


Projected climate change impacts on vegetation distribution over Kashmir Himalayas

Irfan Rashid^{1,2}  · Shakil Ahmad Romshoo¹ ·
Rajiv Kumar Chaturvedi³ · N. H. Ravindranath^{3,4} ·
Raman Sukumar^{4,5} · Mathangi Jayaraman³ ·
Thatiparthi Vijaya Lakshmi² · Jagmohan Sharma³

Received: 2 August 2014 / Accepted: 19 June 2015 / Published online: 5 July 2015
© Springer Science+Business Media Dordrecht 2015

Abstract Despite high vulnerability, the impact of climate change on Himalayan ecosystem has not been properly investigated, primarily due to the inadequacy of observed data and the complex topography. In this study, we mapped the current vegetation distribution in Kashmir Himalayas from NOAA AVHRR and projected it under A1B SRES, RCP-4.5 and RCP-8.5 climate scenarios using the vegetation dynamics model-IBIS at a spatial resolution of 0.5°. The distribution of vegetation under the changing climate was simulated for the 21st century. Climate change projections from the PRECIS experiment using the HADRM3 model, for the Kashmir region, were validated using the observed climate data from two observatories. Both the observed as well as the projected climate data showed statistically significant trends. IBIS was validated for Kashmir Himalayas by comparing the simulated vegetation distribution with the observed distribution. The baseline simulated scenario of vegetation (1960–1990), showed 87.15 % agreement with the observed vegetation distribution, thereby increasing the credibility of the projected vegetation distribution under the changing climate over the region. According to the model projections, grasslands and tropical deciduous forests in the region would be severely affected while as savannah, shrubland, temperate evergreen broadleaf forest, boreal evergreen forest and mixed forest types would colonize the area currently under the cold desert/rock/ice land cover types. The model predicted that a substantial area of land, presently

Electronic supplementary material The online version of this article (doi:10.1007/s10584-015-1456-5) contains supplementary material, which is available to authorized users.

✉ Irfan Rashid
irfangis@gmail.com

¹ Department of Earth Sciences, University of Kashmir, Srinagar, India

² Centre for Environment, Jawaharlal Nehru Technological University, Hyderabad, India

³ Centre for Sustainable Technologies, Indian Institute of Science, Bangalore, India

⁴ Divecha Centre for Climate Change, Indian Institute of Science, Bangalore, India

⁵ Centre for Ecological Sciences, Indian Institute of Science, Bangalore, India

under the permanent snow and ice cover, would disappear by the end of the century which might severely impact stream flows, agriculture productivity and biodiversity in the region.

1 Introduction

Climate exhibits a dominant control over the natural distribution of ecosystems. Fossil records (Davis and Shaw 2001; Morley 2011) and observed trends (Hughes 2000; Walther et al. 2002) showed that the changing climate has a profound influence on the vegetation distribution (Suárez et al. 2002; Beniston 2003). It is therefore inevitable that the projected climate change by the end of 21st century will have a significant impact on the vegetation distribution at global level (IPCC 2013; Parmesan and Yohe 2003). The impact of climate change in mountainous regions is expected to result in the loss of cooler climatic zones at mountain peaks and the upward shifting of tree line (Gottfried et al. 2012; Engler et al. 2011). 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 a more thermophilous species (Gottfried et al. 2012; McMahon et al. 2011). The indicators of climate change are quite loud and clear in the Himalayas (Romshoo and Rashid 2014; Immerzeel et al. 2012). The Himalayas are experiencing a temperature increase that is higher than the global mean of about 0.7 °C in 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 Himalayas potentially inducing strong impact on the high-altitude ecosystems especially changes in the vegetation structure and biodiversity (Aryal et al. 2014). There is a significant dependence of mountain communities on forest products and services (Roy et al. 2013). It, therefore, becomes imperative to assess the likely impact of climate change on vegetation distribution and composition in mountainous regions.

The development of Dynamic Global Vegetation Models (DGVMs), which include mechanistic representations of the associated physiological, biophysical and biogeochemical processes, has allowed significant progress in the modelling of vegetation-climate interactions (Cramer et al. 2001; Woodward and Beerling 1997). DGVMs provide a 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 DGVMs at regional scale indeed has increased the knowledge base pertaining to the climate change impact on vegetation (Sykes et al. 2001; Pearson and Dawson 2003). Several studies using DGVMs have demonstrated that the changing climate can affect the distribution of vegetation types and there could even be a potential vegetation dieback (McClellan et al. 2005; Seppälä 2009). Recent studies in the Himalayas reveal that most of the areas are likely to experience a shift in vegetation types due to changing climate (Zomer et al. 2014).

