

# Land Cover/Land Use Change and Fragmentation in Uttarakhand, the Western Himalaya Based on GlobeLand30 Datasets



A. Arun Kumar, Tanvi Gaur, Sujata Uppgupta, K. Ramesh and Sanjeev Kumar

**Abstract** Globally, a widespread decline of the forest ecosystems and increasing fragmentation has been reported, yet there is no comprehensive assessment of degradation across the country. In this study, land cover change and fragmentation from 2000 to 2010 were analyzed for the state of Uttarakhand, using GlobeLand30 datasets at 30-m spatial resolution (GlobeLand30) developed by the National Geomatics Center of China (NGCC). Further, spatial patterns were analyzed, focusing on forest loss and patch matrices. The results show that during the last decade, vegetation cover has reduced by 523 km<sup>2</sup>, whereas the artificial surface has increased by 103 km<sup>2</sup>. Also, the fragmentation analyses show that the intact forests have reduced about 105 km<sup>2</sup> resulting in more open and patchy forests. The paper also highlights the effectiveness of using global land cover datasets and digital techniques for monitoring the forest structure spanning over vast areas and to see the effectiveness of management policies in the long run.

**Keywords** Deforestation · Fragmentation · Uttarakhand · Landscape fragmentation tool · Himalaya

## 1 Introduction

Land use/land cover (LULC) change is a dynamic process that takes place over space and time and is of enormous importance in natural resource management studies. Land cover is the characteristic of the earth's surface that spatially captures the distribution of vegetation, water, barren land, and ice, and it also includes the man-made structures such as settlement [1]. Land use is the management and modification of land, to exploit the land cover and captures the distribution of human activities includ-

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ing industrial zones, residential zones, agricultural fields, grazing, logging, mining, and many others [2]. Information on land cover/use is important for the selection, planning, and implementation of management policies to meet the increasing human needs as well as the wildlife conservation.

Changes in land use and cover do not essentially indicate degradation of the land. However, human activities cause shifting land use patterns that result in land cover changes that affects ecosystems and biodiversity [3]. Land conversion results in habitat loss and is the single greatest cause of extinction of species [4, 5]. Use of satellite imagery along with fragmentation analysis is becoming a valuable technique for assessing the temporal changes in the land cover and its effect on various ecosystem [6–10].

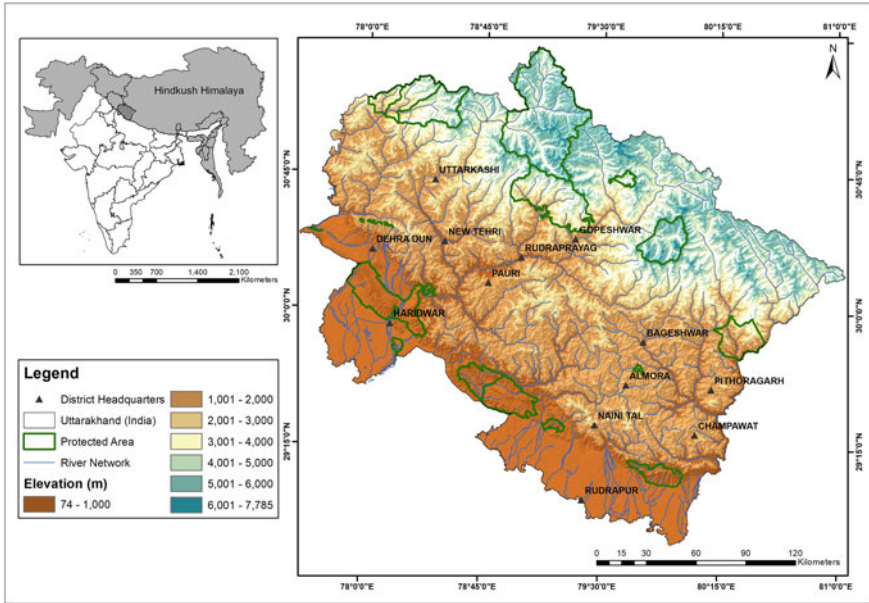
Forest degradation is the conversion of forest to some other land use, and forest fragmentation is breaking down of a large forest into a smaller patch of forest habitat [11]. The forest fragmentation in general is a consequence of increasing agricultural practices; logging and deforestation; development projects. Forest deforestation and fragmentation not only modify the natural landscapes, but also will lead to loss of habitat and biodiversity, and ecosystem functioning [12–16]. The single most significant factor for biodiversity loss is forest fragmentation [17]. Habitat fragmentations have forced many species to become highly vulnerable [18]. Evaluation of landscape indices has been recognized as the most effective way to quantify forest fragmentation [19–22]. Contrary to the availability of a large number of deforestation studies from the tropical forest, there are very few studies that report deforestation and fragmentation of the tropical forests [23].

