# Chapter 40
# Impact of Climate Change on Vegetation Distribution in the Kashmir Himalaya

**Irfan Rashid and Shakil Ahmad Romshoo**

**Abstract** Current vegetation distribution in the Kashmir Himalaya was mapped using remote sensing data supported with extensive ground validation. The vegetation distribution under A1B SRES scenario ending 2085 was projected using IBIS vegetation dynamics model. Climate change projections, from the PRECIS experiment using the HADRM3 model, for the Kashmir region were validated using observed climatic data from two stations. Both the observed and projected climatic data show statistically significant trends across the years. The IBIS model was validated by comparing the model-generated vegetation distribution with the observed vegetation distribution over the Kashmir Himalaya. IBIS-simulated baseline scenario of vegetation (1960–1990) is in good agreement (87.15%) with the observed vegetation distribution, giving credence to the future model projections of vegetation under the changing climate in the region. The projections suggest that grasslands and tropical deciduous forests shall altogether vanish from the region ending this century, whereas the savannah, temperate evergreen broadleaf forest, boreal evergreen forest, and the mixed forest types shall colonize the areas under polar desert/rock/ice. The projections further suggest that a substantial area under permanent snow and ice may vanish by the end of century which shall have severe impact on the streamflows, agriculture productivity, and biodiversity, thus adversely affecting the livelihoods and food security in the region.

**Keywords** Climate change · Kashmir Himalaya · PRECIS RCM · IBIS · Vegetation dynamics

I. Rashid · S. A. Romshoo (✉)
Department of Earth Sciences, University of Kashmir, Srinagar, Jammu and Kashmir, India
e-mail: shakilrom@kashmiruniversity.ac.in



G. H. Dar, A. A. Khuroo (eds.), *Biodiversity of the Himalaya: Jammu and Kashmir State*, Topics in Biodiversity and Conservation 18,
https://doi.org/10.1007/978-981-32-9174-4_40

## 40.1 Introduction

The indicators of climate change are evidential all over the globe (Cox et al. 2000). Evidences suggest warming attributable to human activities (IPCC 2001, 2007; Alley et al. 2003). Many components of the climate system – including temperatures of the atmosphere, land and ocean, the extent of sea ice and mountain glaciers, the sea level, the distribution of precipitation, and the length of seasons are now changing at rates and in patterns that are not natural and are best explained by the increased atmospheric abundance of greenhouse gases and aerosols generated by human activity during the twentieth century (American Geophysical Union 2008).

The potential consequences of the climate change have been established beyond any doubt at the global level (Rosenzweig and Solecki 2001). Climate exhibits a dominant control over the natural distribution of ecosystems. Fossil records (Davis and Botkin 1985; Woodward 1987) and the observed trends (Hughes 2000; Walther et al. 2002) show that changing climate has a profound influence on the vegetation distribution (Suárez et al. 2002; Beniston 2003). It is, therefore, to be expected that the projected climate change (IPCC 2001) will have a significant impact on the vegetation distribution (Peters and Darling 1985; Parmesan and Yohe 2003; Nautiyal et al. 2004). The expected impacts of climate change in mountainous regions will result in the loss of cooler climatic zones at the peaks of the mountains and the shifting of tree line upslope (Beniston 2003; Dullinger 2012; Gottfried et al. 2012). Huntley (1991) advocated that climate change might result in shifts in the distribution of species, biological invasions, and even species extinctions. Adaptation pathways in the face of changing climate include the replacement of the currently dominant species by more thermophilous species (Thuiller et al. 2005; McMahon et al. 2011; Gottfried et al. 2012).

The indicators of climate change are quite loud and clear in the Himalaya (Scherler et al. 2011; Immerzeel et al. 2012; Romshoo and Rashid 2014; Romshoo et al. 2015). Several studies suggest that Himalaya is experiencing temperature increase that is higher than the global mean of about 0.7 °C for the last century (Bhutiyani et al. 2007). In particular, a strong increase in the mean temperature of about 1.7 °C was recorded in the Himalaya, potentially inducing strong impacts on high-altitude ecosystems, especially changes in the vegetation structure and biodiversity of high-altitude environments (Shrestha et al. 1999; Aryal et al. 2014). With vast areas covered by the natural vegetation, there is a large dependence of communities on forest products and services (Roy et al. 2013). It, hence, becomes imperative to assess the likely impacts of climate change on vegetation distribution and composition.

The impact of climate change is seen everywhere in the Himalaya, as it affects key sectors like snow and glaciers, agriculture, biodiversity, and energy. Significant progress in the modelling of vegetation-climate interactions have been witnessed with the development of dynamic global vegetation models (DGVMs), which include mechanistic representations of the physiological, biophysical, and biogeochemical processes (Woodward and Beerling 1997; Cramer et al. 2001). DVGMs endow with the most comprehensive and flexible approach for generating probabilistic projections of changes in vegetation under changing climate scenarios (Bachelet et al. 2000; Lenihan et al. 2003). The application of DVGMs at the regional scale, indeed, has increased the knowledge base pertaining to the climate change impacts on vegetation (Sykes et al. 2001; Pearson and Dawson 2003). DVGMs have demonstrated that the changing climate can affect the distribution of vegetation types, and there could be a potential vegetation dieback (Solomon 1986; King and Neilson 1992; Grime 1997; Solomon et al. 2007). Recent studies in the Himalaya reveal that most of the areas are very likely to experience shift in the vegetation types as a consequence of changing climate (Brandt et al. 2013; Khan et al. 2013).

This chapter maps the current vegetation distribution in the Kashmir Himalaya and projects its evolution under the changing climate. The studies conducted so far across India have certain limitations as far as the validation of vegetation as simulated by DVGMs is concerned. This chapter also aims to map the current vegetation distribution in the region using remotely sensed data, together with extensive field validations, analyse the hydro-meteorological indicators for changing climatic signals over the region, and project the distribution and composition of potential vegetation in the region as simulated by IBIS and its validation.

## 40.2 Materials and Methods

### *40.2.1 Vegetation Mapping and Its Validation*

A medium-resolution vegetation map from NOAA AVHRR, with a spatial resolution of 1 km, was generated for the entire Kashmir Himalaya. The map was reclassified into broader vegetation types. Stratified random sampling approach, involving the sampling of different vegetation types based on their spatial extent, was adopted to validate the vegetation types. Although ground samples should have been ideally chosen in proportion to the spatial extent of the vegetation types, inaccessibility and challenging topography of the region did not allow it to be done. Overall accuracy of the vegetation-type map was calculated using the following formula:

$$\rho = \left(n / N\right) \times 100$$

where $\rho$ is classification accuracy, $n$ is number of points correctly classified on image, and $N$ is number of points checked in the field.

Species composition of vegetation types was determined through fieldwork, following a nested-quadrant approach (Rashid et al. 2013). Published literature was also consulted to know the species composition of vegetation types and look for any possible signal of climate-driven ecosystem change in the region.

### 40.2.2 Observed and Projected Climate Data

Time series meteorological data from 1980 to 2010 for two observation stations, Pahalgam and Gulmarg, were procured from the Indian Meteorological Department (IMD) to look into the signals of changing climate in the study area and to validate the projected temperature and precipitation predictions in the region. The projected climate data from 1960 to 2099 under A1B scenario were extracted from a PRECIS (Predicting Regional Climates for Impact Studies) run simulated over the study area with a spatial resolution of 0.5° × 0.5°. A time series of meteorological projections, ending 2099, from PRECIS under A1B scenario comprising average annual maximum and minimum temperature, and total annual precipitation from 2011 to 2098, was analysed for the region, which centred at $CO_2$ concentrations of 437 and 630 ppm for the years 2025 and 2075, respectively.

