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ORIGINAL PAPER

Quantifying nationwide land cover and historical changes in forests of Nepal (1930–2014): implications on forest fragmentation

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Abstract This study quantifies the nationwide land cover and long-term changes in forests and its implications on forest fragmentation in Nepal. The multi-source datasets were used to generate the forest cover information for 1930, 1975, 1985, 1995, 2005 and 2014. This study analyzes distribution of land cover, rate of deforestation, changes across forest types, forest canopy density and pattern of fragmentation. The land cover legend for 2014 is consisting of 21 classes: tropical dry deciduous sal forest, tropical moist deciduous sal forest, subtropical broad-leaved forest, subtropical pine forest, lower temperate broad leaved forest, upper temperate broad leaved forest, lower temperate mixed broad leaved forest, upper temperate mixed broad leaved forest, temperate needle leaved forest, sub-alpine forest, plantations, tropical scrub, subtropical scrub, temperate scrub, alpine scrub, grassland, agriculture, water bodies, barren land and settlements. The forest cover statistics for Nepal obtained in this study shows an area of 76,710 km^2 in 1930 which has decreased to 39,392 km^2 in 2014. A net loss of 37,318 km^2 (48.6%) was observed in last eight decades. Analysis of annual rate of net deforestation for the recent period indicates 0.01% during 2005–2014. An increase in the number of forest patches from 6925 (in 1930) to 42,961 (in 2014) was noticed. The significant observation is 75.5% of reduction in core 3 forest, whereas, patch, perforated and edge classes show the increase in percentage of fragmentation classes from 1930 to 2014. The results of this work will support the

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understanding of deforestation and its consequences on fragmentation for maintaining and improving the forest resources of Nepal.

Keywords Forest cover · Change · Conservation · Remote sensing · Nepal

Introduction

Nepal is a South Asian country, exhibits the typical characteristics of the Himalayan range (Stads and Shrestha 2008). The forests of Nepal were little disturbed until the late 1920s when the government initiated expansion of agricultural lands by clearing some forests and extracting timber in other forests for export to India (Joshi 1993). Realising the significance of natural resources, private forests were nationalised with the Private Forest Nationalization Act in 1957. In the early 1950s and 1960s, the lower belt of Nepal was considered unsafe for human living due to malaria. However, with the elimination of malaria in the early 1960s in the Tarai, road infrastructure was developed, encouraging the conversion of forests into agricultural lands. Since the 1950s, infrastructure development, intensification of cultivation and government policies to convert forest into other land use have been the primary causes of deforestation in certain parts of southern Nepal (Bhattarai et al. 2009). The National Forest Plan of 1976 accepted the need for people's participation (Kanel et al. 2005). The current national forest policy declared in 2000 which gives emphasis on community participatory forestry. Around 21% of the forests are now managed as community forests, with a management plan approved by the government (Khatri 2010). Stainton (1972) recognized 35 forest types under 10 major groups in Nepal.

Studies suggest that community-based forest management has been effective in combatting forest degradation in Nepal over the last 25 years (Nagendra 2007; Stræde and Treue 2006). Nepal is representative of the land cover diversity in the Hindu Kush Himalayas region. The Intergovernmental Panel on Climate Change (2007) has recognised the Hindu Kush Himalayas region as a 'data deficit area'. The study shows that forest is the dominant form of land cover in Nepal covering 57,538 km^2 (Uddin et al. 2015). However, the results were based on forests which include plantations in the quantification of forest area. The nation-wide studies have quantified long-term changes in forests of India, Bangladesh, Bhutan and Sri Lanka (Reddy et al. 2016a, b, c, d). The lack of effective mapping for forest cover changes across the whole of Nepal is a major challenge that hinders national level understanding of forest conservation. Thus, an attempt has been made to study land cover and forest cover changes in Nepal using multi-temporal remote sensing datasets and historical topographical maps.

Study area

Nepal is situated between latitudes 26°22′N to 30°27′N and longitudes 80°40′E to 88°12′E and shares an international border with China to the north and India to the south, east, and west. Nepal is located in between China and India, covering an area of 147,181 km^2. The country's altitude ranges from 51 m above sea level in the south to 8848 m at the summit of Mt Everest. Nepal experiences a wide range of climates, ranging from sub-tropical in the lowlands to the arctic climate in the high mountains. It harbors a total population of 23.15 million with 2.24% annual growth rate. Rice is the primary crop in the lower elevation

regions of the country, wheat is grown in the Terai and the valleys of the Himalayas, and corn is the principle crop of the hilly regions (FAO 2010).

Materials and methods

Mapping of forest and land cover

The topographical maps prepared by Army Map Service, U.S. Army, Washington (http://www.lib.utexas.edu/maps/ams/india) were acquired (Table 1). Landsat MSS provided by Global Land Cover Facility Programme was downloaded from the website (http://glcfapp.glcf.umd.edu:8080/esdi/index.jsp). Landsat 8 OLI images were downloaded from USGS earth explorer (http://earthexplorer.usgs.gov). Indian Remote Sensing satellite data were procured from National Remote Sensing Centre, Hyderabad. All the raw satellite images were geometrically co-registered with orthorectified Landsat TM data using first order polynomial transformation fit. The nearest neighbour resampling method was used. Best possible contrasts and band combinations were used for analysing the land cover patterns. The enhancement techniques are being extensively used in digital image processing as the first step after rectifying the scene. It has also been noticed that the identification of different forest type/density classes needs a thorough understanding of phenology and visual key elements of the multi-season images. Forest cover from topographical maps was interpreted using visual interpretation technique. In gap areas of forest survey for the 1930s period, the data from 1975 used for finalising 1930s period assuming the forests of 1975 exists in the 1930s. Hybrid classification techniques were utilised in the study for mapping land cover using remote sensing data. This study combined the use of very high-resolution images from Google Earth (http://earth.google.com) to aid in interpretation of forest cover. The Landsat ETM+ images of 2000 were used as a reference. In this study, forest is defined as land spanning more than 1 ha, dominated by indigenous tree species with an overstorey canopy cover of greater than 10% (Reddy et al. 2016a). This study has separated plantations/orchards from the forest to have precise and useful information on the natural ecosystem changes. The forest canopy cover above 40% is included under dense forests. Forest canopy cover between 10 and 40% is classified under open forests. Deforestation is considered as a replacement of native forest by other land use and/or