In this study, we mapped the current vegetation distribution in Kashmir Himalayas and projected its evolution under the changing climate. The studies conducted across India have certain limitations as far as the validation of simulated vegetation by DGVMs is concerned. The study was conducted with the following goals 1) Map the current vegetation distribution in the region using remotely sensed data supplemented by extensive field observations 2) Analyze the meteorological indicators for the changing climate signals over the region and 3) Project the distribution and composition of vegetation in the region using a DGVM-Integrated Biosphere Simulator (IBIS).

2 Methodology

2.1 Study area

The study area is located in the northwestern part of the Himalayas (Online Resource 1), covering an area of approximately 222, 236 km² and forms the north most state of India. The region lies between lat: 32.28–37.06° and lon: 72.53–80.32° with altitudinal extremes of 305 asl metres (in South) to 8238 m asl (in North). Areas above 3600 m asl are mostly covered by snow and glaciers. Because of the large variations in climate and topography, the region supports a rich biodiversity (Champion and Seth 1968).

2.2 Vegetation mapping and its validation

A medium resolution vegetation map from NOAA-AVHRR (National Oceanic and Atmospheric Administration- Advanced Very High Resolution Radiometer) with a spatial resolution of 1 km was extracted for the entire study area. The map was reclassified into broader vegetation types. Stratified random sampling approach involving sampling of different vegetation types, based on their spatial extents, was adopted for the validation of the vegetation types. Although the ground samples should were ideally chosen in proportion to the spatial extent of the vegetation type, but the challenging topography of the region did not allow this criterion to be met. Published material (Dar et al. 2002; Rashid et al. 2013) was consulted to supplement the ground truth about the species composition of the vegetation types and for any possible indication of climate driven ecosystem changes in the region.

The overall accuracy of the vegetation type map was calculated using the following formula:

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

where ‘ ρ ’ is classification accuracy; ‘ n ’ is number of points correctly classified on image and ‘ N ’ is number of points checked in the field.

2.3 Observed and projected climate data

Time series meteorological data (1980–2010) for two Indian Meteorological Department (IMD) observatories; Pahalgam and Gulmarg, was analyzed to look into the signals of the changing climate over the region and to validate the temperature and precipitation predictions over the study area. The projected climate data from 1960 to 2099 under A1B scenario was extracted for the study area from a PRECIS (Providing REgional Climates for Impact Studies) run simulated over the study area with a spatial resolution of 0.5°×0.5° (Jones et al. 2004). The PRECIS data has been used comprehensively for assessing the impact of climate change on agriculture, terrestrial vegetation, water resources and atmospheric dynamics (Akhtar et al. 2008; Xiong et al. 2007). A time series of meteorological projections, ending 2099, from PRECIS under A1B Scenario and comprising of average annual maximum, minimum temperature and total annual precipitation from 2011 to 2098 was analyzed, centered at CO₂ concentrations of 437 and 630 ppm for the year 2025 and 2075 respectively. In addition, we also analyzed temperature and precipitation changes from the ensemble mean of 5 CMIP5

(Coupled Model Intercomparison Project) models for RCP (Representative Concentration Pathway) 4.5 and RCP 8.5 by the mid and end of 21st century (Online Resource 2).

Projected temperatures from PRECIS have a spatial resolution of 50×50 km while the observed data from IMD is localized weather station data. IMD temperature data was hence upscaled to 50×50 km using GTOPO (Global TOPOgraphy) data with 1 km spatial 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 the IMD observation station. In case of PRECIS (with a 50×50 km dimension), average elevation from 2500 pixels was taken as a representative of the whole grid. Lapse rate was applied to the IMD data taking into consideration the elevation difference between the PRECIS grid and the IMD station.

2.3.1 Trend analysis of climate data

A time series of the observed streamflow, temperature and precipitation (1979–2010) and projected climate data (2010–2099) were used for trend analysis and the interpretation about the significance of the observed trends is based on non-parametric Mann-Kendall test (Yue and Pilon 2004). Man-Kendall static (S) 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:

$$S = \sum_{i=1}^{n-1} \left[\sum_{j=i+1}^n \text{sgn}(R_i - R_j) \right]$$

where, $\text{sgn}(x)=1$ for $x>0$, $\text{sgn}(x)=0$ for $x=0$ and $\text{sgn}(x)=-1$ for $x<0$

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

2.4 Impact of changing climate on vegetation distribution

IBIS was used to assess the spatial distribution of current and future vegetation under the changing climate utilizing high resolution projected climate simulations from PRECIS (A1B scenario) and CMIP5 (RCP4.5 and RCP8.5). The climate change projections using a single climate model are likely to have large uncertainties and hence a multiple model ensemble mean has been used in this study to reduce uncertainty (Chaturvedi et al. 2012). The ensemble mean data from five CMIP5 climate models was used and the models provide all the climate variables necessary to drive IBIS-DGVM. Simulations were generated for two time-frames; (i) Time-frame of 2021–2050 labelled as '2035'. (ii) Time-frame of 2071–2100, labelled as '2085'. The model was run continuously for 200 years to reach the equilibrium. Soil carbon and total biomass carbon takes a minimum of 125 years to stabilize. We compared the projected simulations with the 'baseline' scenario, which was generated using the 1960–90 observed climate data.