Projected temperatures from PRECIS have a spatial resolution of 50 × 50 km, whereas the observed data from IMD are based on local weather stations. IMD temperature data were, thus, up-scaled to 50 × 50 km using GTOPO (1 km resolution) and applying a standard atmospheric lapse rate of −6.5 $km^{-1}$. This was done by computing the elevation difference between a PRECIS grid and IMD observation station. In case of PRECIS (with a 50 × 50 km dimension), average elevation value from 2500 pixels was taken as a representative of the whole grid. Lapse rate was applied to the IMD data taking elevation difference between PRECIS and IMD station into consideration.

### 40.2.3 Trend Analysis of Climate Data

A time series of observed streamflow (1971–2010), meteorological data – temperature and precipitation (1979–2010) – and projected climate data (2010–2099) were used for trend analysis, and the interpretation of the significance of observed trends is based on a non-parametric Mann-Kendall test. The use of non-parametric tests ensures independent use of a series of assumptions about the population values and is well suited for analysing trends in time series data over time (Gilbert 1987). Thus, Mann-Kendall statistical test was used for monotonic and piecewise trend analyses of the time series of hydro-meteorological data. The test does not assume any special form for the distribution function of the data, including missing data (Yue and Pilon 2004). Man-Kendall static is denoted by S and varies between −1 and +1. Rank 1 is assigned to the highest value in the set. The 'n' time series value (X1, X2, X3… Xn) are replaced by their relative ranks (R1, R2, R3…Rn). The test statistic S is given as:

$$S = \sum_{i=1}^{n-1} \left[ \sum_{j=i+1}^{n} \operatorname{sgn}\left(Ri - Rj\right) \right] \tag{40.1}$$

where sgn $(x) = 1$ for $x > 0$, Sgn $(x) = 0$ for $x = 0$, and Sgn $(x) = -1$ for $x < 0$

If the null hypothesis $H_0$ is true, then $S$ is normally distributed, and its positive value is an indicator of an increasing trend.

### *40.2.4 Impact of Changing Climate on Vegetation Distribution*

Impact of climate change on vegetation distribution was assessed on the basis of changes observed in distribution of different forest types using future climate change scenario. For this, the global vegetation dynamics model – IBIS (Integrated Biosphere Simulator) – was used to assess the spatial distribution of current and future climate projected by the high-resolution regional climate model, PRECIS, for A1B scenario. Simulations were generated for two future time-frames: (i) Time-frame of 2021–2050, labelled as ‘2035’ (median of the period) and (ii) Time-frame of 2071–2100, labelled as ‘2085’. The simulated results of future scenarios were compared with the ‘baseline’ scenario, which was generated using 1960–1990 observed climate data.

#### 40.2.4.1 Vegetation Dynamics Model

Designed around a hierarchical, modular structure, the dynamic vegetation model IBIS comprises four modules: the land surface module, vegetation phenology module, carbon balance module, and the vegetation dynamics module (Foley et al. 1996; Kucharik et al. 2000). Despite operating at different time steps, these modules are integrated into a single physically consistent model that may be directly incorporated within AGCMs (atmospheric general circulation models). IBIS is currently coupled with two AGCMs, namely, GENESIS-IBIS (Foley et al. 2000) and CCM3-IBIS (Winter et al. 2009). The state description of the model allows trees and grasses experience different light and water regimes, competition for sunlight and soil moisture which determines the geographic distribution of plant functional types, and the relative dominance of trees and grasses, evergreen and deciduous phenologies, broad-leaf and conifer-leaf forms, and C3 and C4 photosynthetic pathways.

#### 40.2.4.2 Input Data

IBIS requires a range of input parameters, including climatic as well as pedologic parameters. The main climatic parameters required are monthly mean cloudiness (%), monthly mean precipitation rate (mm/day), monthly mean relative humidity (%), monthly minimum, maximum, and mean temperature (°C), and wind speed (m/s). The main soil parameter is the texture of soil (i. e. % age of sand, silt, and clay). The model also requires topography information. The available soil and topographic information was re-gridded to a 0.5° × 0.5° resolution and used for the run. The observed climatic variables were obtained from CRU (New et al. 1999), while the soil data were obtained from IGBP (IGBP 2000). For climate change projections, RCM outputs from PRECIS were used (Rupakumar et al. 2006). The climate variables for future scenarios were obtained using the method of anomalies (Bretherton et al. 1992). This involved computing the difference between the projected values for a scenario and the control run of the PRECIS model and adding this difference to the value corresponding to the current climate as obtained from the CRU climatology.

#### 40.2.4.3 Simulating Vegetation Distribution and Composition

The spatial resolution of vegetation simulated with IBIS is 0.5°. For validation, baseline vegetation of the region simulated with IBIS was compared with the vegetation map at 50 × 50 km grid resolution, developed after modifying vegetation map from NOAA AVHRR, ISRO (2010), and Champion and Seth (1968). A digital vegetation-type map of the study area (ISRO 2010) at 1:50,000 scale was used for checking and validation purposes. Since the highest resolution data available for running IBIS had 0.5° resolution, the study area was divided into 0.5° grids, and the vegetation map was reclassified to assess the accuracy of vegetation types and distribution simulated with IBIS. The validation of simulated vegetation was done using kappa coefficient, which is a robust indicator for accuracy assessment, and was calculated using the following formula:

$$k = \frac{N\sum_{i=1}^{r} X_{ii} - \sum_{i=1}^{r}\left(X_{i+}.X_{+i}\right)}{N^2 - \sum_{i=1}^{r}\left(X_{i+}.X_{+i}\right)}$$

where $\boldsymbol{r}$ is number of rows in error matrix
$\boldsymbol{x_{ii}}$ is number of observations in row i and column i (on the major diagonal)
$\boldsymbol{x_{i+}}$ is total of observations in row i (shown as marginal total to right of the matrix)
$\boldsymbol{x_{+i}}$ total of observations in column i (shown as marginal total at bottom of the matrix)
and $N$ is total number of observations included in the matrix

In addition, vegetation distribution for two future time periods, centred at 2035 and 2085, was simulated using IBIS.

## 40.3 Results and Discussion

### *40.3.1 Vegetation Mapping*

The study area showing Jammu and Kashmir state is depicted in Fig. 40.1.