Table 1 Data used in the study

Sl. no.	Type	Period	Scale/resolution[a]	No. of scenes/maps	Source
1	Topographical maps	1926–1939	1:250,000	17	U.S. Army
2	Landsat MSS	1975	80 m	11	NASA
3	Landsat MSS	1985	80 m	9	NASA
4	IRS 1A LISS-I	1995	72.5 m	7	ISRO
5	IRS P6 AWiFS	2005	56 m	3	ISRO
6	IRS P6 LISS-III	2006	23.5	8	ISRO
6	Landsat 8 OLI	2014	30 m	12	NASA
7	Resourcesat-2 AWiFS	2014	56 m	4	ISRO

[a] Scale for topographical maps

reduction of forest canopy cover to less than 10 percent. In the classification of forest types, four criteria have been used: (1) life form (predominance of tree cover), (2) forest cover (>10% canopy cover), (3) leaf type (broad leaved or needle leaved) and (4) leaf longevity/phenology (evergreen or deciduous) (Reddy et al. 2015). The forest class is subdivided into forest types following Stainton's (1972) classification scheme. Tropical Sal forests are confined to an elevation zone of below 1000 m. The subtropical broad leaved forests are mostly starts from elevation of 700 m and continue up to 1200 m. Subtropical pine forest is most common forest type in western Nepal and in central parts in altitudinal range of 1000–2200 m. The temperate zone exists at an elevation of 2000–3500 m and consists of broadleaved forests followed by mixed broadleaved and needle leaved forests. The lower temperate mixed broadleaved forest is found between 1700 and 2200 m and confined to north and west facing slopes. The upper temperate broad leaved forest is exists between 2200 and 3000 m. The upper temperate mixed broad leaved forest is exists between 2500 and 3500 m. Needle leaved forests of temperate zone (temperate coniferous forests) are situated at an elevation zone of 2000–3000 m. The subalpine forests are distributed at an elevation range of 3000–4200 m. MODIS 8-day composites LAI product of 2013–2014 (https://modis.gsfc.nasa.gov/data/dataprod/mod15.php/) were used as a reference. Dry deciduous sal forest was delineated from moist deciduous sal forest based on length of growing period (<120 days) which was derived from MODIS leaf area index. Areas with length of growing period between 75 to less than 120 days are considered as dry semiarid (http://www.fao.org/docrep/x5308e/x5308e02.htm). The climatic data pertaining to temperature and rainfall was collected from the site www.worldclim.com. SRTM Digital Elevation Model was used to understand the relation of elevation and forest types (Rabus et al. 2003). Elevation zone map of Nepal is given in Fig. 1.

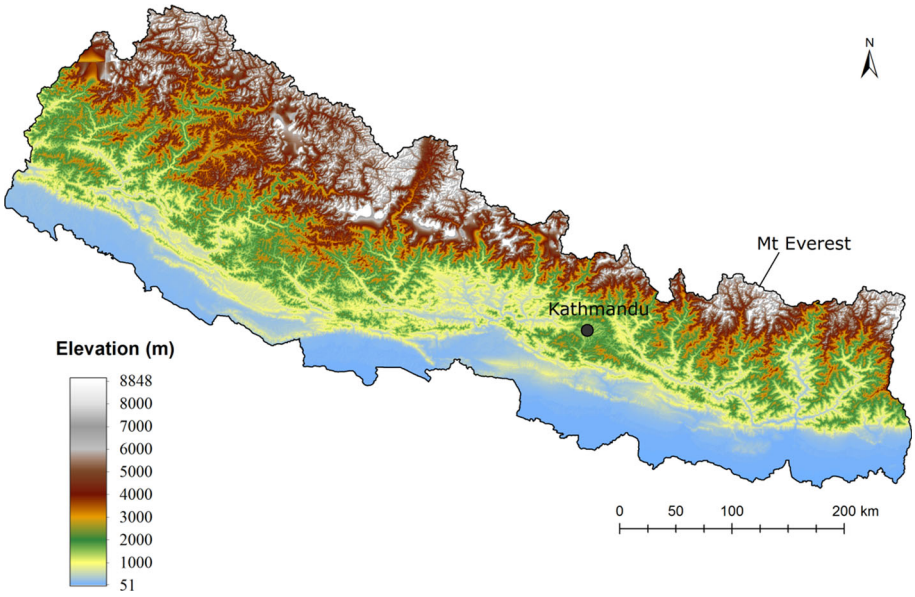

Fig. 1 Elevation map of Nepal

Spatial change analysis

The change in the area of forest was compared in GIS domain by generating 5 km × 5 km grid cells. The spatial distribution of forest was calculated and the change has been evaluated across the identified classes, i.e. <1, 1–5, 5–10, 10–15, 15–20 and >20 km^2 for (1930–1975, 1975–1985, 1985–1995, 1995–2005 and 2005–2014). Spatial analysis of land cover change due to deforestation has been carried out to interpret the influence of land use drivers. The land use/land cover in the deforested area has been quantified based on a classified map of 2014. The annual rate of forest cover change is calculated by comparing the area under forest cover in the same region at two different times. The annual rate of change was derived from the compound interest formula (Puyravaud 2003).

$$r = \frac{1}{(t_2 - t_1)} \times \ln \frac{a2}{a1}$$

where r is the annual rate of change (percentage per year), a_1 and a_2 are the forest cover estimates at time t_1 and t_2 respectively.

