

Development of deforestation and land cover database for Bhutan (1930–2014)

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Abstract Bhutan is a mountainous country located in the Himalayan biodiversity hotspot. This study has quantified the total area under land cover types, estimated the rate of forest cover change, analyzed the changes across forest types, and modeled forest cover change hotspots in Bhutan. The topographical maps and satellite remote sensing images were analyzed to get the spatial patterns of forest and associated land cover changes over the past eight decades (1930–1977–1987–1995–2005–2014). Forest is the largest land cover in Bhutan and constitutes 68.3% of the total geographical area in 2014. Subtropical broad leaved hill forest is predominant type occupies 34.1% of forest area in Bhutan, followed by montane dry temperate (20.9%), montane wet temperate (18.9%), Himalayan moist temperate (10%), and tropical moist sal (8.1%) in 2014. The major forest cover loss is observed in subtropical broad leaved hill forest

(64.5 km²) and moist sal forest (9.9 km²) from 1977 to 2014. The deforested areas have mainly been converted into agriculture and contributed for 60.9% of forest loss from 1930 to 2014. In spite of major decline of forest cover in time interval of 1930–1977, there is no net rate of deforestation is recorded in Bhutan since 1995. Forest cover change analysis has been carried out to evaluate the conservation effectiveness in “Protected Areas” of Bhutan. Hotspots that have undergone high transformation in forest cover for afforestation and deforestation were highlighted in the study for conservation prioritisation. Forest conservation policies in Bhutan are highly effective in controlling deforestation as compared to neighboring Asian countries and such service would help in mitigating climate change.

Keywords Deforestation · Protected area · Conservation · Remote sensing · Bhutan

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Introduction

Assessing changes in forest cover is a challenging research and operational topic that addresses issues like climate change, biodiversity conservation, and ecosystem management (Grinand et al. 2013). Land cover assessment and monitoring is essential for the sustainable management of natural resources, environmental protection, and food security. Studies of land cover change provide information about the past and current situation and can be used to predict future trends, for preparing effective plans for natural resource

management (Gilani et al. 2015). The study by using numerical model of global atmosphere and biosphere found that when the Amazonian forests were replaced by pastures, there was a significant increase in the mean surface temperature of about 2.5 °C, 30% decrease in the annual evapo-transpiration, 25% reduction in precipitation, and 20% reduction in runoff in the Amazon region (Nobre et al. 1991). Estimates contain considerable uncertainty, impeding the estimation of carbon emissions caused by deforestation and forest degradation in the tropics (Harris et al. 2012). At regional levels, forest estimates derived by aggregation of national forest data are often affected by incompatibilities of the individual inventory methodologies, definitions, and inventory dates (Stibig et al. 2014). Evaluation of the effectiveness of past conservation efforts can inform the design of interventions to promote REDD (Reduced Emissions from Deforestation and Degradation) agenda (Nelson and Chomitz 2011). Protected areas are notified to conserve biodiversity from anthropogenic activities and recognised as core “units” for in situ conservation. A large number of protected areas fail for a variety of reasons in effectively conserving species, habitats, and landscapes (CBD 2004). Data on the conservation effectiveness of protected areas is must be available for conservation planning. Because of this, knowledge about the historical land cover changes is essential to better understand the causative factors and conservation planning. Historical topographical maps can be used to quantify forest changes and for a long period of time (Wulf and Rujner 2011). Remote sensing is as an important tool in providing reliable historical and current land cover information at the local to global level (Foley et al. 2005). Land cover changes quantified at temporal scales using remote sensing data aid in the implementation of location specific mitigation measures (Ramachandra et al. 2016). National level spatial explicit studies that aimed to assess long-term forest changes were carried out in India, Bangladesh, and Sri Lanka (Reddy et al. 2016a, b, c).

Bhutan is eastern part of the Himalayan biodiversity hotspot (Myers 1988). Environmental protection is a deep-rooted tradition in the Buddhist Kingdom of Bhutan (Zurick 2006). Ministry of Agriculture and Forests land cover assessment of 2010 shows a forest cover of 27,052.9 km² (70.46%) in Bhutan (RGoB 2010). Food and Agriculture Organisation (FAO) reported a constant annual (0.34%) increase in forests of Bhutan from 1990–2000, 2005–2005, and 2005–2010 (FAO 2010).