2.4.1 Vegetation dynamics model

DGVMs are the most advanced tools to comprehensively estimate the impact of climate change on vegetation dynamics at global scale (Fischling et al. 2007). Although a number of DGVMs are available to understand vegetation dynamics, we selected the IBIS as it has been widely tested and validated in different geographies (Yuan et al. 2011; Yu et al. 2014;

Chaturvedi et al. 2011). IBIS model uses physiological formulations with much greater detail than other DGVMs (Cramer et al. 2001). IBIS is currently incorporated into two AGCMs (Atmospheric General Circulation models) namely GENESIS-IBIS (Foley et al. 2000) and CCM3-IBIS (Winter et al. 2009). IBIS is designed around a hierarchical modular structure (Foley et al. 1996; Kucharik et al. 2000). It considers transient changes in vegetation composition and structure in response to climatic and environmental changes (details of working framework and input data of IBIS are given in Online Resource 3).

2.4.2 Simulating vegetation distribution and composition

The spatial resolution of vegetation simulated by IBIS is 0.5° . Although it would have been prudent to use high resolution simulations but due to the non-availability of high resolution input parameters over the study area, IBIS DGVM was run at 50×50 km. For validation, baseline vegetation of the region simulated by 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). Digital vegetation type map of the study area (ISRO 2010) at 1:50,000 scale was used for 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 by IBIS.

The validation of simulated vegetation was done using kappa coefficient. Kappa coefficient is a robust indicator of accuracy assessment, and is calculated using the following formula:

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

where r is the number of rows in error matrix; x_{ii} is the number of observations in row i and column i ; x_{i+} is the total of observations in row i ; x_{+i} the total of observations in column i and N is the total number of observations included in the matrix

3 Results and discussion

3.1 Vegetation mapping

Nine land cover types were delineated in the region during the present study (Fig. 1; Table 1). It is evident from the Fig. 1 that 56 % of the area is covered by vegetation while the non-vegetated areas cover ~44 % of the area. Major vegetation types include shrublands (33.62 %), forests (16.69 %) and grasslands (5.89 %). The vegetation types were checked and validated at 451 ground locations spread across various geographic and vegetation belts of the study area. Ancillary data in the form of coarse resolution maps and google earth was used for validating the vegetation types in the Chinese and Pakistan administered territories. The overall accuracy (86.47 %) and the class-wise accuracy are given in Table 1. The dominant shrubland species in the areas with elevation less than 3000 m include *Berberis lyceum*, *Viburnum grandiflorum*, *Indigofera heterantha*, *Parratiopsis jacquemontiana* and *Betula utilis*, while as the vegetation

species in the alpine shrubland areas comprise of *Juniperous squamata*, *Rhododendron companulatum* and *Rosa webbiana*. The forest species include *Pinus wallichiana*, *Pinus roxburghii*, *Pinus gerardiana*, *Cedrus deodara*, *Abies pindrow*, *Quercus semicarpifolia*, *Quercus leucotricophora*, *Olea cuspidata* and *Ulmus wallichiana*. Grasslands were dominated by *Cynodon dactylon*, *Stipa siberica*, *Poa alpina* and *Poa annua* (Rashid et al. 2013). It has been observed that the climate change in the region is one of the important factors responsible for the proliferation of alien invasive species (Khuroo et al. 2007). Many alien invasive species are reported to have invaded forest, grassland and wetland ecosystems across Kashmir Himalayas (Masoodi et al. 2013).

The land cover types, delineated from AVHRR, were compared with the 2010 ISRO land cover map. For the comparison, the land cover classes were generalised (Buyantuyev and Wu 2007) into five categories as the classification scheme involved in AVHRR and ISRO maps is different. While the AVHRR adopts IGBP land cover nomenclature, the ISRO has adopted land cover nomenclature as per Champion and Seth (1968). As can be seen in the Online Resource 4, there is a very good agreement for the croplands and forests but variations exist in the spatial extents of grasslands, shrub lands and non-vegetated areas on the two maps. The variations occurred mainly because of the differences in the spatial resolution and mapping scale used for the two data sets (Shao and Wu 2008; Achard et al. 2001). In AVHRR data, the areas falling under grassland and non-vegetated areas got classified into shrubland.