Ten classes of vegetation were delineated in this chapter (Table 40.1; Fig. 40.2). It is evident from the figure that 60% of the area is covered by vegetation, whereas the non-vegetated areas (snow-covered areas, barren lands, water-bodies, and builtup areas) cover ~4 0%. Major vegetation types include shrublands (33.62%), forests (16.69%), grasslands (5.89%), and croplands (3.89%). Vegetation types were checked and validated with extensive ground truthing at 450 samples spread over various geographic and vegetation belts in the study area. However, ground truthing could not be carried out in the Chinese- and Pakistan-administered territories within the study area. The dominant shrubland species observed in the areas with altitude less than 3000 m include *Berberis lycium*, *Viburnum grandiflorum*, *Indigofera heterantha*, *Parrotiopsis jacquemontiana*, *Betula utilis*, while the prevailing vegetation in alpine shrublands includes *Juniperus squamata*, *Rhododendron campanulatum*, and *Rosa webbiana*. Forest species included *Pinus wallichiana*, *Pinus roxburghii*, *Pinus gerardiana*, *Cedrus deodara*, *Abies pindrow*, *Quercus semecarpifolia*, *Q. leucotrichophora*, *Olea cuspidata*, and *Ulmus wallichiana*. Grasslands were dominated by *Cynodon dactylon*, *Stipa sibirica*, *Poa alpina*, and *P. annua* (Rashid et al. 2010; Rashid et al. 2013). It is observed that climate change has resulted in the proliferation of alien invasive species in the region (McCarty 2001; Chen et al. 2003; Williams et al. 2007). Many of these alien species are reported to have invaded forest, grassland, and wetland ecosystems across the Kashmir Himalaya (Zutshi 1975; Khuroo et al. 2007; Masoodi et al. 2013).

Another aspect of this chapter was to compare the land cover types as delineated from AVHRR with land cover map from ISRO, developed in 2010 for part of the Indian-administered Jammu and Kashmir (~1,05,102 km$^2$). For this purpose, land cover classes were generalised into five categories (Petit and Lambin 2002; Buyantuyev and Wu 2007). This is because of the fact that the classification schemes used in AVHRR and ISRO land-cover maps are different, while AVHRR adopts IGBP land-cover nomenclature, and ISRO adopts nomenclature as per Champion and Seth (1968). There is a good agreement as far as cropland and forested area delineation is concerned, but differences occur in spatial extents of grasslands,

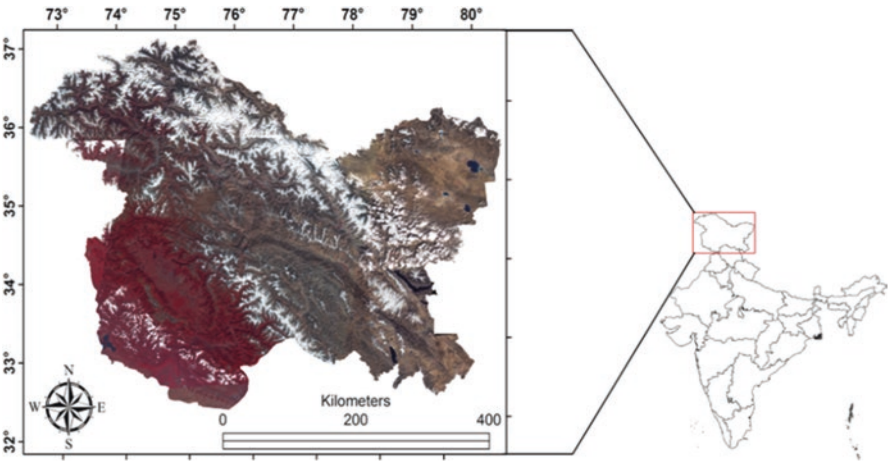


**Fig. 40.1** Study area showing Jammu and Kashmir state

**Table 40.1** Land cover statistics for Jammu and Kashmir state

| Vegetation type | Area (km$^2$) | % age |
|---|---|---|
| Non-vegetated | 88737.45 | 39.93 |
| Closed shrubland | 1208.42 | 0.54 |
| Cropland | 8652.29 | 3.89 |
| Deciduous broadleaf forest | 253.58 | 0.11 |
| Evergreen broadleaf forest | 360.67 | 0.16 |
| Evergreen needleleaf forest | 8394.99 | 3.78 |
| Grassland | 13080.68 | 5.89 |
| Open shrubland | 73478.65 | 33.06 |
| Wooded frassland | 14207.30 | 6.39 |
| Woodland | 13862.25 | 6.24 |
| **Total Area** | **2,22,236.27** | **100.00** |

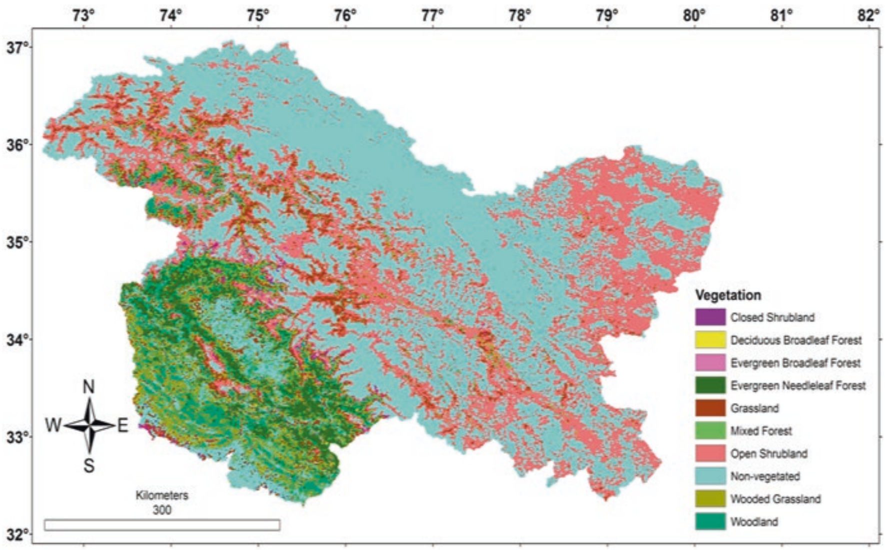


**Fig. 40.2** Major land cover/vegetation types in Jammu and Kashmir state

shrublands, and non-vegetated areas. These variations result partly because of differences in the spatial resolution and mapping scale adopted (Ardizzone et al. 1999; Achard et al. 2001; Shao and Wu 2008). As the spatial resolution of AVHRR is very coarse, grasslands and non-vegetated areas get classified as shrublands.

### 40.3.2 Historical Hydro-meteorological Data

Analysis of the time series of average annual minimum and maximum temperatures at Pahalgam meteorological observation station in the study area from 1980 to 2010 depicts a significant rising trend (99%) over the years with $R^2$ of 0.45 and 0.38, respectively. The mean annual precipitation at Pahalgam shows a slightly decreasing but insignificant trend with a very weak $R^2$ of 0.02 (Fig. 40.3a, b, c). Average annual minimum and maximum temperatures at Gulmarg station from 1980 to 2010 also depict a rising trend over the years with $R^2$ of 0.33 and 0.10, with significance values of 90% and 99%, respectively (Fig. 40.3d, e, f). Statistically insignificant trends were observed in case of observed and projected precipitation patterns over the region (Table 40.2).

