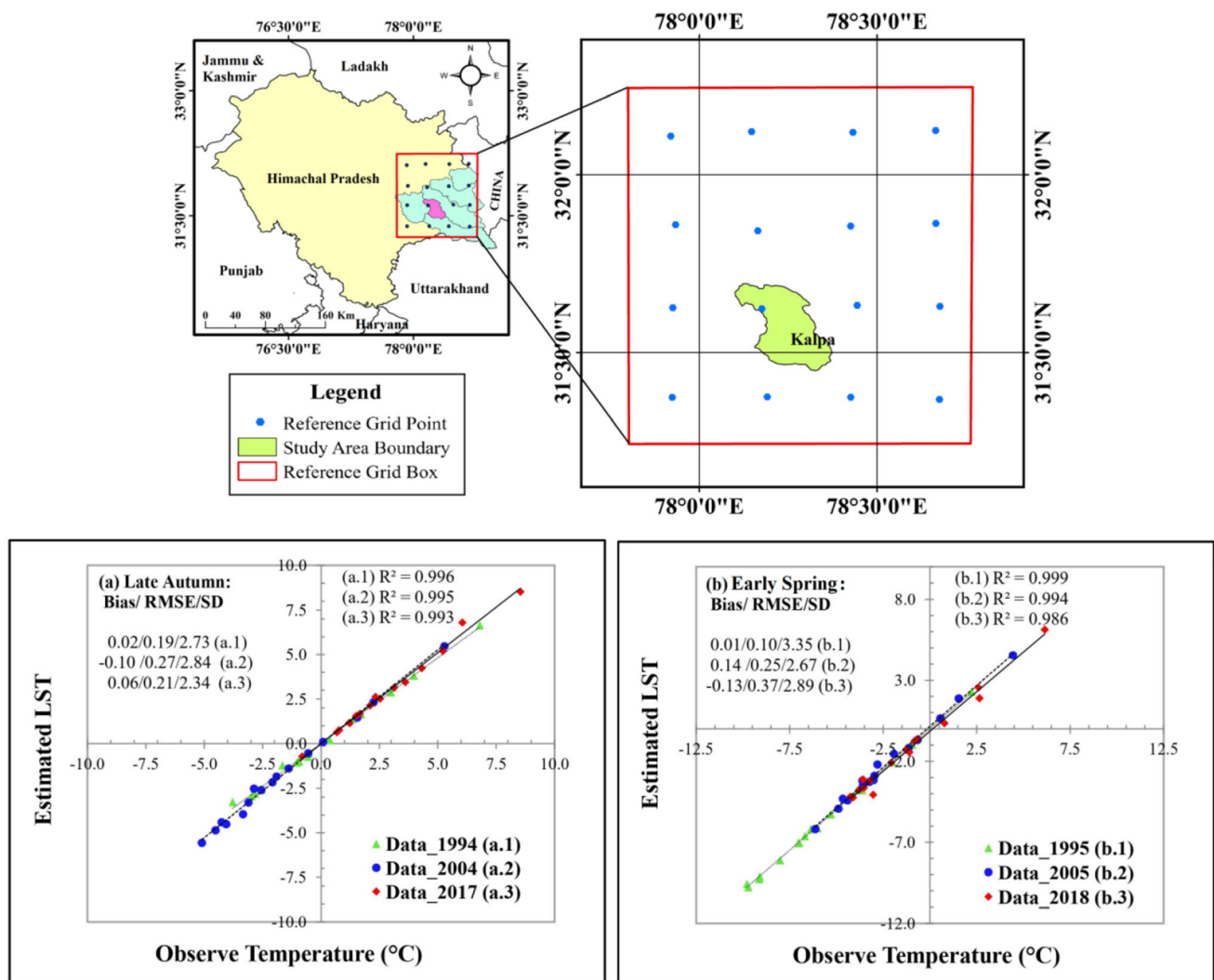
Fig. 10 a, b Validation of land surface temperature

seasons but snow fall due to cold weather, with a long chilling period is most important for apple budding. To acquire fresh snow in early winter, people wish to develop their orchards at uphill areas replacing the deep alpine forest, previously covered in snow. Thus, deforestation is the result of apple orchard practices of Kalpa, where farmers are replacing the barren or alpine snow covered areas in higher altitudes with apple orchards. This shift is seen in the higher NDVI values from the years of 1994, 2004 to 2017, where previously non-vegetative lands with NDVI value of < 0 in 1994 and 2004 are having higher NDVI values in 2017.

Apple Suitability Zone (ASZ) Assessment

To analyze the apple suitability zone using the AHP method, the criteria of rainfall, soil depth, altitude preference, LST, NDVI, NDSI were taken into consideration,

where they were given a criteria weight, along with weight and sub-scores of their criteria and sub-criteria. In our study area for apple suitability zone identification, climatic factors (LST and rainfall) were given more weightage than soil and others factors because climatic conditions have higher variation than soil conditions. Climatic variability has a greater influence on the growth and productivity of apple trees. It can also be said that poor soil conditions can be overcome by simple and easy soil management strategies. With respect to relevant literature, questionnaire based personal interviews with farmers, horticulturists, and farm managers in December, 2018 advocate the highest criterion weight is given to LST (0.51), followed by rainfall (0.21), soil depth (0.11), NDVI (0.09), NDSI (0.05) and altitude preference (0.03) (Table 3).