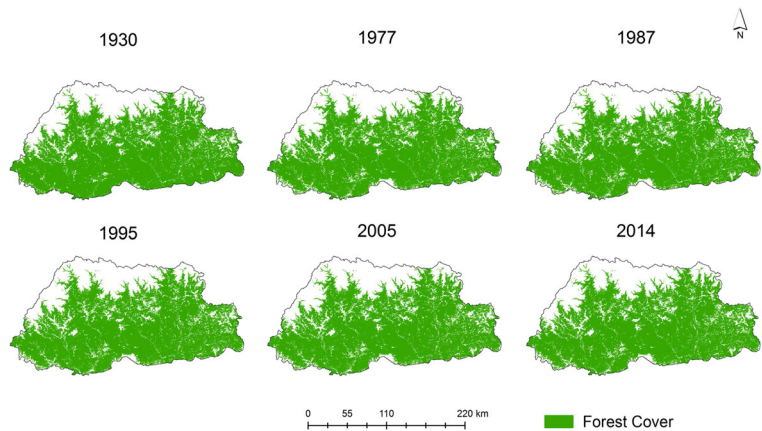
FAO Forest Resources Assessment reported a linear increase in forests between 1990 and 2015 by extrapolating estimates of forest cover change (FAO 2015). The study by Bruggeman et al. (2016) confirmed that the high forest cover of Bhutan was maintained since 1990, with a slight increase during the 2000s. A trend reversal occurred as a net forest loss of 91 km² during the 1990s was followed by a net forest gain of 52 km² during the following decade (Bruggeman et al. 2016). At the national level, overall forest increased from 25,558 to 26,732 km² between 1990 and 2010, with a net increase of 1174 km², equivalent to an average annual growth rate of 59 km²/year or 0.2% (Gilani et al. 2015). The growth in forest area in Bhutan from 1990 to 2010 was much higher than the loss of forest, mainly due to the annual plantation activities (Gilani et al. 2015). There was an overall reduction in grassland, shrubland, and barren area, but the observations were highly dependent on time of acquisition of the satellite data and climatic conditions in Bhutan (Gilani et al. 2015).

This study mapped and quantified the extent and trends of land cover in Bhutan for the periods 1930–1977, 1977–1987, 1987–1995, 1995–2005, and 2005–2014 and provides analysis of spatio-temporal changes in forest using consistent natural definition of forest. The present study brings out a comprehensive analysis of the long-term forest cover change as one of the potential indicator for the conservation appraisal of protected areas of Bhutan.

Study area

The study area cover the whole of Bhutan, a land locked Himalayan country lying between latitudes 26° 40' and 28° 20' N and longitude 88° 45' and 92° 7' E, with an area of 38,394 km² (RGoB 2010). Bhutan has tropical, subtropical, temperate, and alpine climatic zones. The altitude ranges from 97 to 7553 m above mean sea level (FAO 1999). Mean annual temperature varies from 5.5 to 23.6 °C, and mean annual precipitation ranges from less than 652 to 5500 mm. However, both temperature and precipitation patterns are extremely vary according to season and altitudinal gradient. Each climatic zone has different forest types such as mixed conifer, fir, blue pine, mixed (broadleaved and conifer), and broadleaved forests. Scrub, grasslands, and pastures are co-elements in forest landscapes (FAO 2007). Forests in Bhutan are strictly regulated by the government since the

Fig. 1 Forest cover of Bhutan (1930, 1977, 1987, 1995, 2005, and 2014)



nationalisation of forests in 1969. The forest harbors a wide variety of habitats for native species diversity. Total of 5603 species of angiosperms and gymnosperms, includes 369 species of wild orchids, 46 species of rhododendrons, around 30 bamboo species. The fauna includes close to 200 species of mammals, 677 species of avifauna, 23 species of reptiles, 140 species of invertebrates, and 50 species of fishes (<https://www.cbd.int>). It has the greatest proportion of forest cover compared to any Asian country. Bhutan has large protected area network with forests occupies around 72% of the total geographical area is under forest cover (Gilmour et al. 2009).

The forests of Bhutan are considered as a valuable carbon sinks and significantly absorbing an estimated

more than four times the country’s emissions (6.3 MT of carbon per year) (RGoB 2011). Bhutan has population of 745,600 people. Agriculture is the main source livelihood for 69% of the population. Rice, maize, wheat, barley, buckwheat, and millets are the major cereal crops, and rice is by far the most important and preferred food crop of the Bhutanese. Majority of Bhutanese farmers are small holder with an average farm size of 3 acres and practice a self-sustaining subsistence integrated farming systems (<http://www.nbc.gov.bt/>). Population growth is estimated at an average rate of 1.4% per annum. The density of the population is 16 people per km², and by 2020, the number of persons living per km² will increase from 16 persons (2005 estimate) to about 21 persons (Norbu et al. 2008).