As is evident from the analysis, the minimum temperatures are rising faster than maximum temperatures over the region. This may bring about significant habitat alteration in the alpine zone (Hamann and Wang 2006; Telwala et al. 2013; Ernakovich et al. 2014). The rise in temperature, together with decreasing precipitation regimes in the region, can have serious impact on forest distribution

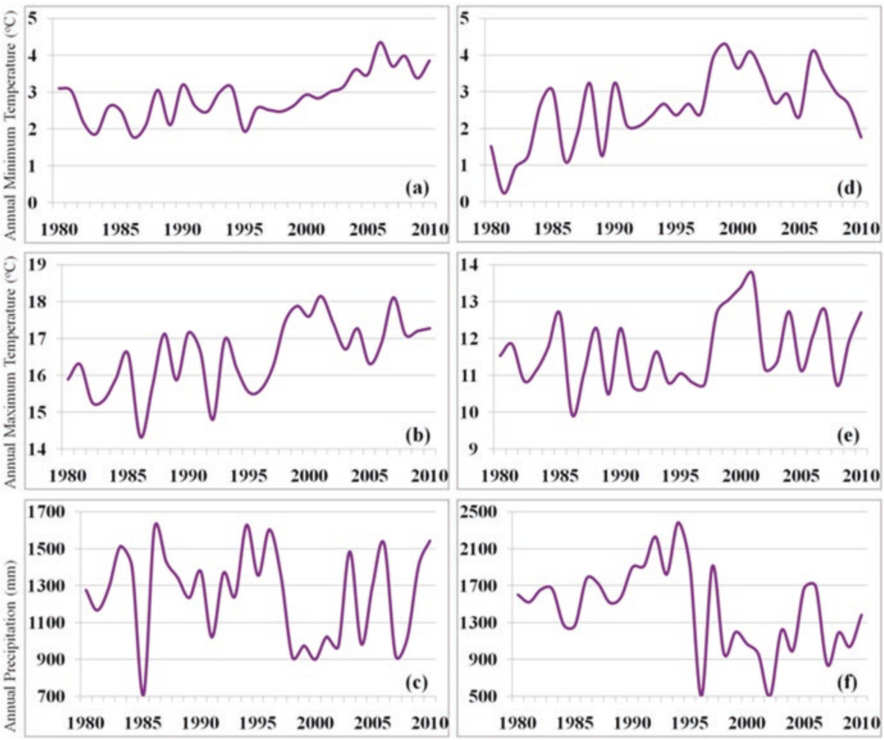


**Fig. 40.3** Observed trends in temperature and precipitation at Pahalgam (**a**, **b**, **c**) and Gulmarg (**d**, **e**, **f**)

**Table 40.2** Mann-Kendall statistics for significance of observed and projected climate data

| Parameter | Test static | Result | |
|---|---|---|---|
| Annual maximum temperature | 3.519 | S (0.01) | Observed climate at Pahalgam |
| Annual minimum temperature | 3.773 | S (0.01) | |
| Annual precipitation | −0.425 | NS | |
| Annual maximum temperature | 1.666 | S (0.1) | Observed climate at Gulmarg |
| Annual minimum temperature | 3.059 | S (0.01) | |
| Annual precipitation | −1.615 | NS | |
| Annual maximum temperature | 9.11 | S (0.01) | Projected climate at Pahalgam |
| Annual minimum temperature | 10.722 | S (0.01) | |
| Annual precipitation | −0.205 | NS | |
| Annual maximum temperature | 9.54 | S (0.01) | Projected climate at Gulmarg |
| Annual minimum temperature | 10.841 | S (0.01) | |
| Annual precipitation | −2.627 | S (0.01) | |

*S* significant, *NS* non-significant

(Joshi et al. 2012; Cong et al. 2013), snow and glacier resources (Murtaza and Romshoo 2017; Romshoo et al. 2015), water availability (Immerzeel et al. 2010; Jeuland et al. 2013; Sharif et al. 2013), and recreation (Dar et al. 2014).

As far as the climate projections for the area are concerned, both average minimum and maximum projected temperatures show an increasing trend at both Pahalgam (with $R^2$ values of 0.90 and 0.77, respectively) (Fig. 40.4a, b) and Gulmarg stations (with $R^2$ values of 0.91 and 0.81, respectively) (Fig. 40.4d, e). Precipitation projections (Fig. 40.4c, f) show a very weak increasing trend with $R^2$ values of 0.04 and 0.005 for Pahalgam and Gulmarg, with significant interannual variations across the time series. The overall average annual maximum and minimum temperatures over Pahalgam are projected to increase, respectively, by 7.23 °C (±1.84 °C) and 4.89 (±1.51) from 2011 to 2098 under the A1B SRES scenario. Likewise, the average annual maximum and minimum temperatures over Gulmarg are projected to increase by 7.68 (±2.01) and 5.88 (±1.51), respectively. Mann-Kendall analysis of time series for observed and projected climate data (Table 40.2) reveals that temperatures are going to rise very significantly (99% significance value). Similar increases are being simulated over other areas in the region. The trend analysis of the average yearly discharge using Man-Kendall tests at Aru (Pahalgam) hydrological station is given in Table 40.2. A significantly decreasing trend (with significance value of 99%) is observed in case of streamflow observations from 1980 to 2010 at this station.

From the analysis of climatic data for the study area, it can, hence, be inferred that there will be a significant increase in the temperatures, decrease in the streamflow, and comparatively insignificant change in the precipitation pattern by the end of this century. Upon comparison of the upscaled IMD data with the PRECIS projected temperatures during the baseline period, it is found that the two datasets agree reasonably well (Fig. 40.5a, b). Thus, the model is considered credible and cogent for simulating future temperatures over the region. Similar findings have

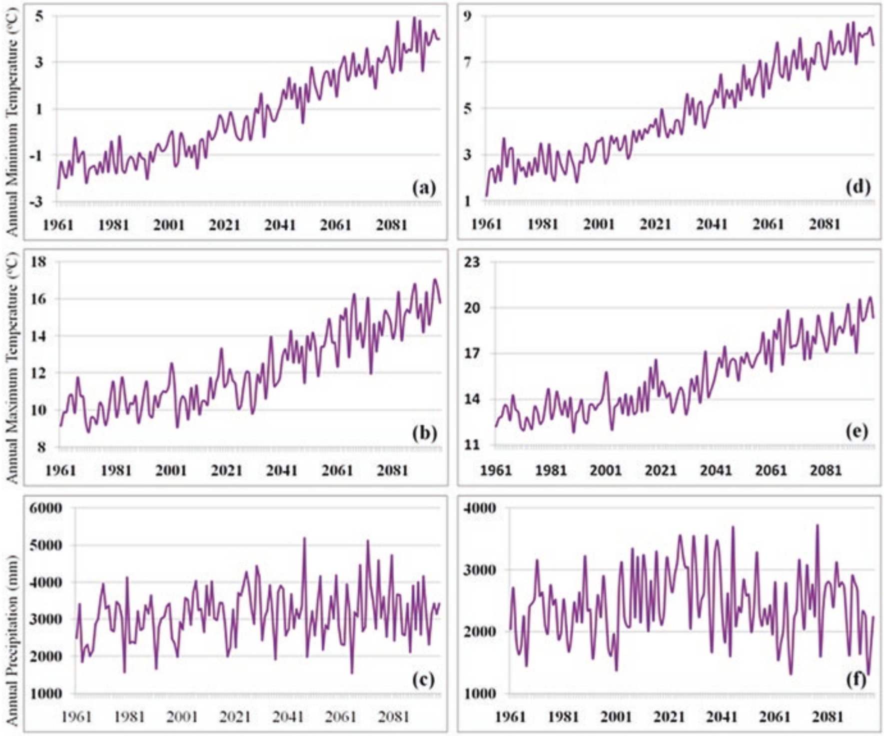


**Fig. 40.4** Projected climate trends at Pahalgam (**a**, **b**, **c**) and Gulmarg (**d**, **e**, **f**)

been reported about the use of PRECIS in Himalaya (Akhtar et al. 2008; Kulkarni et al. 2013) and other parts (Tadross et al. 2005; Xu et al. 2006 Giannakopoulos et al. 2013).