The final apple suitability map is grouped into six classes, where the higher altitude indicates the most suitable area for apple cultivation due to the presence of

suitable environments and cold temperatures. Though, the extremely high altitudinal areas are found to be an unsuitable zone for the apple production because there is an absence of soil formation due to steep slope and the presence of heavy snow cover. From Fig. 9, we can clearly depict that only 6.55% (24.89 sq. km) of the total study area as highly suitable (HSZ) for apple production. The suitable zone (SZ) occupied almost 22.43% (85.24 sq. km) in the study area, 5.49% (20.86 sq. km) falls under moderately suitable zone (MSZ), 4.71% (17.88 sq. km) falls under low suitable zone (LSZ), very low suitable zone (VLSZ) covers 4.93% (18.74 sq. km) and unsuitable zone (UZ) covers 55.89% (212.39 sq. km). The area under different suitable classes is shown in Table 4. Thus, the AHP-based apple suitable map helps us to determine how climatic conditions are the major controlling factors for apple cultivation in our study area. Finally, all the classes of apple suitable zones is verified by ground truth data (Table S8), and accuracy assessment also has been done using important accuracy assessment elements like, overall accuracy, user's and producer's accuracy, and also different errors, i.e., commission error, omission error, and Kappa (k) coefficient (Lu and Weng, 2007).

Validation of Retrieved LST

To validate LST, daily observed CPC girded data are taken for the same day. There are generally errors found between observed temperature data and LST retrieved temperature data, due to them being measured from a different aspect. But, by using CPC gridded data, we find a strong co relation between the retrieved LST and observed temperature. Since our study area is very small, we extrapolated our study area so that we get as many grid points, using which we can validate our LST data (Fig. 10a, b). In late autumn and early spring, there is a high correlation between LST and observed data, as the lower RMSE value indicating less bias and high accuracy between LST and observed data and a perfect linear regression line. Thus, we can say that our LST value is very consistent and accurate for our study area.

Conclusion

This work finds an interlinked relation between local temperature change with snow cover line, snow cover area, shifting in vegetation cover and apple orchard patches through the earth observatory data. It further helps us to understand the changes due to climate variability over time. More than 85% of orchards have experienced changes in land utilization also impacted agricultural practices, which further leads to alternative form of land use through

climatic adaptation. Considering the vast production of apples from Himachal's orchards, the much-awaited delicious variety of apples from the Kalpa region is one of the best. Besides tourism, it is found that still now horticulture is considered as a major livelihood of the households being involved in its allied activity. The warm winters resulted in a shortage of spurs capable of forming flower buds, which delayed and protracted flowering season with poor fruit development and irregular ripening. There are several reports stating that the texture and taste of fruits are changing due to the effects of global warming, especially apples, which is sensitive to increasing temperature, leading to low-quality apples due to short chilling period, becoming a burning issue in the past few decades for farmers. Based on the farmers' perception (67% of total respondent farmers), it is stated that due to such variability in seasons and receding snow fall and retreating snow line condition, the apple quality is reduced in the slopes where previously good-quality apples were produced. Climate change seems to be inevitable; thus, people adopted temporary methods to cope up, but in this changing climate there is no permanent solution. As the apple orchards shifts toward higher altitude to gain favorable climatic conditions, the land of natural vegetation is being cleared rampant for orchard's growth by 52% of respondents, but it is not a solution as the land is fixed and finite in this high elevated mountain region. From the view of alpine ecology, there is a limitation to how much they can shift toward higher altitudes.

The study shows how climate variability is affecting the location attributes of orchards in the alpine region and land utilization practices. According to this study, various climatic factors have changed their characteristics in past three decades. The integrated attempt, adopted in this work, depicts the ability to understand these types of changes. The AHP method of apple suitability zonations plays an important role in decision-making for sustainable areas for apple cultivation in the study area. It also offers an opportunity to enhance the quality of apple production by providing the essential facts and information to the apple growers. The result of using the AHP method brings about a better understanding of suitable sites of apple cultivation. This will further lead to the future development of the horticultural sector. The results show the optimum condition for apple productivity, along with favorable climate and environmental characteristics. There is a visible increase in temperature, especially in winter and early spring seasons with less amount of precipitation, and it has brought forth changes in the snow cover and vegetation patterns. The crops and orchards, which are sensitive to climate variability, have been affected largely in the study area; in order to cope and adapt with such changes, vegetation patches, orchards and house clusters in

this region have shifted toward the high from lower altitudes.

Declarations

Conflict of interest None.

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