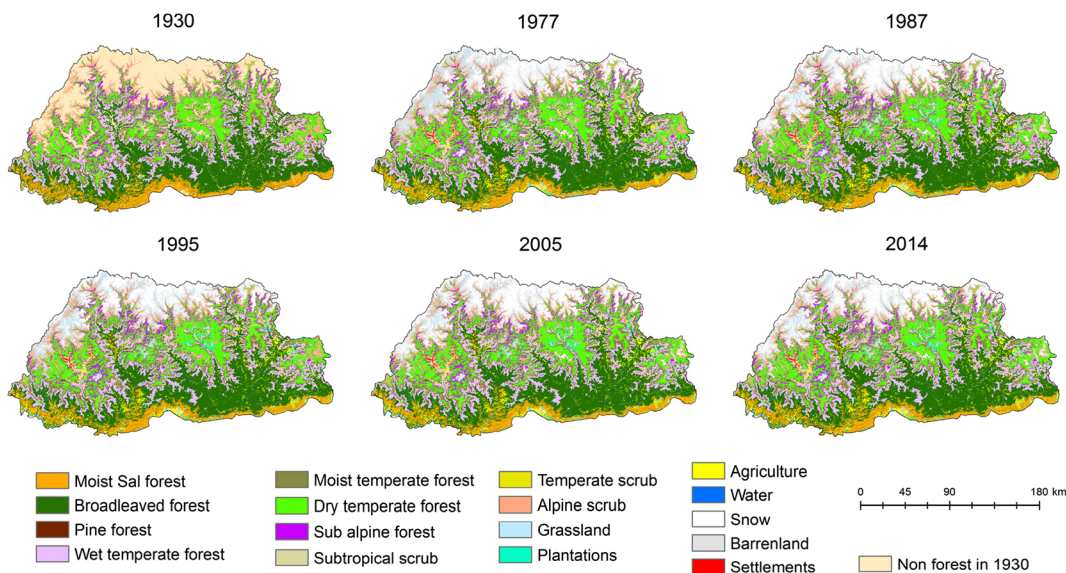


Fig. 2 Land cover and forest types in Bhutan (1930, 1977, 1987, 1995, 2005, and 2014)

Table 1 Details of data used in the study

Sl. no.	Type	Period	Scale/resolution*	Source	No. of maps/scenes
1	Topographical maps	1912–1944	1:250,000	U.S. Army	6
2	Landsat MSS	1977	80 m	NASA	4
3	Landsat TM	1987	30 m	NASA	2
4	IRS 1B LISS-I	1995	72.5 m	ISRO	8
5	IRS P6 AWiFS	2005	56 m	ISRO	2
6	Landsat OLI	2014	30 m	NASA	2

Material and methods

This study is primarily focused on mapping and GIS analysis of land cover using multi-source data.

Spatial data and source

The topographical maps were downloaded from <http://www.lib.utexas.edu/maps/ams/india>. Orthorectified data of Landsat Multispectral Scanner System (Landsat MSS) and Landsat Thematic Mapper (Landsat TM) acquired from Global Land Cover Facility Programme (<http://glcfapp.umiacs.umd.edu:8080/esdi>). Landsat 8 Operational Land Imager (OLI) images were downloaded from USGS earth explorer (<http://earthexplorer.usgs.gov>). Orthorectified IRS 1B LISS I (1995) and IRS P6 AWiFS (2005) datasets were procured from National Remote Sensing Centre, ISRO, Hyderabad (Table 1). Very high-

resolution images from Google Earth (<http://earth.google.com>) were used to aid in interpretation of land cover. Spatial maps of Bhutan generated by Gilani et al. (2015) were consulted.

Definition of forest

The existing forest definitions appeared to be rather difficult during the implementation of afforestation and reforestation activities under the Clean Development Mechanism in the Kyoto protocol (Romijn et al. 2013). We have used natural forest definition of forest to analyze the forest cover and change. Natural forest definition differentiates forests from plantations. In the present study, forest is defined as land spanning more than 1 ha, dominated with native tree species having a minimum stand height of 5 m with an overstorey canopy cover of greater than 10% or trees able to reach these thresholds “in situ” (Reddy et al. 2016a, b). We have separated plantations from the forest to have precise

Table 2 Areal extent of land cover in Bhutan (area in km²)

Sl. no.	Class	1930	1977	1987	1995	2005	2014	% area for 2014
1	Forest	26,895.9	26,269.4	26,313.1	26,140.6	26,136.5	26,206.9	68.3
	Nonforest							
2	Scrub	–	2585.7	2419.7	2690.0	2386.0	2310.2	6.0
3	Grassland	–	1631.5	1424.2	1823.5	1505.0	1494.1	3.9
4	Barren	–	2262.3	1698.0	1702.2	1694.3	1744.7	4.5
5	Snow	–	4023.8	4652.6	4094.3	4728.7	4676.1	12.2
6	Water	–	120.8	108.1	116.1	116.1	114.2	0.3
7	Plantations	–	135.0	336.6	352.1	352.1	359.2	0.9
8	Agriculture	–	1298.6	1372.2	1404.7	1404.7	1417.7	3.7
9	Settlements	–	66.8	69.6	70.5	70.5	70.9	0.2
	Sub total	11,498.1	12,124.6	12,080.9	12,253.4	12,257.5	12,187.1	31.7
	Grand total	38,394	38,394	38,394	38,394	38,394	38,394	100