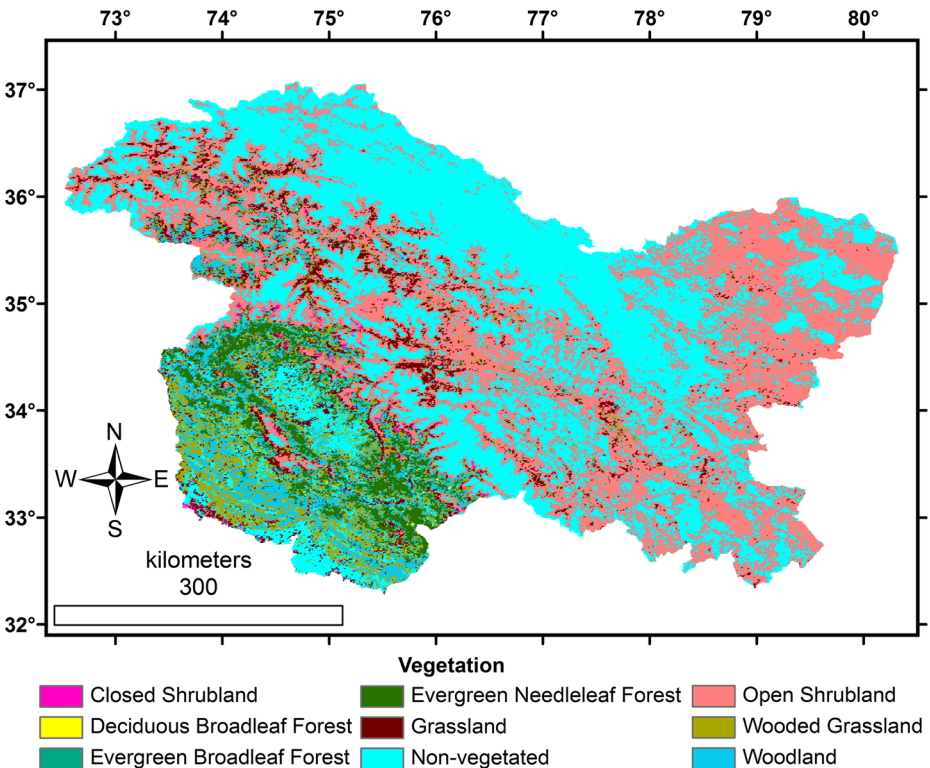


Fig. 1 Major land cover/vegetation types in Jammu and Kashmir

Table 1 Land cover statistics for Jammu and Kashmir

Vegetation type	Area (km ²)	%	N	n	ρ
Non-vegetated	97389.74	43.82	50	46	92.00
Closed shrubland	1208.42	0.54	25	21	84.00
Deciduous broadleaf forest	253.58	0.11	22	19	86.36
Evergreen broadleaf forest	360.67	0.16	21	18	85.71
Evergreen needle leaf forest	8394.99	3.78	71	61	85.92
Grassland	13080.68	5.89	66	56	84.85
Open shrubland	73478.65	33.06	102	91	89.22
Wooded grassland	14207.3	6.39	58	48	82.76
Woodland	13862.25	6.24	36	30	83.33
Total area	222236.28	100.00	451	390	86.47

N Number of ground samples taken, *n* Number of samples correctly classified, ρ Accuracy

3.2 Historical hydrometeorological data analysis

The analysis of time series of the observed average annual minimum and maximum temperature from 1980 to 2010 at Pahalgam station showed a significant rising trend over the years. Mean annual precipitation at Pahalgam showed a slightly decreasing but insignificant trend with a very weak R^2 (Online Resource 5). Similarly, the analysis of time series of the observed average annual minimum and maximum temperature at Gulmarg showed a significant rising trend (Online Resource 5). Statistically insignificant trends were manifest in case of the observed and projected precipitation over the region (Online Resource 6). As is clear from the analysis, the minimum temperature in the region is rising faster than the maximum temperature. This may bring about significant habitat alterations in the alpine zones (Ernakovich et al. 2014; Telwala et al. 2013). Rise in the temperature together with the insignificant decreasing precipitation in the region can have serious impacts on the forest distribution (Joshi et al. 2012), snow and glacier resources (Immerzeel et al. 2010) and water availability (Sharma et al. 2000).

The projected temperature showed an increasing trend under all the climate scenarios for both Pahalgam and Gulmarg stations while as the precipitation showed insignificant changes for both Pahalgam and Gulmarg with inter-annual variations (Online Resource 7, 8). The average annual maximum and minimum temperatures over Pahalgam are projected to increase by 7.23 °C (± 1.84 °C) and 4.89 (± 1.51) from 2011 to 2098. The average annual maximum and minimum temperatures over Gulmarg are projected to increase by 7.68 (± 2.01) and 5.88 (± 1.51). Mann-Kendall analysis of time-series of the observed and projected climate data (Online Resource 6) revealed that the temperatures are going to rise very significantly. Similar increasing trends were simulated over other areas of the region.