Modelling the forest fragmentation

Shrinkage of core forest patches is an indicator of increasing fragmentation. The fragmentation at the national level for the periods 1930, 1975, 1985, 1995, 2005 and 2014 was assessed using Patch Analyst (Elkie et al. 1999) and Landscape Fragmentation Tool (Vogt et al. 2007). Patch analyst is useful to estimate landscape metrics. The Landscape Fragmentation Tool (LFT) provides spatial data of fragmentation classes: core 1, core 2, core 3, perforated, edge and patch. Core forest pixels that are relatively far from the forest/non-forest boundary. Essentially these are forested areas surrounded by more forested areas. Core forest is divided into three classes. Core 1/small core forest: Small core consists of those forest patches that are smaller than 250 acres. Core 2/medium core forest: Core forest patches that are between 250 and 500 acres. Core 3/large core forest: Core forest patches that are greater than 500 acres. Perforated forest pixels that define the boundary between core forest and relatively small clearings (perforations) within the forested landscape. The perforated forest must be within 100 m of a relatively small forest clearing and adjacent to core forest. Edge forest pixels that define the boundary between core forest and large non-forested land cover features. In the case of the forest fragmentation results presented here, the edge forest must be within 100 m of a large non-forest land cover feature and adjacent to core forest. Patch forest pixels that comprise a small forested area surrounded by a non-forested land cover. The patch forests have complete edge influence.

The change of the fragmentation during the 1930–2014 periods was carried out by cross-referencing the fragmentation classes. The resulting spatial information supports in a better understanding of the historical changes of forest fragmentation and in identifying possible transformations.

Accuracy assessment

The classification performance was evaluated by confusion matrix and to obtain overall classification accuracy. In addition, the Kappa accuracy is also to be provided along with

the area statistics. Public domain satellite data and online visualisation tools like Google Earth allows end users to assess the accuracy of land cover data based on very high-resolution satellite images and observations (Uddin et al. 2015).

Results and discussion

This study has analysed the land cover for 2014, the total area under forest cover over eight decades, the spatial tracking of changes in forest cover, forest types, forest canopy density and fragmentation.

Land cover

The land cover legend for 2014 is consisting of 21 classes, i.e. tropical dry deciduous sal forest, tropical moist deciduous sal forest, subtropical broad-leaved forest, subtropical pine forest, lower temperate broad leaved forest, upper temperate broad leaved forest, lower temperate mixed broad leaved forest, upper temperate mixed broad leaved forest, temperate needle leaved forest, subalpine forest, plantations, tropical scrub, subtropical scrub, temperate scrub, alpine scrub, grassland, agriculture, water bodies, barren land and settlements. The area occupied under each of the land cover class is given in Table 2. The predominance of agricultural land is evident, constituting 28.2% of the total geographical area followed by forest (26.8%) (Fig. 2). Among the man-made land use/land cover categories, plantations occupy second highest (5.7%) geographical area after agriculture. Of the five major development regions of Nepal, the highest forest cover was found in the Mid-western region (23.9%) followed by Central (23.4%) and Western region (22.3%). While the lowest forest cover (9.4%) found in the Far-western region.

Major changes in forest cover

The classified map of Nepal shows 76,710 km^2 of forests in 1930 which has decreased to 39,392 km^2 in 2014, a net loss of 37,318 km^2 (48.6%) (Fig. 3). The first forty-five years of study (1930–1975) accounted for major forest loss (34,223 km^2) and only 3095 km^2 was lost from 1975 to 2014. The forest cover decline was 2117 km^2 during 1975–1985, followed by 567 km^2 in 1985–1995, 377 km^2 in 1995–2005 and 34 km^2 during 2005–2014. The highest forest loss was noticed with 760 km^2 per year during 1930–1975, 212 km^2 per year during 1975–1985, 57 km^2 per year during 1985–1995, 38 km^2 per year during 1995–2005 and 4 km^2 per year during 2005–2014. During the recent period (i.e. 2005–2014), forest loss is mainly attributed to the developmental activities. The decreasing trend of deforestation is primarily due to community forest implementation activities carried out by the Government of Nepal (GoN 2014). Among the development regions of Nepal the highest forest cover loss found in Mid-Western region (13.9%), followed by Western region (10.6%), Central (9.6%), Eastern (9.1%) and lowest deforestation was found in Far-Western region (5.5%) during 1930–2014 period. Table 3 shows the forest cover of Nepal in various periods. The Forest Resources Survey Office had mapped 45.5% of the geographical area as forest in Nepal in 1964 and it does not cover high altitude forests areas (FAO 2010). High altitude forests are degraded due to the stocking of livestock units 9 times higher than their carrying capacities (NBS 2002). The average rate of