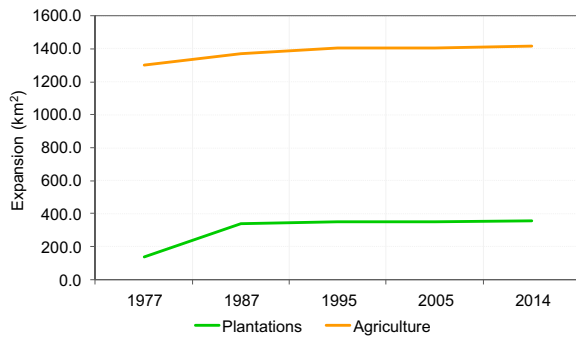


Fig. 3 Increasing trend of plantations and agriculture in Bhutan

information on the natural forest cover. Deforestation is considered as replacement of forest by other land use and/or depletion of forest canopy cover to less than 10% (Reddy et al. 2016a, b).

Total area under forest and land cover

Geometrically uncorrected satellite data was first co-registered to each other using image to image correction using orthorectified Landsat TM data as master image. Spatial data sets used in the study were processed using ERDAS Imagine. The land cover data was produced from the Landsat 8 OLI images of 2014 using hybrid classification techniques. Resourcesat-2 AWiFS images of 2014 were used for reference. The forest area shown in the topographical maps was captured using on screen digitization. In gap areas of survey for the 1930s period, the forest cover information from 1977 was incorporated. To analyze changes in land cover, additional multi-temporal set of four remote sensing satellite datasets were acquired for the period 1977, 1987, 1995, and 2005 were used. The forest cover mapping has been carried out for 1977, 1987, 1995, and 2005 through visual image interpretation technique on the basis of tonal, textural variations, and based on other key elements within a given scene and by referring 2014 classified land cover map. Change areas were incorporated to the spatial data of the corresponding period. Seven forest types are delineated i.e. tropical moist deciduous

forest (Moist Sal forest), subtropical broad leaved hill forest (Broadleaved forest), subtropical coniferous forest (Pine forest), montane wet temperate forest, Himalayan Moist temperate forest, Himalayan Dry temperate forest and subalpine forest. Areas of forest cover change were calculated by analyzing the changes for each time interval between 1930–1977, 1977–1987, 1987–1995, 1995–2005, and 2005–2014. A statistical evaluation of forest cover changes were carried out to consider the role of protected areas for the conservation efficacy.

Spatial change analysis

The changes in the area of forest were compared in spatial domain by generating 1 km × 1 km grid cells. The spatial distribution of forest was calculated and the change evaluated for any trend across the five classes, i.e., <10, 10–25, 25–50, 50–75, and >75 ha for 1930–1977, 1977–1987, 1987–1995, 1995–2005, and 2005–2014.

Rate of forest cover change

To assess the magnitude of the changes of various forest classes, the compound interest formula was used due to its explicit biological meaning (Puyravaud 2003). The annual rate of forest cover change was calculated by comparing the area under forest cover in the same region at two different time periods.

$$r = \frac{1}{(t_2 - t_1)} \times \ln \frac{a_2}{a_1}$$

where *r* is the annual rate of change and *a*₁ and *a*₂ are the forest cover estimates at time *t*₁ and *t*₂, respectively.

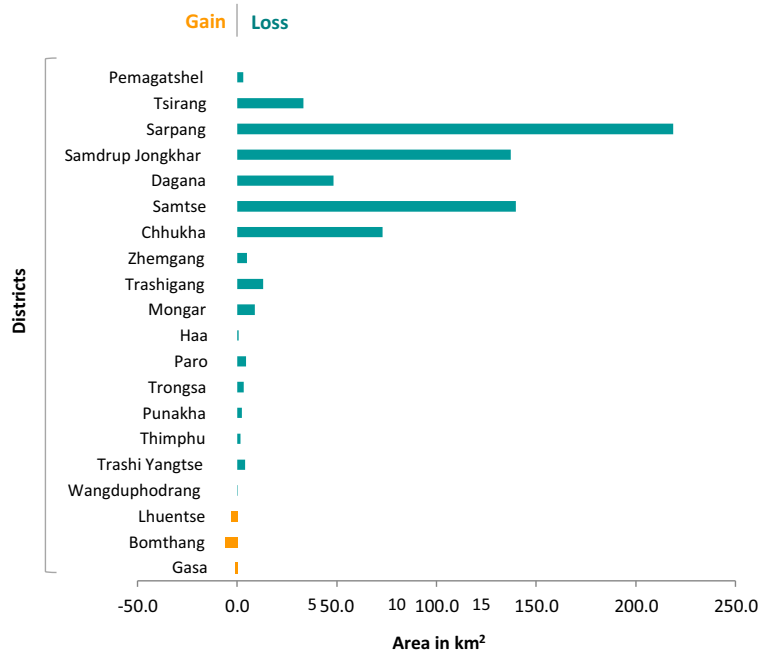
Replacement land use in deforested area

Land cover change due to forest loss has been accounted to analyze the influence of land use drivers. The land cover classes in deforested area have been quantified based on land cover map of 2014.