The trend analysis of the average yearly discharge using Man-Kendall test at Pahalgam has been plotted (Online Resource 9) and the statistics shown in the Online Resource 6. A significantly decreasing trend was observed for stream flow measurements from 1980 to 2010. In view of the depletion of 27.47 % in the glacier area during the last 51 years in the Lidder valley, impact of the depleting cryosphere under the changing climate is quite evident on the streamflows at Pahalgam (Romshoo et al. 2015).

From the analysis of the climatic data over the area, we hence infer that there will be a statistically significant increase in the temperatures, decrease in the streamflows and comparatively insignificant changes in the precipitation patterns by the end of 21st century.

Upon comparison of the upscaled IMD data with the PRECIS projected temperatures during the baseline period, it was found that the two datasets are agreeing reasonably well as can be seen in Fig. 2a and b and hence the model is considered credible and cogent for projecting temperatures over the region. Similar findings have been reported about the use of PRECIS in Himalayas (Kulkarni et al. 2013; Akhtar et al. 2008)

3.3 Impact of changing climate on vegetation distribution

In order to assess the accuracy and credibility of the IBIS simulations, the baseline vegetation simulated by IBIS (Fig. 3a) was compared with the actual vegetation on the ground. It is pertinent to mention that IBIS results are to be interpreted as a state towards which the vegetation distribution will have a tendency to evolve by the end of the 21st century. For this purpose, vegetation map (Fig. 3b) was developed at a resolution of 50x50km after modifying (Online Resource 10) the vegetation maps from NOAA AVHRR, Champion and Seth (1968) and ISRO (2010). Some categories of the vegetation were reclassified as per the IBIS nomenclature of vegetation. A kappa coefficient of 87.15 % (Table 2) indicates that IBIS

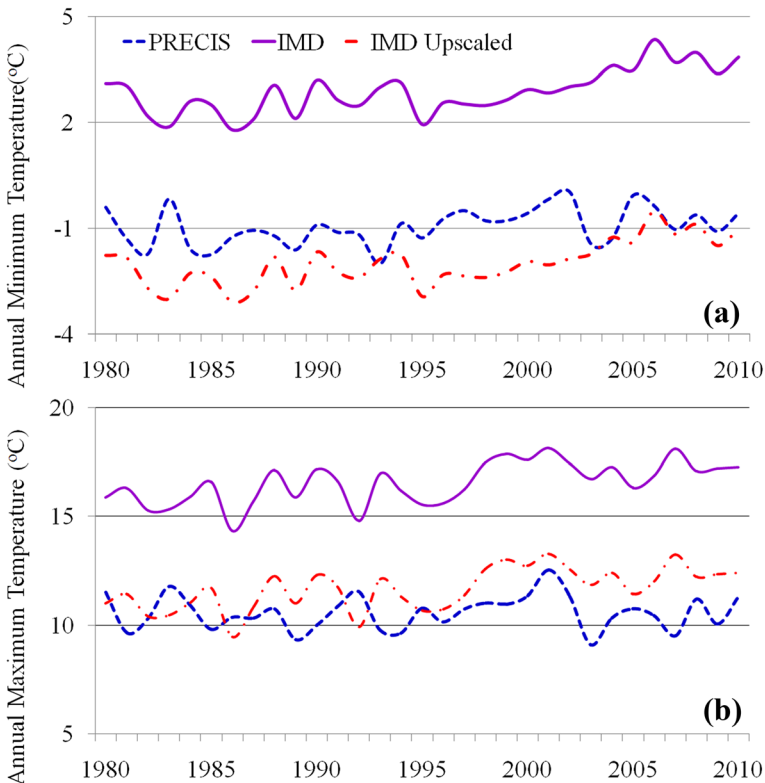


Fig. 2 Validation of PRECIS with IMD upscaled data (for Pahalgam)

simulated the baseline vegetation very well (Yuan et al. 2011) and hence could be relied upon for projecting vegetation distribution. As seen from Table 2, IBIS simulated temperate evergreen forest and tropical deciduous forest very well during the baseline period with 100 % agreement. It slightly over-estimates the grasslands with only 66.66 % agreement with the observed vegetation and tundra (only 72.42 % similarity). The model slightly under-estimates dense shrubland (by 33.33 %), open shrubland (by 14.28 %) and polar desert/rock/ice (by 13.63 %). These dissimilarities between the observed and the simulated baseline vegetation distribution and type are insignificant keeping in view the spatial resolution of 50x50km. Considering the complex terrain and the spatial resolution of 0.5° of IBIS-projected vegetation, many of the vegetation types like grasslands are not captured well due to their smaller size. The table, showing average patch size of the major vegetation types in the region, might help to assess how well IBIS DGVM captures the actual vegetated landscape (Online Resource 11). Biomass and Leaf Area Index (LAI) values are representative of the Plant Function Types (PFT). The projected changes in the biomass and LAI over Jammu and Kashmir by the end of 21st century corroborate PFTs simulated by IBIS (Online Resource 12).