Table 2 Areal extent of land cover in Nepal: 2014

Sl. no.	Class	Area (km^2)	% of total geographical area
I	Forest		
1	Tropical dry deciduous sal	2168	1.5
2	Tropical moist deciduous sal	7938	5.4
3	Subtropical broad-leaved	10,540	7.2
4	Subtropical pine	6575	4.5
5	Lower temperate broad leaved	307	0.2
6	Upper temperate broad leaved	2990	2.0
7	Lower temperate mixed broad leaved	1119	0.8
8	Upper temperate mixed broad leaved	3385	2.3
9	Temperate needle leaved	3725	2.5
10	Subalpine	645	0.4
	Sub total	39,392	26.8
II	Non-forest		
11	Plantation	8325	5.7
12	Tropical scrub	2913	2
13	Subtropical scrub	4009	2.7
14	Temperate scrub	3063	2.1
15	Alpine scrub	5608	3.8
16	Grassland	13,434	9.1
17	Agriculture	41,493	28.2
18	Water	944	0.6
19	Barren land	15,697	10.7
20	Snow	11,576	7.9
21	Settlement	726	0.5
	Sub total	107,789	73.2
	Total	147,181	100

forest conversion to shrubland (5.57%/year) is significantly higher than deforestation (1.7%/year) for the same period of 1978/79 to 1994 (DFRS 1999).

There are total 6261 grids to analyse the change in spatial patterns of forest cover. The spatial data analysis for forest cover in 1930, 1975, 1985, 1995, 2005 and 2014 are shown in Table 4. Spatial change analysis exhibits that the highest number of grids has undergone negative changes during 1930–1975 (Table 5). There are total 67 grids that have shown loss of forest cover during 2005–2014. The forest cover change map of 1930–2014 is shown in Fig. 4. The highest annual net rate of deforestation was 1.31% during 1930–1975, followed by 0.51, 0.14, 0.1 and 0.01% for 1975–1985, 1985–1995, 1995–2005 and 2005–2014 respectively. Between 1930 and 1975, forests of India had experienced large-scale deforestation at a net annual rate of 0.63% which has declined to 0.23, 0.12, 0.06 and 0.03% for the 1975–1985, 1985–1995, 1995–2005 and 2005–2013 periods respectively (Reddy et al. 2016a).

A large number of areas of forests were degraded and lost by increasing demand on land and population growth. Scrub is one of the predominant land conversion, which is due to overexploitation of forest cover. Agriculture and plantations were contributed for major forest loss. Forest loss in the recent time period was due to Sikta Irrigation Project in the

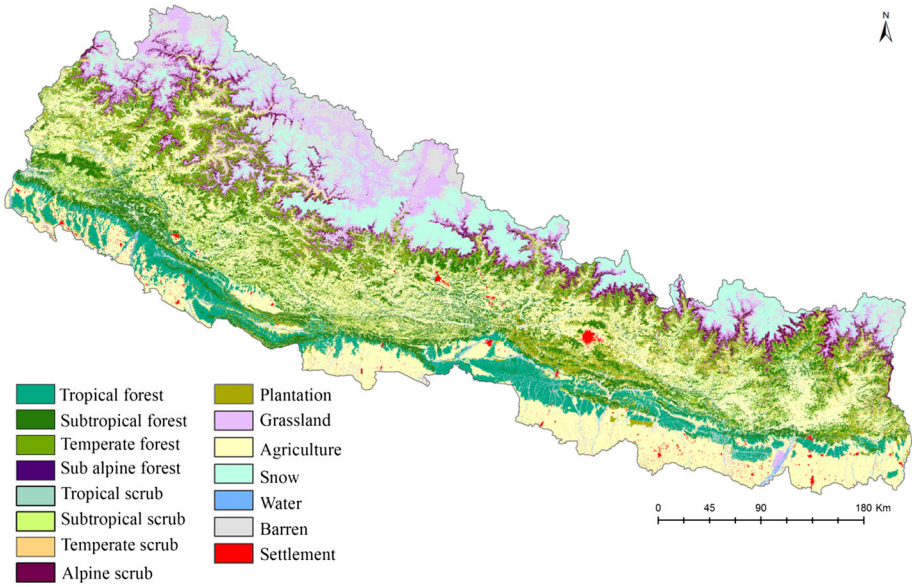

Fig. 2 Land use/land cover map of Nepal (2014)

Banke District of the Mid-Western Development Region (Table 6). Slope class of <10° is a significant indicator for deforestation in Nepal which shows 70.7% of total forest loss, followed by 19.5 and 9.8% in 11–20° and >20° respectively. Deforestation was more on low elevation and gentle slope, since such terrain is suitable for agriculture. Of the total deforested area (1930–2014), elevation below 1500 m represents 44.3% of forest loss, indicates low and moderate elevation zones were affected by large-scale deforestation.

The forest area of Nepal is estimated to be about 40% of the total geographical area of the country, out of which 29% is forest and 10.6% is shrubland (DFRS 1999). The area covered by national forests and protected area systems is 39.6% of the total area of the country (DFRS 1999). During the mid-20th Century, the lowland forests of southern Nepal were rapidly cleared in response to national policies promoting timber harvest, agricultural expansion, and malaria eradication (Schweik et al. 2003). Nepal is now considered as one of the world's leading examples of successful community-based forest management (Gautam et al. 2004). Forests cover approximately 25.4% of the country (World Bank 2013). The conservation of forest is attributed in large part to the success of the community forestry programme. In spite of this, deforestation and forest degradation continue to pose a problem in some areas, and there is still need for improvement (Gilani et al. 2015).