Table 3 Regional distribution of forest cover in Bhutan (area in km²)

Region	1930	1977	1987	1995	2005	2014
Eastern Bhutan	8667.4	8532.2	8544.0	8487.4	8485.2	8504.3
Central Bhutan	6797.9	6582.5	6602.4	6560.5	6559.3	6577.3
Western Bhutan	11,410.2	11,137.0	11,152.4	11,075.7	11,075.1	11,107.5

Fig. 4 Net forest cover change across the districts of Bhutan (1930–2014)



Forest cover change hotspots

In order to quantify the change, G_i^* statistic was computed which measures the degree of spatial clustering of a local sample and how it is different from the expected value. It is calculated as the sum of the differences between values in the local sample and the mean and is standardised as a z score. The G_i^* statistic is two-tailed, e.g., a score of ± 2 represent strong clustering, as 95% of the data under a normal distribution should be within two standard deviations of the mean. Similarly, values between ± 2 may be interpreted as weakly clustered and values being less than 2 standard deviations is expected to indicate no spatial clustering. While positive values of G_i^* represent clusters that are, on average, greater than the mean (hotspots), the negative values represent clusters that are less than the mean (cold spots)

(Getis and Ord 1996; Cohen et al. 2011). It represents the frequency of detection as a hotspot relative to the number of input afforested and deforested points covered the area (1930–1977–1987–1995–2005–2014).

The following equation is used for calculation of Getis-Ord G_i^* :

$$G_i^* = \frac{\sum_{j=1}^n w_{i,j} x_j - \bar{X} \sum_{j=1}^n w_{i,j}}{S \sqrt{\frac{[n \sum_{j=1}^n w_{i,j}^2 - (\sum_{j=1}^n w_{i,j})^2]}{n-1}}}$$

$$\bar{X} = \frac{\sum_{j=1}^n x_j}{n}$$

$$S = \sqrt{\frac{\sum_{j=1}^n x_j^2}{n} - (\bar{X})^2}$$

Table 4 Grid-wise analysis of forest cover (no. of 1×1 km grid cells)

Class	1930	1977	1987	1995	2005	2014
<10 ha	941	1008	1011	1040	1042	1032
10–25 ha	1029	1168	1162	1187	1185	1183
25–50 ha	1960	2165	2171	2232	2232	2213
50–75 ha	3315	3703	3690	3865	3863	3794
>75 ha	25,429	24,489	24,526	24,216	24,214	24,336
Total	32,674	32,533	32,560	32,540	32,536	32,558

Table 5 Analysis of grid-wise negative and positive changes in Bhutan (no. of 1 × 1 km grid cells)

Change	1930–1977	1977–1987	1987–1995	1995–2005	2005–2014
Forest loss					
<10 ha	2090	3308	7302	15	758
10–25 ha	802	0	6	0	0
25–50 ha	534	0	0	0	0
50–75 ha	208	0	0	0	0
>75 ha	119	0	0	0	0
Total	3753	3308	7308	15	758
Forest gain					
<10 ha	428	3954	990	0	3861
10–25 ha	0	86	0	0	2
25–50 ha	0	11	0	0	0
50–75 ha	0	0	0	0	0
>75 ha	0	0	0	0	0
Total	428	4051	990	0	3863

where X_j is the attribute value for feature j , $W_{i,j}$ is the spatial weight between feature i and j , n is equal to the total number of feature.

The G_i^* is a z score so no further calculations required.

Accuracy evaluation

The classification accuracy is usually calculated by comparing the classification with some reference data that is believed to accurately reflect the land cover (Reddy et al. 2016a). The accuracy of the classified

maps was estimated using a set of randomly selected ground control points on very high-resolution images available in Google Earth.