### *40.3.3 Impact of Changing Climate on Vegetation Distribution*

Before going for the impact assessment of climate change on vegetation distribution, it is important to assess the accuracy of the baseline vegetation scenario, simulated by IBIS, with the actual vegetation on ground. For this purpose, an actual vegetation map (Fig. 40.6a) was developed at a resolution of 50 × 50 km by modifying the vegetation maps prepared by NOAA AVHRR, Champion and Seth (1968), and ISRO (2010). Some categories of the vegetation were reclassified as per the IBIS vegetation nomenclature. The baseline map, simulated by IBIS for the region (Fig. 40.6b), was compared with the vegetation map developed at 50 × 50 km. A Kappa coefficient of 87.15% (Table 40.3) indicates that the IBIS simulated the baseline vegetation very well (Yuan et al. 2011; Cunha et al. 2013) and, hence, could be

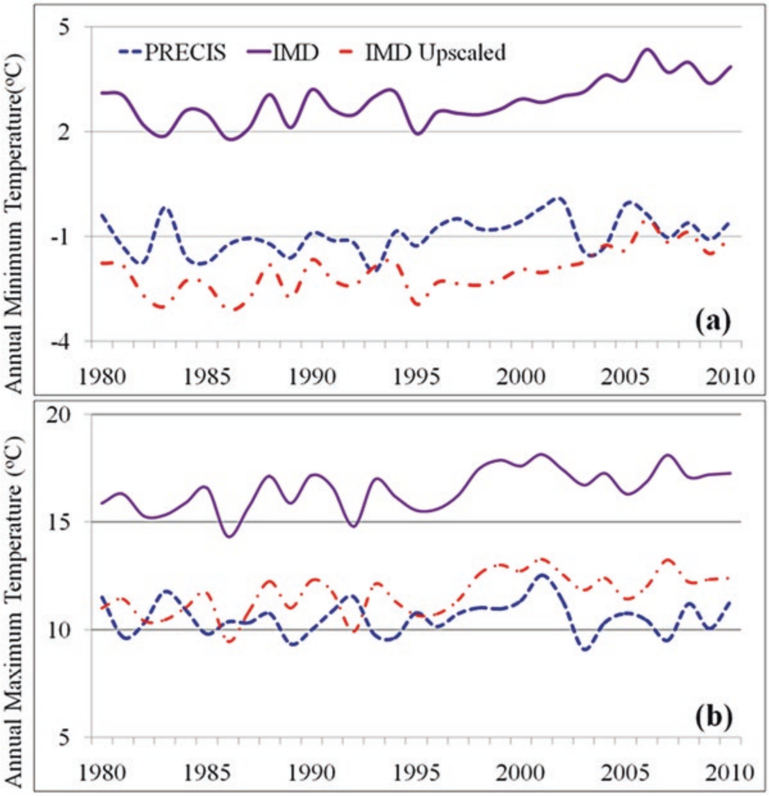


**Fig. 40.5** Validation of PRECIS with IMD upscaled data at Pahalgam. (**a**) Average annual minimum temperature (**b**) Average annual maximum temperature

relied upon for effectively projecting the future vegetation types ending the current century. IBIS simulates temperate evergreen forest and tropical deciduous forest very well during the baseline period as is evident from 100% agreement between the observed and IBIS simulated vegetation. It slightly over-predicts grasslands (only 66.66% correspondence with the vegetation scenario on ground) and tundra (only 72.42% similarity) and slightly under-predicts dense shrublands (by 33.33%), open shrublands (by 14.28%), and polar desert/rock/ice areas (by 13.63%). These dissimilarities in the observed and simulated baseline vegetation distribution and type are insignificant at the spatial resolution of 50 × 50 km.

For the projected vegetation distribution by 2035 (Table 40.4, Fig. 40.6c), most of the area under polar desert/rock/ice is taken over by boreal evergreen forests, and some part of it may be covered by tundra vegetation. Moreover, a substantial part currently under the temperate evergreen forests is colonized by temperate deciduous forests. Areas under open shrublands are taken over by temperate evergreen broad-

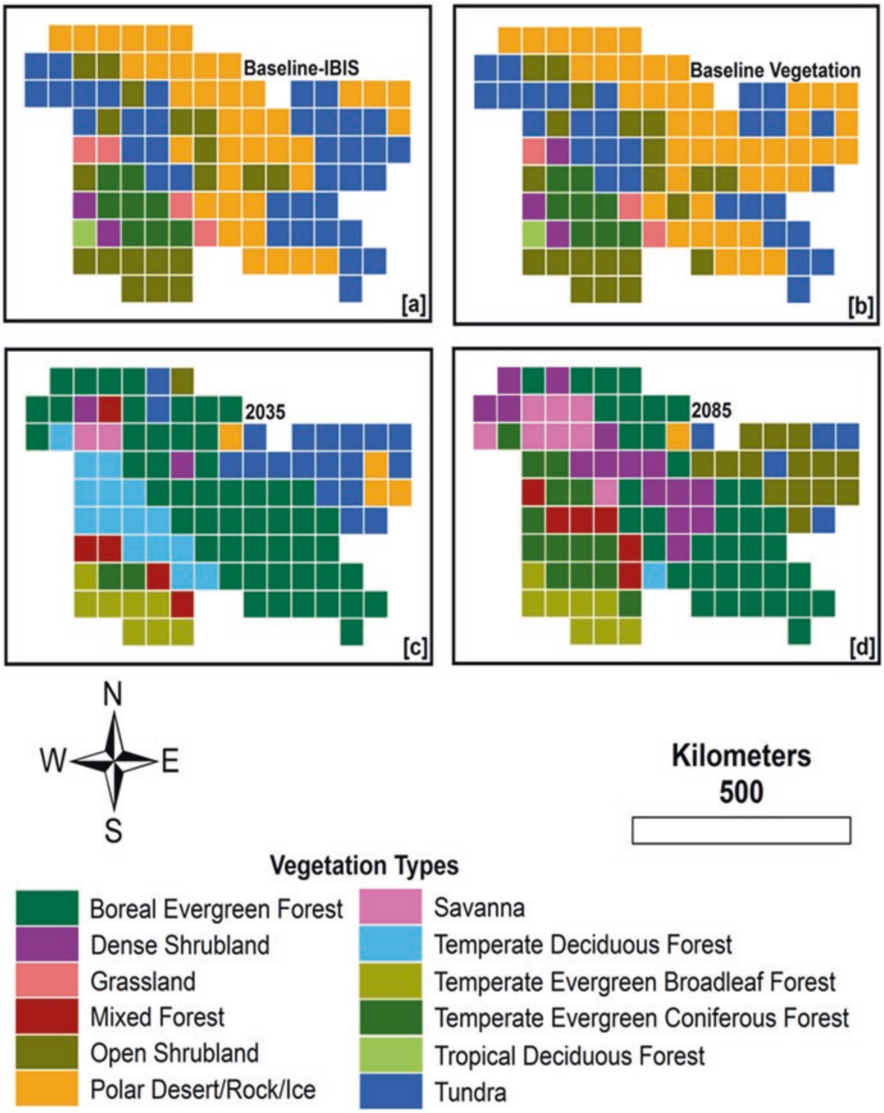


**Fig. 40.6** (**a**) Baseline vegetation simulated with IBIS. (**b**) Actual vegetation after AVHRR, Champion and Seth (1968), ISRO (2010). (**c**) Projected vegetation types by 2035. (**d**) Projected vegetation types by 2085

leaf forests. In addition, mixed forests and savannahs appear due to the increase in the projected temperatures observed over the region.