Major changes in forest types and forest canopy density

A total of ten forest types along with canopy density were delineated. The Subtropical broad-leaved forest (26.8%) dominates the total forest area of Nepal. The other major forest types are Tropical moist deciduous sal forest (20.2%), Tropical dry deciduous sal forest (5.5%), Subtropical Pine forest (16.7%), Upper Temperate Mixed Broad leaved forest (8.6%), Upper Temperate Broad leaved (7.6%) and sub alpine forest (1.6%) in 2014. The forest area was getting depleted of the forest types especially the tropical deciduous sal forests and Subtropical broadleaved forests. The forest type-wise distribution across the

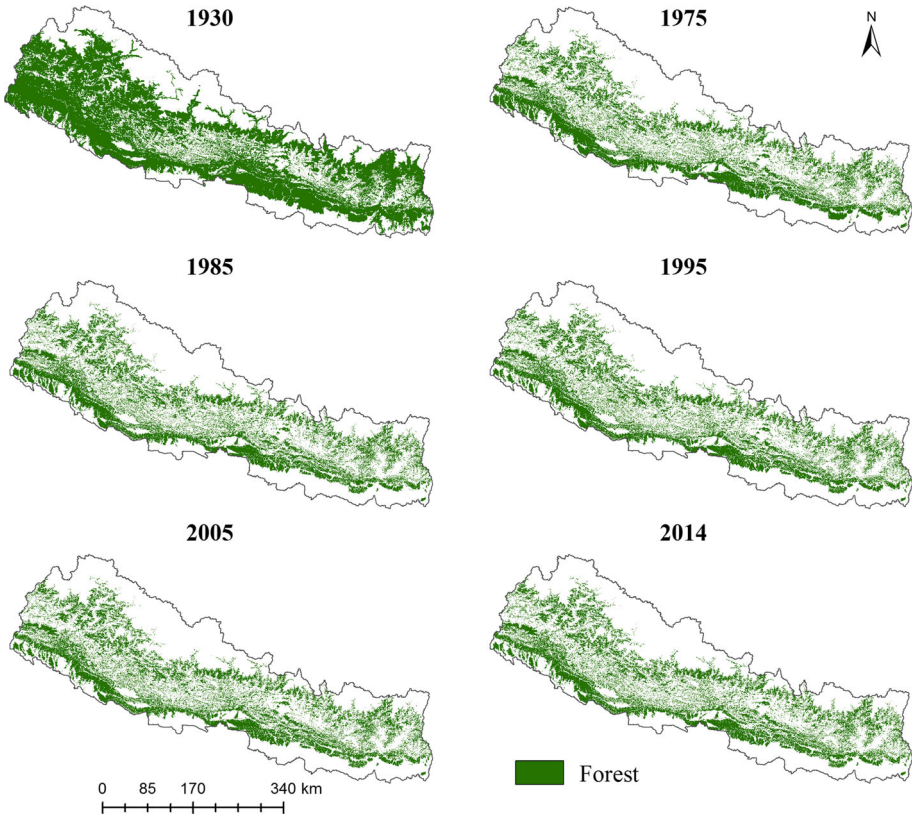

Fig. 3 Forest cover maps of Nepal (1930, 1975, 1985, 1995, 2005 and 2014)

Table 3 Areal extent of forest cover in Nepal (1930–2014)

Period	Area (km^2)	% of TGA
1930	76,710	52.1
1975	42,487	28.9
1985	40,370	27.4
1995	39,803	27
2005	39,426	26.8
2014	39,392	26.8

forest canopy density categories for the years 1975–2014 are presented in Fig. 5 and Table 7. The overall loss of dense forest is high as compared to open forest. Among forest canopy density categories, dense forests and open forests occupy 23,889 km^2 (60.6%) and 15,503 km^2 (39.4%) of total forest area of Nepal during 2014. During 1975, dense forests and open forests occupy 60.4 and 39.6% of total forest area. The loss of an area of 1768 km^2 (6.9%) of dense forest was found from 1975 to 2014. Tropical deciduous sal forests show more spatial changes followed by Subtropical broad leaved forest from 1975 to 2014.

Table 4 Grid wise analysis of forest cover (number of grid cells)

Class	1930	1975	1985	1995	2005	2014
<1 km^2	225	336	340	341	345	346
1–5 km^2	438	1042	1069	1081	1086	1086
5–10 km^2	649	1314	1321	1325	1329	1328
10–15 km^2	757	879	908	912	924	928
15–20 km^2	894	573	595	589	581	579
>20 km^2	1964	387	258	232	214	213
Total	4927	4531	4491	4480	4479	4480

Table 5 Analysis of grid-wise negative and positive changes in Nepal (No. of 5 × 5 km cells)

Change	1930–1975	1975–1985	1985–1995	1995–2005	2005–2014
Deforestation			No. of grids		
<1 km^2	520	405	98	942	55
1–5 km^2	1587	525	159	48	12
5–10 km^2	1427	88	29	1	0
10–15 km^2	852	7	2	0	0
15–20 km^2	384	3	1	0	0
>20 km^2	89	0	0	0	0
Total	4859	1028	289	991	67
Afforestation/reforestation					
<1 km^2	25	4	675	0	7
1–5 km^2	22	0	0	0	0
5–10 km^2	3	0	0	0	0
10–15 km^2	0	0	0	0	0
15–20 km^2	0	0	0	0	0
>20 km^2	0	0	0	0	0
Total	50	4	675	0	7

Species composition in forest types

Tropical Sal forest is distributed throughout flatlands of Siwaliks. Sal (*Shorea robusta*) is the dominant species. The lower flatlands are relatively dry. The forest canopy of this forest is dominated by *Shorea robusta*, *Terminalia alata*, *Terminalia bellirica, Buchanania latifolia, Dillenia pentagyna and Cleistocalyx operculatus*. However, the proportion of species composition varies regionally. The subtropical broad leaved forests are dominated by *Schima wallichii* and *Castanopsis indica*. Whereas, in western and central Nepal, *Terminalia alata* forms a few distinct patches. Other moist and wet areas are dominated by *Quercus dialata, Quercus incana, Acer oblongum, Eugenia tetragona, Carpinus viminea and Alnus nepalensis* (Timilsina et al. 2007; Kindlmann 2011). Subtropical pine forests are characterised by Chir pine (*Pinus roxburghii*), however, Chir pines usually associated with broad leaved trees such as *Shorea robusta* and *Lyonia ovalifolia* at lower limit, *Quercus*