Results and discussion

The present study has analyzed

1. Status and change of land cover
2. Spatial changes in forests

Fig. 5 Forest cover change in Bhutan, 1930–2014

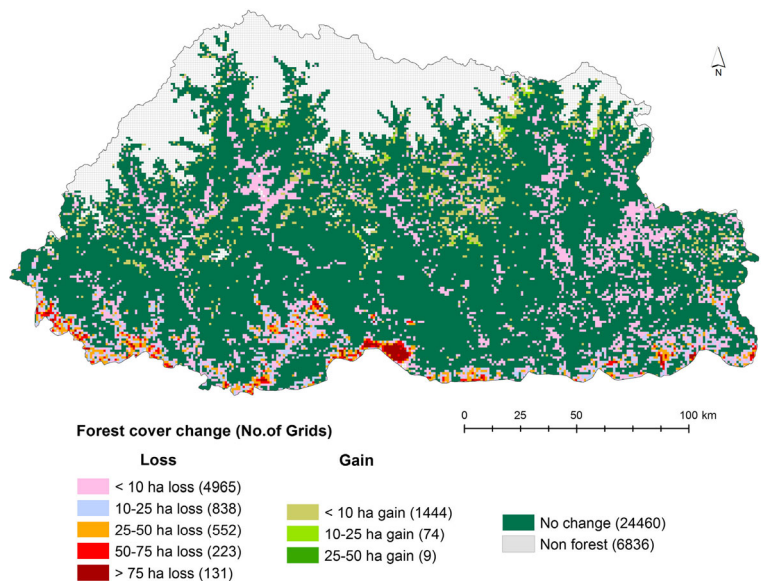


Table 6 Annual rate of forest change in Bhutan

T1	T2	Net rate of forest change	Gross rate of forest change	Net rate of afforestation
1930	1977	0.05	0.06	0.01
1977	1987	0.00	0.08	0.10
1987	1995	0.07	0.13	0.07
1995	2005	0.00	0.00	0.00
2005	2014	0.00	0.05	0.08

3. Rate of forest cover change
4. Major changes in forest types
5. Protected area wise forest cover change
6. Replacement land cover in deforested areas
7. Forest cover change hotspots

Status and change of land cover

At national level, forest constitutes 68.3% of the total geographical area in 2014 (Fig. 1). Land cover map consisting of nine classes were mapped for the 1977, 1987, 1995, 2005, and 2014 (Fig. 2; Table 2). The classified map consists of forest, scrub, grassland, barren land, snow, agriculture, plantations, water, and settlements. The results show that forest is the largest land cover in Bhutan throughout the study period. Snow is the predominant natural nonforest cover (12.2%), followed by scrub (6.0%), barren land (4.5%), and grassland (3.9%) in 2014. However, snow, water, barren, and grasslands are temporally dynamic throughout the year, due to natural cyclic phenomena and thus area varies based on dates of satellite images used. The land cover changes took place mainly during the period of 1930–1977–1987–1995. In total, Bhutan shows

26,895.9 km² of forests in 1930 which has decreased to 26,206.9 km² in 2014, a loss of 689 km² (2.6%) in eight decades. The dynamics of agricultural area (including fallow) is significant which has increased from an area of 1298.6 km² in 1977 to 1417.7 km² in 2014. Plantations are showing increasing trend in area from 1977 to 2014 (Fig. 3). As per the plantation records by forest department, 217 km² area was reforested in Bhutan by 2008 which includes barren, degraded lands, and cleared forests (Norbu et al. 2008). This study has estimated area under settlements about 70.9 km² in 2014, while Gilani et al. (2015) has reported 68 km² for 2010. Western region of Bhutan has the highest forest coverage (Table 3). Loss of forest was very high in Sarpang, Samdrup Jongkhar, Samtse, and Chhukha districts. Forest gain is evident in Bomthang, Lhuentse, and Gasa districts (Fig. 4).

Spatial change analysis

The grid cell wise spatial data analysis for forests in 1930, 1977, 1987, 1995, 2005, and 2014 is given in Table 4. Grid cell wise change analysis exhibits that the large-scale negative changes occurred during 1930–1977 (Table 5). There are total 758 grids that have shown loss of forest cover during 2005–2014. Highest number of grids shown positive changes during 1977–1987 and 2005–2014. The forest cover change map is shown in Fig. 5.

Rate of forest cover change

Annual gross rate of deforestation has been estimated as 0.05% between 2005 and 2014. Annual net rate of deforestation is nil during 1995–2014 while it was 0.07% during 1987–1995 (Table 6). The highest net

Table 7 Forest types of Bhutan (area in km²)

Sl. no.	Forest class	1977	1987	1995	2005	2014
1	Moist sal	2138.7	2137.7	2127.1	2127.1	2128.8
2	Broadleaved	9012.7	8994.5	8944.9	8944.9	8948.2
3	Pine	613.7	615.4	612.0	612.0	612.9
4	Wet temperate	4968.1	4967.3	4947.8	4947.8	4950.8
5	Moist temperate	2619.3	2627.9	2613.4	2613.4	2619.4
6	Dry temperate	5448.9	5522.0	5422.1	5418.8	5477.4
7	Sub alpine	1468.2	1448.2	1473.4	1472.7	1469.5
Total		26,269.4	26,313.1	26,140.6	26,136.5	26,206.9

Table 8 Land cover in deforested areas of Bhutan (area in km²)

Sl. no.	Class	1930–2014	%
I	Vegetation		
1	Agriculture	533.4	60.9
2	Plantations	90.1	10.3
3	Alpine scrub	52.9	6
4	Grassland	28.1	3.2
5	Temperate scrub	15.9	1.8
6	Subtropical scrub	1.1	0.1
II	Nonvegetation		
1	Barren	135.8	15.5
2	Water	8.5	1
3	Snow	6.8	0.8
4	Settlements	3.4	0.4
	Grand total	876	100

annual rate of afforestation was 0.08% during 2005–2014 followed by 1987–1995. Results indicate effectiveness of forest conservation policies in Bhutan as compared to Bangladesh and India (Reddy et al. 2016a, b).