Vegetation simulated with IBIS for the period towards the end of this century (Table 40.4, Fig. 40.6d) shows expansion of savannahs, reappearance of temperate evergreen coniferous forests, and open shrublands in the Karakoram belt. Dense

**Table 40.3** Matrix showing the comparison of IBIS-simulated baseline vegetation with respect to satellite-derived vegetation

| Vegetation types | | Satellite data | | | | | | | Column totals |
|---|---|---|---|---|---|---|---|---|---|
| | | DS | GR | OS | PD | TE | TD | TU | |
| IBIS baseline | DS | **2** | 0 | 0 | 0 | 0 | 0 | 0 | 2 |
| | GR | 1 | **3** | 0 | 0 | 0 | 0 | 0 | 4 |
| | OS | 0 | 0 | **19** | 0 | 0 | 0 | 0 | 19 |
| | PD | 0 | 0 | 2 | **35** | 0 | 0 | 1 | 38 |
| | TE | 0 | 0 | 0 | 0 | **8** | 0 | 0 | 8 |
| | TD | 0 | 0 | 0 | 0 | 0 | **1** | 0 | 1 |
| | TU | 0 | 0 | 0 | 9 | 0 | 0 | **28** | 37 |
| Row totals | | 3 | 3 | 21 | 44 | 8 | 1 | 29 | **109** |

*DS* dense shrubland, *GR* grassland, *OS* open shrubland, *PD* polar desert/rock/ice, *TE* temperate evergreen coniferous forest, *TD* tropical deciduous forest, *TU* tundra
Kappa = (sum of diagonals/total) × 100 = (96/109) × 100 = 88.07

**Table 40.4** Changes in vegetation composition across different scenarios from 1960 to 2099

| Vegetation types | Baseline | | Futuristic scenarios | |
|---|---|---|---|---|
| | IBIS projected | Satellite derived | 2035 | 2085 |
| Boreal evergreen forest | 0 | 0 | 51 | 37 |
| Dense shrubland | 2 | 3 | 2 | 15 |
| Grassland | 4 | 3 | 0 | 0 |
| Mixed forest | 0 | 0 | 5 | 6 |
| Open dhrubland | 18 | 21 | 1 | 14 |
| Polar desert/rock/ice | 38 | 44 | 4 | 1 |
| Savannahs | 0 | 0 | 2 | 8 |
| Temperate deciduous forest | 0 | 0 | 15 | 1 |
| Temperate evergreen broadleaf forest | 0 | 0 | 8 | 8 |
| Temperate evergreen coniferous forest | 8 | 8 | 2 | 14 |
| Tropical deciduous forest | 1 | 1 | 0 | 0 |
| Tundra | 37 | 29 | 19 | 5 |

shrublands will overtake boreal evergreen forests in north-western and central part of the region. There remains only one pixel/grid that comes under rock/ice by the end of the century. As such, it is predicted that snow and glacier resources in the region shall recede due to the rising temperatures discerned over here (Bajracharya et al. 2007; Archer et al. 2010; Immerzeel et al. 2010; Romshoo et al. 2015).

## 40.4 Concluding Remarks

This chapter indicates that climate change is evident in the Kashmir Himalaya and affects significantly the naturally occurring vegetation. Northwest Himalaya covers a substantial part of the Himalayan biodiversity hotspot, which signifies the importance of this chapter. A close agreement of the regional climate model projections with the upscaled meteorological data gives credence to the projected vegetation distribution under changing climate, as generated for the region using IBIS. The study demonstrated that the climate change is going to bring about significant changes in the vegetation types and their distribution in the region and might, therefore, adversely affect the products and services available from the forests that currently support a number of livelihoods here. Subalpine and alpine pasture and scrubland vegetation in the upper reaches (>2800 m), which are habitat to many endemic and medicinally important species, are very sensitive to any subtle variation in climate. Hence, in light of the changing climate over the region, these species may get extirpated on altering the fragile ecology of the region. Moreover, the introduction of alien invasive species in terrestrial and aquatic ecosystems in the region can seriously alter the biogeochemical cycling, affecting the biodiversity richness and composition in the Kashmir Himalayan region.

**Acknowledgements** The authors express their gratitude to the National Remote Sensing Centre (NRSC), ISRO, Hyderabad, for financing the development of vegetation map of Kashmir Valley under Biodiversity Characterization project. Also, provision of grant by the Ministry of Earth Sciences, Government of India, for climate change impact studies over Kashmir is thankfully acknowledged. Gratefulness is due to the Centre for Ecological Studies, Indian Institute of Science (IISc), Bangalore, for providing technical assistance in running the IBIS model simulations.

## References

Achard F, Eva H, Mayaux P (2001) Tropical forest mapping from coarse spatial resolution satellite data: production and accuracy assessment issues. Int J Remote Sens 22(14):2741–2762

Akhtar M, Ahmad N, Booij MJ (2008) The impact of climate change on the water resources of Hindukush–Karakorum–Himalaya region under different glacier coverage scenarios. J Hydrol 355(1):148–163

Alley RB, Marotzke J, Nordhaus WD, Overpeck JT, Petect DM, Pielke RA Jr, Pierrehumbert RT, Rhines STF, Talley LD, Wallance JM (2003) Abrupt climate change. Science 299:2005–2010

American Geophysical Union (2008) American Geophysical Union revises position on climate change. Science Daily. Retrieved January 19, 2010, from http://www.sciencedaily.com/releases/2008/01/080125154628.htm

Archer DR, Forsythe N, Fowler HJ, Shah SM (2010) Sustainability of water resources management in the Indus Basin under changing climatic and socio economic conditions. Hydrol Earth Syst Sci 14:1669–1680

Ardizzone F, Cardinali M, Carrara A, Guzzetti F, Reichenbach P (1999) Impact of mapping errors on the reliability of landslide hazard maps. Nat Hazards Earth Syst Sci 2:3–14