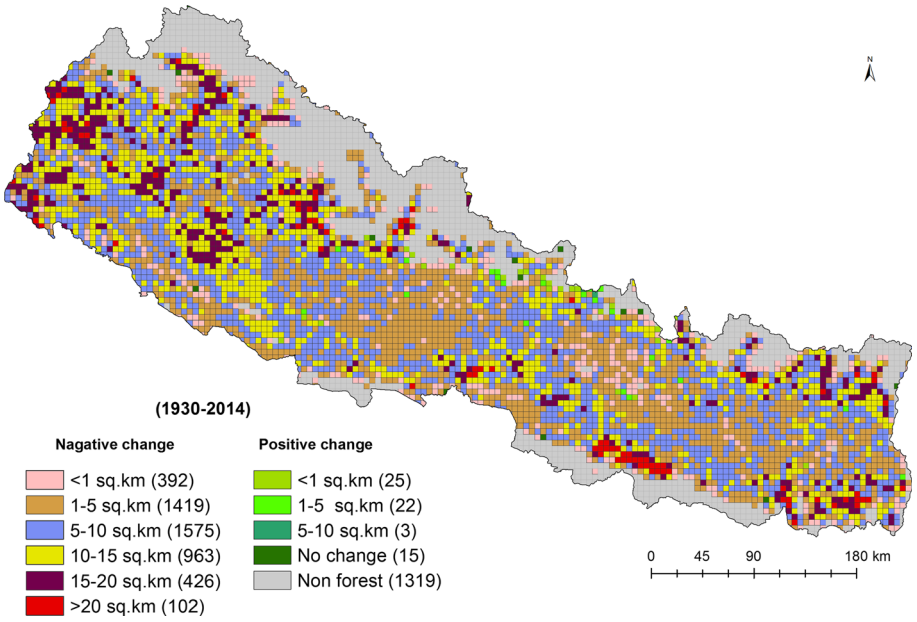

Fig. 4 Forest cover changes in Nepal, 1930–2014

Table 6 Land use/land cover in deforested areas of Nepal (area in km^2)

Forest to other land use/land cover	1930–2014		1975–2014		1985–2014		1995–2014		2005–2014	
	Area	%	Area	%	Area	%	Area	%	Area	%
Plantation	5075	13.4	719	22.6	251	21.7	30	7.1	11	30.6
Scrub	11,083	29.3	596	18.8	362	31.3	287	67.8	6	16.7
Grassland	3367	8.9	75	2.4	14	1.2	1	0.2	0	0.0
Agriculture	15,614	41.2	1430	45.0	408	35.2	92	21.7	12	33.3
Water	411	1.1	66	2.1	19	1.6	1	0.2	0	0.0
Barren	1579	4.2	239	7.5	95	8.2	12	2.8	7	19.4
Snow	568	1.5	0	0.0	0	0.0	0	0.0	0	0.0
Settlement	192	0.5	51	1.6	9	0.8	0	0.0	0	0.0
Grand total	**37,889**	100	**3176**	100	**1158**	100	**423**	100	**36**	100

incana, Quercus lanata and species of *Rhododendron* are the major associates at upper limit (TISC 2002).

The forests in temperate zone have further separated as lower temperate broadleaved forest, upper temperate broadleaved forest, lower temperate mixed broadleaved forest and upper temperate mixed broadleaved forest. *Alnus nitida, Quercus lamellosa*, *Castanopsis tribuloides*, *Castanopsis hystrix* and *Lithocarpus pachyphylla* are the dominant species in lower temperate broadleaved forest. The upper broad leaved forest represents *Quercus semecarpifolia, Alnus nepalensis* and *Daphniphyllum himalayense*. The lower temperate

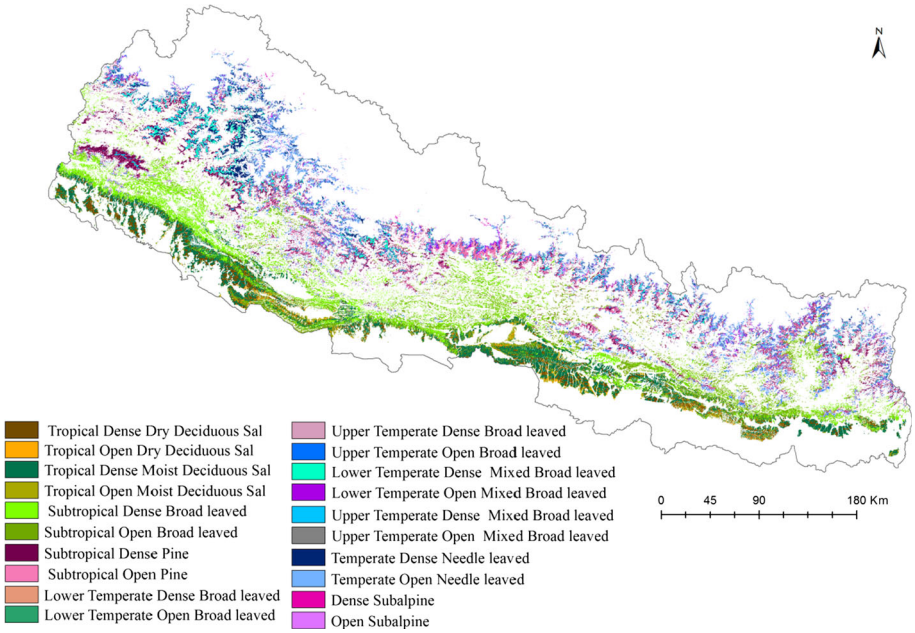

Fig. 5 Forest type and canopy density map of Nepal (2014)