For all the three projected vegetation distribution scenarios (Fig. 3c, e and g; Table 3), most of the area under polar desert/rock/ice is taken over by boreal evergreen forest, tundra and

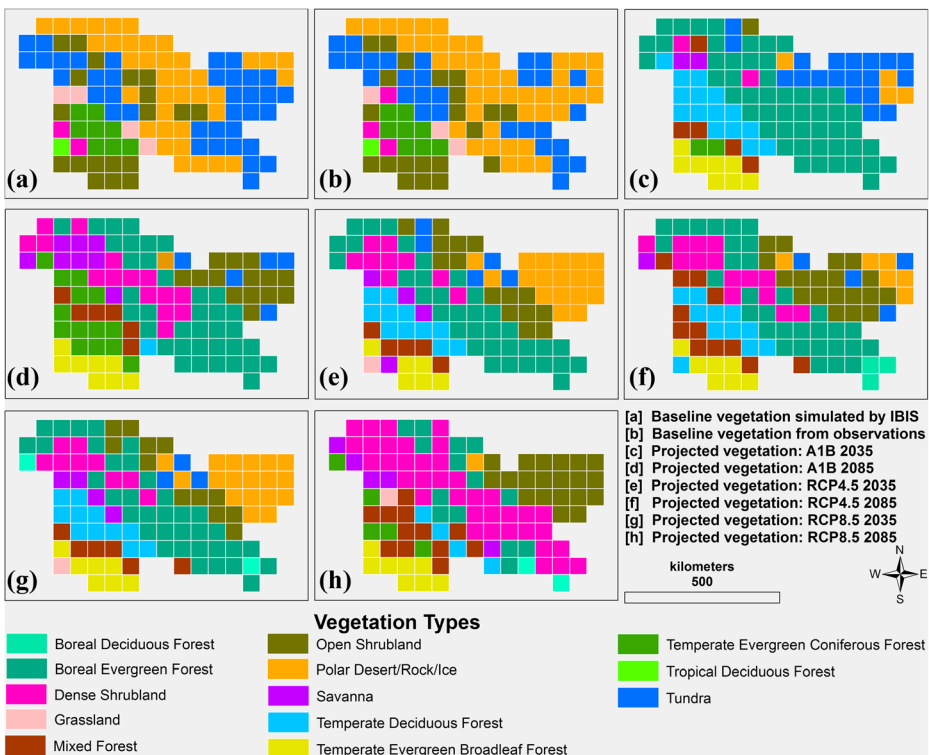


Fig. 3 Vegetation distribution under changing climate. **a** Baseline vegetation simulated by IBIS **b** Actual vegetation after AVHRR, Champion and Seth(1968) and ISRO (2010) **c, d** Projected vegetation distribution (A1B scenario) by the mid and end of century **e, f** Projected vegetation distribution (RCP 4.5) by the mid and end of century **g, h** Projected vegetation distribution (RCP 8.5) by the mid and end of century

Table 2 Matrix showing the comparison of IBIS simulated baseline vegetation with respect to satellite derived vegetation

Vegetation type		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=88.07

shrublands by 2035. This can be partly an artifact of coarse resolution (Ni 2001) of projected vegetation and partly reflecting the ecosystem changes happening in response to the changing climate in the region (Sorg et al. 2012; Muhlfeld et al. 2011). Moreover, a substantial part currently under the temperate evergreen forest is colonized by temperate deciduous forest. Areas

Table 3 Changes in vegetation composition across different scenarios from 1960 to 2099. Numbers indicate grid cells with a spatial resolution of $0.5 \times 0.5^\circ$ falling within a particular vegetation type

VEGETATION TYPE	BASELINE		FUTURE SCENARIOS					
	IBIS projected	Satellite derived	A1B		RCP 4.5		RCP 8.5	
			2035	2085	2035	2085	2035	2085
Boreal deciduous forest	0	0	0	0	0	3	2	2
Boreal evergreen forest	0	0	51	37	35	32	36	14
Dense shrubland	2	3	2	15	9	14	9	37
Grassland	4	3	0	0	1	0	1	1
Mixed forest	0	0	5	6	5	12	6	12
Open shrubland	18	21	1	14	15	19	12	20
Polar desert/rock/ice	38	44	4	1	18	6	18	1
Savanna	0	0	2	8	4	1	4	5
Temperate deciduous forest	0	0	15	1	11	11	11	4
Temperate evergreen broadleaf forest	0	0	8	8	6	7	7	8
Temperate evergreen coniferous forest	8	8	2	14	0	0	0	5
Tropical deciduous forest	1	1	0	0	0	0	0	0
Tundra	37	29	19	5	5	4	3	0

under open shrublands are taken over by temperature evergreen broadleaf forest and mixed forest types. In addition, savanna is also projected to invade some landscapes which could be attributed to the elevated CO₂ levels and increase in temperatures projected over the region.