Major changes in forest types

The forest type distribution for 1977 to 2014 is presented in Table 7. The subtropical broad leaved hill forest is a predominant type that occupies 34.1% of forest area in Bhutan, followed by dry temperate (20.9%), montane wet temperate (18.9%), moist temperate (10%), and moist sal (8.1%) in 2014. The forest types undergone major loss in

last four decades are subtropical broad leaved hill forest (64.5 km²) and moist sal forest (9.9 km²). Forest cover change trajectories over Bhutan resulted from both an increase in rates of forest gain and a decrease in rates of forest loss, mostly affecting the broadleaf forest ecosystem of southern low-elevation districts in 1990, 2002, and 2011 (Bruggeman et al. 2016).

Replacement land cover in deforested areas

The deforested areas have mainly been converted into agriculture and contributed for 60.9% of forest loss from 1930 to 2014 (Table 8). Spatial analysis indicates that forest area of 135.8 km² was converted to barren lands. Plantations were responsible for forest loss of 90.1 km² in Bhutan. Settlement is one of the land use change drivers and contributes for 3.4 km² of total forest loss from 1930 to 2014.

Protected area wise analysis

Overall analysis of the changes in forest cover in all protected areas showed that protected area network in Bhutan succeeded in conservation, by preventing illegal logging, agricultural expansion, settlements, and controlling anthropogenic activities (Table 9). Map of protected areas is shown in Fig. 6. As compared with global level study for 198 of the protected areas, 25% of protected areas have shown decline in forest area (Defries et al. 2005), while 100% of protected areas of Bhutan have conservation efficacy for maintaining forest cover and subsequently effective for biodiversity

Table 9 Distribution of forest cover across protected areas of Bhutan (area in km²)

Sl. no.	Protected area	1930	1977	1987	1995	2005	2014
1	Phipsoo Wildlife Sanctuary (PWS)	215.6	207.4	207.3	206.7	206.7	206.7
2	Royal Manas National Park (RMNP)	976.3	935.2	938.0	932.4	932.4	933.9
3	Sakteng Wildlife Sanctuary (SWS)	479.6	479.4	480.8	475.1	473.8	478.3
4	Bumdeling Wildlife Sanctuary (BWS)	827.8	827.8	832.1	826.8	826.7	830.6
5	Torsa Strict Nature Reserve (TSNR)	343.4	343.5	343.9	340.9	340.8	343.4
6	Thrumshingla National Park (TNP)	708.8	708.7	710.9	708.1	707.8	709.7
7	Jigme Singye Wangchuck National Park (JSWNP)	1568.1	1567.9	1570.5	1565.9	1565.9	1568.2
8	Jigme Dorji National Park (JDNP)	1267.8	1267.5	1274.8	1262.8	1262.5	1270.4
10	Wangchuch Centennial Park (WCP)	1380.3	1380.0	1397.4	1380.6	1379.5	1390.4
11	Khaling Wildlife Sanctuary (KWS)	305.4	277.6	278.3	275.9	275.9	276.3
	Total area	10,003.1	9969.9	10,019.0	9970.2	9977.2	10,021.8