mixed broadleaved forest is predominantly occupied by species of Lauraceae. The upper temperate mixed broadleaved forest is predominantly covered by species of *Acer* and *Rhododendron* (GoN 2011). The most of the broad-leaved trees in these forests are deciduous, usually consisting of *Quercus ilex*, *Acer campbellii*, *Prunus nepalensis*, *Magnolia campbellii*, *Rhododendron campanulatum* and *Abies pindrow* (Shrestha 1989; Chaudhary 1998). Whereas needle leaved forests are dominated by conifers, although there is an insignificant mixture of other species which includes *Tsuga dumosa, Betula utilis, Abies spectabilis, Picea smithiana* and *Pinus wallichiana* (Kindlmann 2011). The floristic composition in subalpine forests is varying in eastern and western parts. In the eastern parts *Abies spectabilis* forms pure *Abies* forests and these formations associated with *Betula utilis*, *Pinus excelsa*, *Tsuga dumosa*, *Picea smithiana*, and *Juniperus wallichiana* and whereas in western parts, forests are mostly consisting of Oaks (*Quercus incana, Q. semecarpifolia Q. lanuginosa* and *Q. dilatata*) (Schmidt-Vogt 1990; Shi and Wu 2013). Often *Betula utilis* forms birch forest and it is regulated by the moisture from snowmelt rather than low temperature (Liang et al. 2014).

Analysis of historical fragmentation

The total number of forest patches increased from 1930 to 2014. At the national level total forest patches are 16,925 (in 1930), 41,649 (in 1975) and 42,961 (in 2014). The mean patch size is declining gradually, showing an area of 467.4 ha (in 1930), 104.5 ha (in 1975) and 93.8 ha (in 2014). The patch size standard deviation is decreasing and observed as 56,790.4, 3785.9 and 2336.3 in 1930, 1975 and 2014 respectively. The edge density has been computed as 23.8 in 1930 which was progressively increased to 78.4 in 1975 and 87.1 in 2014. Mean

Table 7 Distribution of forest types of Nepal (area in km^2)

Sl. no	Forest type	1975	1985	1995	2005	2014
1	Tropical dense dry deciduous Sal	3152	2366	2174	1994	1974
2	Tropical open dry deciduous Sal	1083	542	246	198	194
3	Tropical dense moist deciduous Sal	7762	7287	7257	7222	7218
4	Tropical open moist deciduous Sal	1138	814	742	723	720
5	Subtropical dense broad leaved	6266	6240	6247	6211	6211
6	Subtropical open broad leaved	4394	4374	4381	4330	4329
7	Subtropical dense pine	3383	3388	3389	3386	3386
8	Subtropical open pine	3163	3168	3169	3189	3189
9	Lower temperate dense broad leaved	103	103	103	102	102
11	Lower temperate open broad leaved	205	205	205	205	205
10	Upper temperate dense broad leaved	1003	1003	1003	1003	1003
12	Upper temperate open broad leaved	1980	1992	1994	1987	1987
13	Lower temperate dense mixed broad leaved	593	593	593	593	593
15	Lower temperate open mixed broad leaved	526	526	526	526	526
14	Upper temperate dense mixed broad leaved	1554	1554	1554	1554	1554
16	Upper temperate open mixed broad leaved	1825	1836	1838	1833	1831
17	Temperate dense needle leaved	1596	1602	1603	1600	1600
18	Temperate open needle leaved	2122	2128	2128	2125	2125
19	Dense subalpine	245	250	251	248	248
20	Open subalpine	394	399	400	397	397
	Total	42,487	40,370	39,803	39,426	39,392

patch edge is decreased significantly during the last 80 years (Table 8). Table 9 indicates spatio-temporal changes in forest fragmentation classes from 1930 to 2014.

During the 1930–2014 period, the percent changes based on the 2014 area in each fragmentation class were very significant. The core 3 forest shows 75.5% of reduction, while patch (174.3%), perforated (96.1) and edge (68.5%) classes show the largest percent increases based on the areas of forest (Table 8). For 1930–1975 period, >60% of the total core 3 forest area was converted to the other fragmentation classes. Fragmentation classes had indicated 2–15% change from 1975 to 1985, whereas it is only 0.4 to 2.1 from 1985 to 1995. The lowest percent changes (<0.2) occurred from 2005 to 2014. The decrease in core 3 area was accompanied by an increase in the patch, perforated and edge suggests that the majority of forest areas were transformed (Table 10). From 1930 to 1975 the percentage of the area classified into core 3 fragmentation class changing to non-forest is much higher than the percent change compared to 1975–2014. During the 2005–2014 forests experienced very little transitions. Analysis for 1930 indicates 84.5% of forest area in core 3, followed by edge (9.3%), perforated (3.9%), core 1 (1.3%), patch (0.8%) and core 2 (0.3%). Analysis for 2014 indicates 40.2% of forest area in core 3, followed by edge (30.5%), perforated (14.7%), core 1 (7.9%), patch (4%) and core 2 (2.6%). All the fragmentation classes retained most of their areas from 2005 to 2014 (97.8%). The forest fragmentation map for the years 1930–2014 are shown in Fig. 6. The progressive fragmentation might have significant ecological implications for species dependent on interior regions of forest patches (Echeverría et al. 2006).