Aryal A, Brunton D, Raubenheimer D (2014) Impact of climate change on human-wildlife-ecosystem interactions in the Trans-Himalaya region of Nepal. Theor Appl Climatol 115(3–4):517–529
Bachelet D, Neilson RP, Lenihan JM, Drapek RJ (2000) Climate change effects on vegetation distribution and carbon budget in the United States. Ecosystems 4:164–185
Bajracharya SR, Mool P, Shrestha BR (2007) Impact of climate change on Himalayan glaciers and glacial lakes: case studies on GLOF and associated hazards in Nepal and Bhutan. International Centre for Integrated Mountain Development, Kathmandu
Beniston M (2003) Climatic change in mountain regions: a review of possible impacts. In: Climate variability and change in high elevation regions: past, present and future. Springer, Dordrecht, pp 5–31
Bhutiyani MR, Kale VS, Pawar NJ (2007) Long-term trends in maximum, minimum and mean annual air temperatures across the Northwestern Himalaya during the twentieth century. Clim Chang *85*(1–2):159–177
Brandt JS, Haynes MA, Kuemmerle T, Waller DM, Radeloff VC (2013) Regime shift on the roof of the world: Alpine meadows converting to shrublands in the southern Himalayas. Biol Conserv 158:116–127
Bretherton CS, Smith C, Wallace JM (1992) An intercomparison of methods for finding coupled patterns in climate data. J Clim 5(6):541–560
Buyantuyev A, Wu J (2007) Effects of thematic resolution on landscape pattern analysis. Landsc Ecol 22(1):7–13
Champion SH, Seth SK (1968) A revised survey of the forest types of India. Natraj Publishers, Dehradun
Chen XW, Zhang XS, Li BL (2003) The possible response of life zones in China under global climate change. Glob Planet Chang 38:327–337
Cong N, Wang T, Nan H, Ma Y, Wang X, Myneni RB, Piao S (2013) Changes in satellite-derived spring vegetation green-up date and its linkage to climate in China from 1982 to 2010: a multimethod analysis. Glob Chang Biol 19(3):881–891
Cox PM, Betts RA, Jones CD, Spall SA, Totterdell IJ (2000) Acceleration of global warming due to carbon-cycle feedbacks in a coupled climate model. Nature 408:184–187
Cramer W, Bondeau A, Woodward FI, Prentice IC, Betts RA, Brovkin V, Cox PM, Fisher V, Foley JA, Friend AD, Kucharik C, Lomas MR, Ramankutty N, Sitch S, Smith B, White A, Young-Molling C (2001) Global response of terrestrial ecosystem structure and function to CO2 and climate change: results from six dynamic global vegetation models. Glob Chang Biol 7(4):357–373
Cunha AP, Alvalá R, Sampaio G, Shimizu MH, Costa MH (2013) Calibration and validation of the Integrated Biosphere Simulator (IBIS) for a Brazilian Semiarid region. J Appl Meteorol Climatol 52(12):2753–2770
Dar RA, Rashid I, Romshoo SA, Marazi A (2014) Sustainability of winter tourism in a changing climate over Kashmir Himalaya. Environ Monit Assess 186:2549–2562
Davis MB, Botkin DB (1985) Sensitivity of cool-temperate forests and their fossil pollen record to rapid temperature change. Quat Res 23(3):327–340
Dullinger S, Gattringer A, Thuiller W, Moser D, Zimmermann NE, Guisan A, Willner W, Plutzar C, Leitner M, Mang T, Caccianiga M, Dirnböck T, Ertl S, Fischer A, Lenoir J, Svenning JC, Psomas A, Schmatz DR, Silc U, Vittoz P, Hülber K (2012) Extinction debt of high-mountain plants under twenty-first-century climate change. Nat Clim Chang 2:619–622
Ernakovich JG, Hopping KA, Berdanier AB, Simpson RT, Kachergis EJ, Steltzer H, Wallenstein MD (2014) Predicted responses of arctic and alpine ecosystems to altered seasonality under climate change. Glob Chang Biol 20:3256–3269
Foley JA, Prentice IC, Ramankutty N, Levis S, Pollard D, Sitch S, Haxeltine A (1996) An integrated biosphere model of land surface processes, terrestrial carbon balance, and vegetation dynamics. Glob Biogeochem Cycles 10(4):603–628
Foley JA, Levis S, Costa MH, Cramer W, Pollard D (2000) Incorporating dynamic vegetation cover within global climate models. Ecol Appl 10(6):1620–1632

Giannakopoulos C, Kostopoulou E, Hadjinicolaou P, Hatzaki M, Karali A, Lelieveld J, Lange MA (2013) Impacts of climate change over the eastern Mediterranean and Middle East region using the Hadley Centre PRECIS RCM. In: Advances in meteorology, climatology and atmospheric physics. Springer, Berlin/Heidelberg, pp 457–463

Gilbert RO (1987) Statistical Methods for Environmental Pollution Monitoring. New York: Van Nostrand Reinhold, 320 pp

Gottfried M, Pauli H, Futschik A, Akhalkatsi M, Baranˇcok P, Alonso JLB, Coldea G, Dick J, Erschbamer B, Calzado MRF, Kazakis G, Krajˇci J, Larsson P, Mallaun M, Michelsen O, Moiseev D, Moiseev P, Molau U, Merzouki A, Nagy L, Nakhutsrishvili G, Pedersen B, Pelino G, Puscas M, Rossi G, Stanisci A, Theurillat JP, Tomaselli M, Villar L, Vittoz P, Vogiatzakis I, Grabherr G (2012) Continent-wide response of mountain vegetation to climate change. Nat Clim Chang 2(2):111–115

Grime JP (1997) Climate change and vegetation. In: Plant Ecology, 2nd edn, pp 582–594

Hamann A, Wang T (2006) Potential effects of climate change on ecosystem and tree species distribution in British Columbia. Ecology 87(11):2773–2786

Hughes L (2000) Biological consequences of global warming: is the signal already apparent? Trends Ecol Evol 15:56–61

Huntley B (1991) How plants respond to climate change: migration rates, individualism and the consequences for plant communities. Ann Bot 67(Suppl. 1):15–22

Immerzeel WW, Van Beek LPH, Konz M, Shrestha AB, Bierkens MFP (2012) Hydrological response to climate change in a glacierized catchment in the Himalayas. Clim Chang 110(3–4):721–736

Immerzeel WW, Van-Beek LP, Bierkens MF (2010) Climate change will affect the Asian water towers. Science 328(5984):1382–1385

IGBP (2000) Global soil data products CD-ROM. International Geosphere-Biosphere Program (IGBP), Data and Information Services (DIS), Potsdam

IPCC (2001) Climate change 2001: the scientific basis. Contribution of Working Group I- the First Assessment. Report of Intergovernmental Panel on Climate Change. Cambridge University Press, Cambridge/New York

IPCC (2007) Climate change 2007: the physical science basis. Contribution of Working Group I to the 4th Assessment. Report of Intergovernmental Panel on Climate Change. ISBN 978 05

ISRO (2010) Biodiversity characterisation at landscape level in Jammu and Kashmir using satellite remote sensing and geographic information system. Bishen Singh Mahendra Pal Singh, Dehradun

Jeuland M, Harshadeep N, Escurra J, Blackmore D, Sadoff C (2013) Implications of climate change for water resources development in the Ganges basin. Water Policy 15

Joshi PK, Rawat A, Narula S, Sinha V (2012) Assessing impact of climate change on forest cover type shifts in Western Himalayan Eco-region. J For Res 23(1):75–80

Khan SM, Page S, Ahmad H, Ullah Z, Shaheen H, Ahmad M, Harper DM (2013) Phyto-climatic gradient of vegetation and habitat specificity in the high elevation Western Himalayas. Pak J Bot 45:223–230

Khuroo AA, Rashid I, Reshi Z, Dar GH, Wafai BA (2007) The alien flora of Kashmir Himalaya. Biol Invasions 9(3):269–292

King GA, Neilson RP (1992) The transient response of vegetation to climate change: a potential source of CO2 to the atmosphere. Water Air Soil Pollut 64(1–2):365–383

Kucharik CJ, Foley JA, Delire C, Fisher VA, Coe MT, Lenters J, Young-Molling C, Ramankutty N, Norman JM, Gower ST (2000) Testing the performance of a dynamic global ecosystem model: water balance, carbon balance and vegetation structure. Glob Biogeochem Cycles 14(3):795–825

Kulkarni A, Patwardhan S, Kumar KK, Ashok K, Krishnan R (2013) Projected climate change in the Hindu Kush-Himalayan region by using the high-resolution regional climate model PRECIS. Mt Res Dev 33(2):142–151