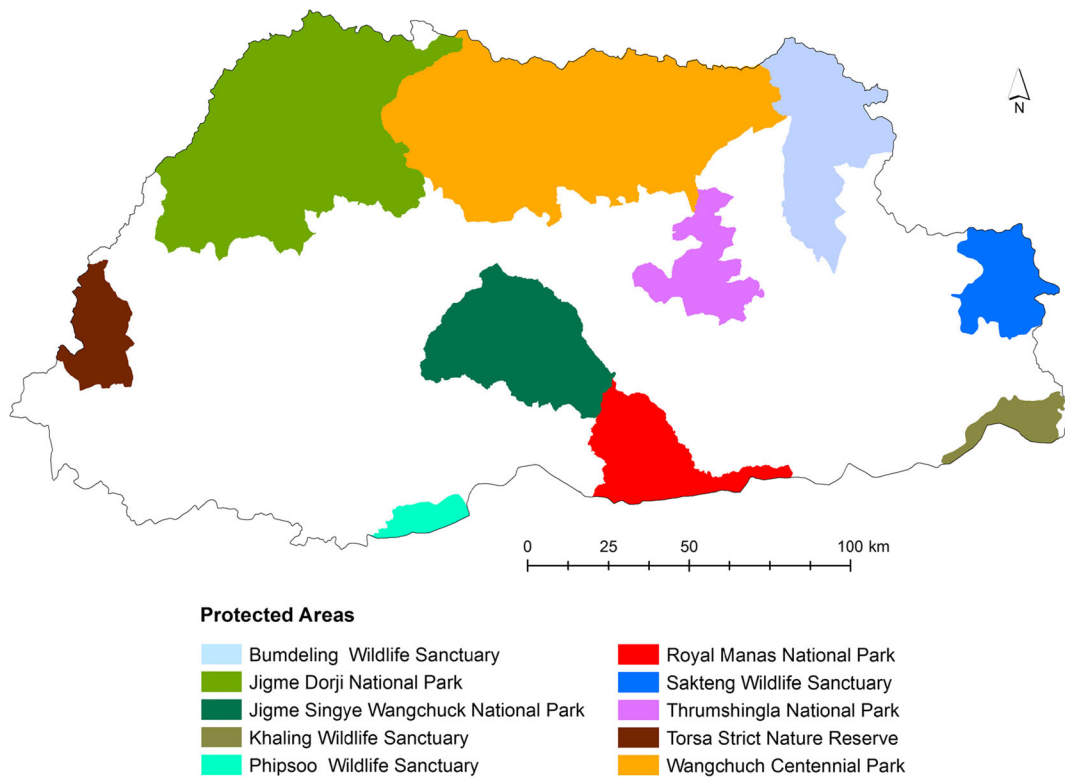
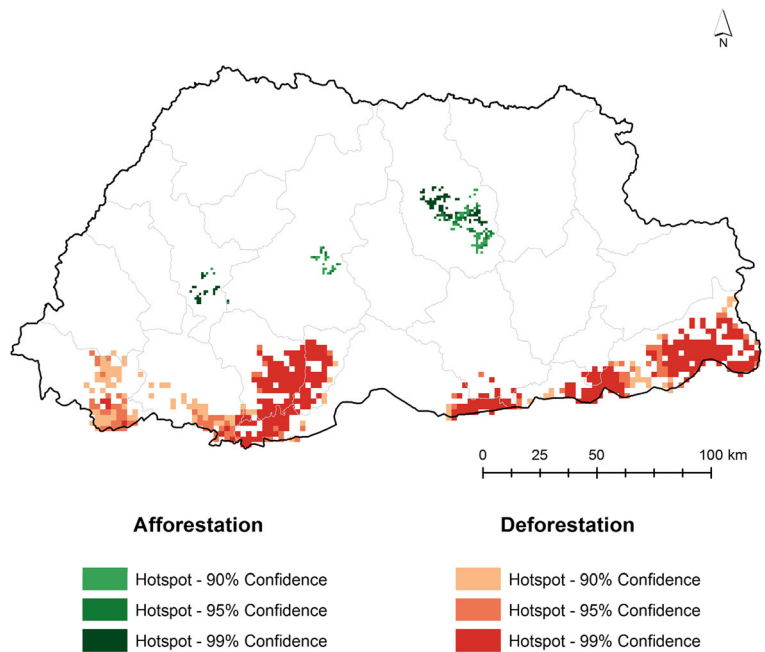


Fig. 6 Protected areas of Bhutan

conservation. Protected area network in Bhutan covers 16,396.4 km² (42.7%) of geographical area of country (RSPN 2016). Protected areas represent an area of

10,916.4 km² under natural vegetation. Among the natural vegetation classes, dry temperate forests occupy the highest area (2632.1 km²) followed by broad leaved hill

Fig. 7 Forest cover change hotspots of Bhutan



forest (1575.1 km²), alpine scrub (1590 km²), wet temperate forest (1245.5 km²), grassland (1090.7 km²), sub alpine forest (974 km²), moist temperate forest (825.2 km²), moist sal forest (651.4 km²), pine forest (169.7 km²), temperate scrub (159.1 km²), and subtropical scrub (3.5 km²) in 2014.

Forest cover change hotspots

Figure 7 shows map of hotspots using the Gi*. Areas that have undergone high transformation in forest cover shows highly clustered distribution and identified as hotspots. The major hotspots of deforestation were concentrated to the south of the Bhutan, while afforestation hotspots in central Bhutan.

Validation of classified maps

Random sample points were generated for accuracy assessment. The accuracy of the maps was validated independently based on 400 sample points using Google Earth images. Validation of forest cover maps for 1977, 1987, 1995, and 2005 was done based on the temporal consistency of ground control points. The overall accuracy of the forest cover maps derived for the years 1977, 1987, 1995, 2005, and 2014 were 88.9, 89.3, 89.8, 90.2, and 90.2%, respectively. All the kappa values were greater than 0.86.

Conclusions

The results are of interest for national level scenario of forest cover and associated changes in land cover for natural resource management in Bhutan. Study found that protected areas of Bhutan are having high conservation potential to maintain populations of varied species. This study showed that long-term forest cover change analysis in Bhutan reveals effectiveness of conservation policies undertaken by the Government of Bhutan, as compared to the neighboring Asian countries. The current conservation planning supporting natural re-growth and regeneration of forests which helps in sustaining the flora and fauna in Himalayan biodiversity hotspot.

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