Table 8 Analysis of spatial pattern of changes in forests from 1930 to 2014

Sl. no	Landscape metrics	1930	1975	1985	1995	2005	2014
I	Patch density and size						
1	NumP—no of patches	16,925	41,649	42,384	42,711	42,952	42,961
2	MPS—mean patch size (ha)	467.4	104.5	97.5	95.3	93.9	93.8
3	PSSD—patch size standard deviation	56,790.4	3785.9	2662.2	2453.2	2345.3	2336.3
II	Edge metrics						
4	ED—edge density	23.8	78.4	85.1	86.3	87.0	87.1
5	MPE—mean patch edge	11,129.0	8194.6	8296.0	8230.1	8166.1	8165.4
III	Shape metrics						
6	MSI—mean shape index	2.3	2.3	2.3	2.3	2.3	2.3
7	MPAR—mean perimeter area ratio	374.5	365.1	365.2	364.9	364.6	364.6
8	MPFD—mean patch fractal dimension	1.4	1.4	1.4	1.4	1.4	1.4

Table 9 Distribution of forest fragmentation classes from 1930 to 2014 (area in km^2)

Sl. no.	Class	1930	1975	1985	1995	2005	2014
1	Patch	576	1535	1566	1577	1581	1581
2	Edge	7135	11,645	11,883	11,965	12,018	12,026
3	Perforated	2962	5920	6263	5964	5819	5810
4	Core 1	966	2965	3106	3093	3111	3111
5	Core 2	265	964	1018	1010	1017	1016
6	Core 3	64,806	19,457	16,535	16,194	15,880	15,847
Total		76,710	42,487	40,370	39,803	39,426	39,392

Table 10 Change matrix of forest fragmentation classes from 1930 to 2014 (area in km^2)

Sl. no.	1930–2014	Patch	Edge	Perforated	Core 1	Core 2	Core 3	Non forest	Total
1	Patch	206	14	3	1	0	1	352	576
2	Edge	502	2424	48	19	4	9	4130	7135
3	Perforated	81	888	639	8	3	8	1336	2962
4	Core 1	17	298	82	467	0	0	101	966
5	Core 2	2	44	21	98	38	0	63	265
6	Core 3	685	8100	4960	2404	957	15,692	32,008	64,806
7	Non forest	89	259	58	115	15	137	69,799	70,471
Total		1581	12,026	5810	3111	1016	15,847	107,789	147,181

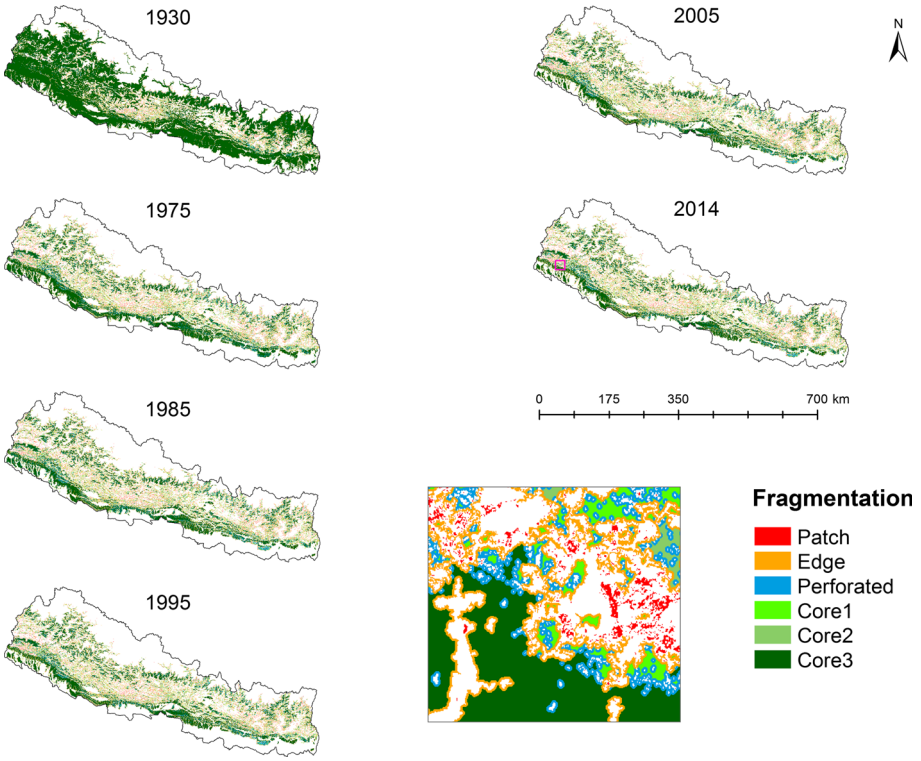

Fig. 6 Forest fragmentation map of Nepal from 1930–2014

Accuracy assessment

The overall accuracy of the 2014 classification, assessed on the basis of Google Earth images was 91%, with a Kappa coefficient of 0.88%. Validation of forest cover maps for 1975, 1985, 1995, 2005 was done based on visual assessment of satellite images and the temporal consistency of ground control points. The accuracy of classified maps derived for the years 1975, 1985, 1995 and 2005 were 88.8, 89.6, 90.2 and 91% % respectively. All the kappa values were more than 0.85.

Conclusions

This study provides changes in forest cover and fragmentation over the past eight decades in Nepal during 1930–1975, 1975–1985, 1985–1995, 1995–2005 and 2005–2014. The spatial database generated on forest types and forest canopy density from 1975 to 2014 and land cover information for 2014 at a national level is useful for land use planning and conservation.

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