Vegetation simulated by IBIS towards the end of 21st century (Fig. 3d, f and h; Table 3) shows the expansion of savannahs, reappearance of temperate evergreen coniferous forest and shrublands in Karakoram belt. Dense shrublands overtake boreal evergreen forest in north and central part of the region with greatest proliferation in RCP 8.5 which could be attributed to very high CO₂ levels. Areas under temperate coniferous forest are overtaken by temperate deciduous and mixed forest categories by the end of century. On a very small scale, there is emergence of boreal deciduous forest by the end of the century using forcing data from both the RCPs. Most of the area under polar desert/rock/ice is projected to shrink considerably. Although the observed impacts of the climate change on vegetation over the region are supporting this argument but it could be also partly due to the coarse resolution of projected vegetation simulations (Dimri 2014). Although a few studies have demonstrated that snow and glacier resources in the region are receding at an accelerated rate due to rising temperatures (Immerzeel et al. 2010; Romshoo et al. 2015) but it is unlikely that any dramatic change will occur in the Himalayan cryosphere in the immediate future (Bolch et al. 2012).

It is important to mention that huge carbon stocks are locked in the vegetation of the region. Therefore the projected vegetation dynamics in response to the future climate change could change the existing carbon stocks in the region.

4 Conclusion

The study indicates that the climate change evidence in the region is clear and most of the naturally occurring vegetation is likely to bear the brunt. The findings assume importance as NW Himalayas host a sizeable proportion of the Himalayan biodiversity hotspot. The PRECIS projections of the climate closely agree with the upscaled meteorological data, thus giving credence to the projected vegetation distribution under the changing climate generated for the region using IBIS. The study demonstrated that the climate change is going to bring about significant changes in the vegetation distribution and type in the region and might therefore adversely affect the services and products available from the forests that currently support a number of livelihoods in the region. Vegetation in the alpine belts, comprising of pastures and shrublands and habitat to many of the endemic and medicinally important species, are very sensitive to any subtle variation in climate. In light of the changing climate over the region, these species may get extinct 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 cycles affecting the biodiversity richness in the region.

Acknowledgments The authors express gratitude to Dr. Christine Delire and another anonymous reviewer for their valuable comments and suggestions on the earlier versions of the manuscript that greatly improved the content and structure of this manuscript.