Lenihan JM, Drapek R, Bachelet D, Neilson RP (2003) Climate change effects on vegetation distribution, carbon, and fire in California. Ecol Appl 13(6):1667–1681

Masoodi A, Sengupta A, Khan FA, Sharma GP (2013) Predicting the spread of alligator weed (Alternanthera philoxeroides) in Wular lake, India: a mathematical approach. Ecol Model 263:119–125

McCarty JP (2001) Ecological consequences of recent climate change. Conserv Biol 15:320–331

McMahon SM, Harrison SP, Armbruster WS, Bartlein PJ, Beale CM, Edwards ME, Kattge J, Midgley G, Morin X, Prentice IC (2011) Improving assessment and modelling of climate change impacts on global terrestrial biodiversity. Trends Ecol Evol 26(5):249–259

Murtaza KO, Romshoo SA (2017) Recent glacier changes in the Kashmir Alpine Himalayas. Geocarto Int 32(2):188–205

Nautiyal MC, Nautiyal BP, Prakash V (2004) Effect of grazing and climatic changes on alpine vegetation of Tungnath, Garhwal Himalaya, India. Environmentalist 24(2):125–134

New M, Hulme M, Jones PD (1999) Representing twentieth century space-time climate variability. Part 1: development of a 1961–90 mean monthly terrestrial climatology. J Clim 12:829–856

Parmesan C, Yohe G (2003) A globally coherent fingerprint of climate change impacts across natural systems. Nature 421:37–42

Pearson RG, Dawson TP (2003) Predicting the impacts of climate change on the distribution of species: are bioclimate envelope models useful? Glob Ecol Biogeogr 12(5):361–371

Peters RL, Darling JDS (1985) The greenhouse effect and nature reserves: global warming could diminish biological diversity by causing extinctions among reserve species. Bioscience 35:707–717

Petit CC, Lambin EF (2002) Impact of data integration technique on historical land-use/land-cover change: comparing historical maps with remote sensing data in the Belgian Ardennes. Landsc Ecol 17(2):117–132

Rashid I, Romshoo SA, Muslim M, Malik AH (2010) Landscape level vegetation characterization of Lidder valley using geoinformatics. J Himal Ecol Sustain Dev 5:11–24

Rashid I, Romshoo SA, Vijayalakshmi T (2013) Geospatial modelling approach for identifying disturbance regimes and biodiversity rich areas in North Western Himalayas, India. Biodivers Conserv 22(11):2537–2566

Romshoo SA, Rashid I (2014) Assessing the impacts of changing land cover and climate on Hokersar wetland in Indian Himalayas. Arab J Geosci *7*(1):143–160

Romshoo SA, Dar RA, Rashid I, Marazi A, Ali N, Zaz S (2015) Implications of shrinking Cryosphere under changing climate on the streamflows in the lidder catchment in the upper Indus basin, India. Arct Antarct Alp Res 47(4):627–644

Rosenzweig C, Solecki WD (eds) (2001) Climate change and a global city: the potential consequences of climate variability and climate change-metro east coast. Report for the U.S. Global Change Research Program, National Assessment of the Potential Consequences of Climate Variability and Change for the United States. Columbia Earth Institute, New York

Roy PS, Murthy MSR, Roy A, Kushwaha SPS, Singh S, Jha CS, Behra MD, Joshi PK, Jagannathan C, Karnatak HC, Saran S, Reddy CS, Kushwaha D, Dutt CBS, Porwal MC, Sudhakar S, Srivastava VK, Padalia H, Nandy S, Gupta S (2013) Forest fragmentation in India. Current Science (00113891) 105(6):774–780

Rupakumar et al (2006) High-resolution climate change scenarios for India for the 21st century. *Curr Sci* 90(3):334–344

Scherler D, Bookhagen B, Strecker MR (2011) Spatially variable response of Himalayan glaciers to climate change affected by debris cover. Nat Geosci 4(3):156–159

Shao G, Wu J (2008) On the accuracy of landscape pattern analysis using remote sensing data. Landsc Ecol 23(5):505–511

Sharif M, Archer DR, Fowler HJ, Forsythe N (2013) Trends in timing and magnitude of flow in the Upper Indus Basin. Hydrol Earth Syst Sci 17(4):1503–1516

Shrestha AB, Wake CP, Mayewski PA, Dibb JE (1999) Maximum temperature trends in the Himalaya and its vicinity: an analysis based on temperature records from Nepal for the period 1971–94. J Clim 12(9):2775–2786

Solomon AM (1986) Transient response of forests to CO2-induced climate change: simulation modeling experiments in eastern North America. Oecologia 68(4):567–579

Solomon S, Qin D, Manning M, Chen Z, Marquis M, Averyt KB, Miller HL (2007) IPCC, 2007: climate change 2007: the physical science basis. Contribution of Working Group I to the fourth assessment report of the Intergovernmental Panel on Climate Change

Suárez A, Watson RT, Dokken DJ (2002) Climate change and biodiversity. Intergovernmental Panel on Climate Change, Geneva

Sykes MT, Prentice IC, Smith B, Cramer W, Venevsky S (2001) An introduction to the European terrestrial ecosystem modelling activity. Glob Ecol Biogeogr 10:581–593

Tadross M, Jack C, Hewitson B (2005) On RCM-based projections of change in southern African summer climate. Geophys Res Lett 32(23):L23713

Telwala Y, Brook BW, Manish K, Pandit MK (2013) Climate-induced elevational range shifts and increase in plant Species richness in a Himalayan biodiversity epicentre. PLoS One 8(2):e57103

Thuiller W, Lavorel S, Araújo MB, Sykes MT, Prentice IC (2005) Climate change threats to plant diversity in Europe. Proc Natl Acad Sci U S A 102(23):8245–8250

Walther GR, Post E, Convey P, Menze A, Parmesan C, Beebee TJC, Fromentin JM, Hoegh-Guldberg O, Bairlein F (2002) Ecological responses to recent climate change. Nature 416:389–395

Williams J, Jackson S, Kutzbach J (2007) Projected distributions of novel and disappearing climates by 2100 AD. Proc Natl Acad Sci U S A 104:5738–5742

Winter JM, Pal JS, Eltahir EA (2009) Coupling of integrated biosphere simulator to regional Climate Model Version 3. J Clim 22(10):2743–2757

Woodward FI (1987) Climate and plant distribution. Cambridge University Press, Cambridge

Woodward FI, Beerling DJ (1997) The dynamics of vegetation change: health warnings for equilibrium ‘dodo’ models. Glob Ecol Biogeogr Lett:413–418

Xu Y, Zhang Y, Lin E, Lin W, Dong W, Jones R, Hassell D, Wilson S (2006) Analyses on the climate change responses over China under SRES B2 scenario using PRECIS. Chin Sci Bull 51(18):2260–2267

Yuan QZ, Zhao DS, Wu SH, Dai EF (2011) Validation of the Integrated Biosphere Simulator in simulating the potential natural vegetation map of China. Ecol Res 26(5):917–929

Yue S, Pilon P (2004) A comparison of the power of the t test, Mann-Kendall and bootstrap tests for trend detection. Hydrological Sciences Journal 49(1):21–37

Zutshi DP (1975) Associations of macrophytic vegetation in Kashmir lakes. Vegetation 30(1):61–66