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
- 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* 115:517–529
- 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
- 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, Netherlands 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* 85:159–177
- Bolch T, Kulkarni A, Kääb A et al (2012) The state and fate of Himalayan glaciers. *Science* 336(6079):310–314
- Buyantuyev A, Wu J (2007) Effects of thematic resolution on landscape pattern analysis. *Landsc Ecol* 22(1):7–13
- Chamption SH, Seth SK (1968) A revised survey of the forest types of India. Natraj Publishers, Dehradun
- Chaturvedi RK, Gopalakrishnan R, Jayaraman M et al (2011) Impact of climate change on Indian forests: a dynamic vegetation modeling approach. *Mitig Adapt Strateg Glob Chang* 16(2):119–142
- Chaturvedi RK, Joshi J, Jayaraman M et al (2012) Multi-model climate change projections for India under representative concentration pathways. *Curr Sci* 103(7):791–802
- Cramer W, Bondeau A, Woodward FI et al (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
- Dar GH, Bhagat RC, Khan MA (2002) Biodiversity of the Kashmir Himalaya. Valley Book House, Srinagar
- Davis MB, Shaw RG (2001) Range shifts and adaptive responses to quaternary climate change. *Science* 292:673–679
- Dimri AP (2014) How robust and (un)certain are regional climate models over Himalayas? *Cryosphere Discuss* 8(6):6251–6270
- Engler R, Randinw CF, Thuiller W et al (2011) 21st century climate change threatens mountain Flora unequally across Europe. *Glob Chang Biol* 17:2330–2341
- Emakovich JG, Hopping KA, Berdanier AB et al (2014) Predicted responses of arctic and alpine ecosystems to altered seasonality under climate change. *Glob Chang Biol*. doi:10.1111/gcb.12568
- Foley JA, Prentice IC, Ramankutty N et al (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 et al (2000) Incorporating dynamic vegetation cover within global climate models. *Ecol Appl* 10(6):1620–1632
- Gottfried M, Pauli H, Futschik A et al (2012) Continent-wide response of mountain vegetation to climate change. *Nat Clim Chang* 2(2):111–115
- 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* 67:15–22
- Immerzeel WW, Van-Beek LP, Bierkens MF (2010) Climate change will affect the Asian water towers. *Science* 328(5984):1382–1385
- Immerzeel WW, Van-Beek LPH, Konz M et al (2012) Hydrological response to climate change in a glacierized catchment in the Himalayas. *Clim Chang* 110(3–4):721–736
- IPCC (2013) *Climate Change 2013: The Physical Science Basis*. In: Stocker TF, Qin D, Plattner GK, Tignor M, Allen SK, Boschung J, Nauels A, Xia Y, Bex V, Midgley PM (eds) *Contribution of Working Group I to the Fifth Assessment Report of the Intergovernmental Panel on Climate Change*. Cambridge University Press, Cambridge, United Kingdom and New York, NY, USA, p 1535
- 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
- Jones RG, Nougier M, Hassel DC et al (2004) Generating high resolution climate change scenarios using PRECIS, report 40pp. Met Off Hadley Centre, Exeter
- Joshi PK, Rawat A, Narula S, Sinha V (2012) Assessing impact of climate change on forest cover type shifts in Western Himalayan Ecoregion. *J For Res* 23(1):75–80
- Khuroo AA, Rashid I, Reshi Z et al (2007) The alien flora of Kashmir Himalaya. *Biol Invasions* 9(3):269–292
- Kucharik CJ, Foley JA, Delire C et al (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 et al (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
- McClellan CJ, Lovett JC, Küper W et al. (2005) African plant diversity and climate change. *Ann Mo Bot Gard* 139–152
- McMahon SM, Harrison SP, Armbruster WS et al (2011) Improving assessment and modelling of climate change impacts on global terrestrial biodiversity. *Trends Ecol Evol* 26(5):249–259
- Morley RJ (2011) Cretaceous and tertiary climate change and the past distribution of megathermal rainforests. In *Tropical rainforest responses to climatic change*. Springer Berlin Heidelberg, pp 1–34
- Muhlfeld CC, Giersch JJ, Hauer FR et al (2011) Climate change links fate of glaciers and an endemic alpine invertebrate. *Clim Chang* 106(2):337–345
- Ni J (2001) Carbon storage in terrestrial ecosystems of China: estimates at different spatial resolutions and their responses to climate change. *Clim Chang* 49(3):339–358
- 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
- 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 et al (2015) Implications of shrinking cryosphere under changing climate on the streamflows of the upper Indus Basin. Arctic, Antarctic and Alpine Research. In Press
- Roy PS, Murthy MSR, Roy A et al (2013) Forest fragmentation in India. *Curr Sci* 105(6):774–780
- Seppälä R (2009) A global assessment on adaptation of forests to climate change. *Scand J For Res* 24(6):469–472
- Shao G, Wu J (2008) On the accuracy of landscape pattern analysis using remote sensing data. *Landsc Ecol* 23(5):505–511
- Sharma KP, Vorosmarty CJ, Moore B III (2000) Sensitivity of the Himalayan hydrology to land-use and climatic changes. *Clim Chang* 47:117–139
- Sorg A, Bolch T, Stoffel M et al (2012) Climate change impacts on glaciers and runoff in Tien Shan (Central Asia). *Nat Clim Chang* 2(10):725–731
- Suárez A, Watson RT, Dokken DJ (2002) Climate change and biodiversity. Intergovernmental Panel on Climate Change, Geneva
- Sykes MT, Prentice IC, Smith B et al (2001) An introduction to the European terrestrial ecosystem modelling activity. *Glob Ecol Biogeogr* 10:581–593
- 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
- Walther GR, Post E, Convey P et al (2002) Ecological responses to recent climate change. *Nature* 416:389–395
- 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, Beerling DJ (1997) The dynamics of vegetation change: health warnings for equilibrium ‘dodo’ models. *Glob Ecol Biogeogr Lett* 6:413–418
- Xiong W, Lin E, Ju H, Xu Y (2007) Climate change and critical thresholds in China’s food security. *Clim Chang* 81(2):205–221
- Yu M, Wang G, Parr D, Ahmed KF (2014) Future changes of the terrestrial ecosystem based on a dynamic vegetation model driven with RCP8.5 climate projections from 19 GCMs. *Clim Chang* 127(2):257–271
- 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/Une comparaison de la puissance de la puissance des tests t de Student, de Mann-Kendall et du bootstrap pour la détection de tendance. *Hydrol Sci J* 49(1):21–37
- Zomer RJ, Trabucco A, Metzger MJ et al. (2014) Projected climate change impacts on spatial distribution of bioclimatic zones and ecoregions within the Kailash Sacred Landscape of China, India, Nepal. *Clim Chang* 1–16 doi: 10.1007/s10584-014-1176-2