Numerous studies have documented the adverse effects of anthropogenic drivers on the biodiversity, habitat loss, and fragmentation in the Hindu Kush Himalaya [24–28], and forest fragmentation studies are still patchy and are not adequate to make any management intervention at the landscape levels. In this study, we have addressed the landscape dynamics in the state of Uttarakhand, in view to detect the integrity of forest ecosystems and the changes that has taken place between 2000 and 2010 using geospatial techniques. Specifically, we aimed (i) to identify and delineate LULC changes in Uttarakhand between 2000 and 2010, (ii) to determine the shift in LULC classes, and (iii) to determine the extent of forest fragmentation as a potential indicator for forest degradation.

## 2 Materials and Methods

### 2.1 Study Area

Uttarakhand state is located in the northern part of India and shares North Western boundary with Himachal Pradesh, North and North Eastern boundary with Tibet, Eastern boundary with Nepal, and Southern boundary with plains of Uttar Pradesh (Fig. 1). Uttarakhand has an area of 51954.76 km<sup>2</sup> (Survey of India) and lies between



**Fig. 1** Map showing the study area, the Uttarakhand

28° 43'N and 31° 27'N latitude and 77° 34'E to 81° 02'E longitude. The recorded forest area in the state is 24,240 km<sup>2</sup> [29], which constitute 46.65% of total geographical area covered by the state. The state lies in the western part of the Indian Himalaya region, with glaciers at the highest and tropical forests at the lowest elevation. The state experiences a wide range of climate and has different vegetation type changing with elevation.

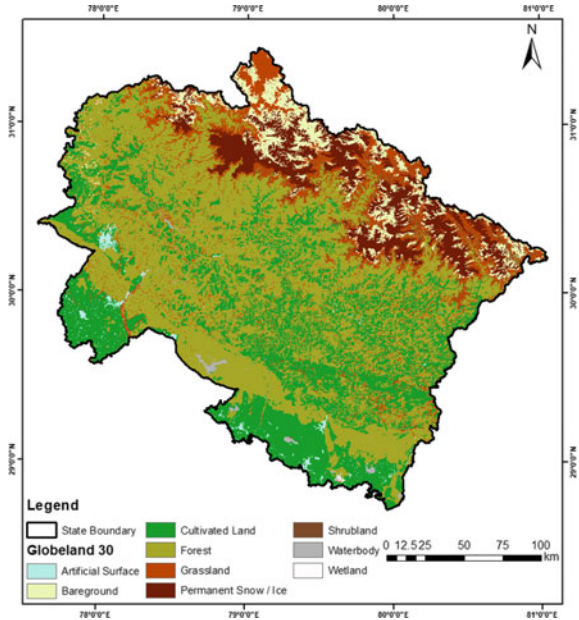
Physiographically, the state can be divided into three parallel zones: the Himalayas, the Shiwaliks, and the Terai region, with temperate climate in higher elevation and tropical climate in plains, with temperatures ranging from sub-zero in the higher regions to >40 °C in the plains.

The state experiences an average annual rainfall of 1432.2 mm with a range varying between 328 and 3673 mm. Some of the major forest types in the state include Tropical Moist Deciduous, Tropical Dry Deciduous, Subtropical Pine, Himalayan Moist Temperate, Himalayan Dry Temperate, Sub-Alpine, and Alpine forests [29, 30].

## 2.2 Dataset

Information on temporal changes in the land cover is vital for any environmental research needs and for the sustainable development planning [2, 3, 31–33]. Since

**Fig. 2** GlobeLand30 data for the Uttarakhand



satellite-based remote sensing has long been a standard tool for broad-scale land cover mapping [34], a number of global land cover datasets have been developed with resolution ranging from 300 m to 1 km, using low-resolution satellite imagery such as the Advanced Very High-Resolution Radiometer (AVHRR), MODIS Moderate Resolution Imaging Spectroradiometer (MODIS), and Medium Resolution Imaging Spectrometer (MERIS) [7, 33–35]. Although researchers have highlighted the shortfalls of these GLC datasets due to its poor resolution, these data products are still being widely used in various research [36–38].

The GlobeLand30 dataset was developed by the National Geomatics Centre of China (NGCC), which provides global land cover data at 30-m resolution (Fig. 2.). The accuracy assessment per class analyses reveals that classes 20 (Forest) and 90 (Bare ground) has an accuracy of 75 and 60%, respectively, while 60 (Water body), 10 (Cultivated land), and 30 (Grassland) have the highest accuracy above 85%, and class 50 (Wetland) is the lowest with 8.3%. The overall accuracy is 78%, which falls into “substantial” category [39]. Covering a decade from 2000 to 2010, the GlobeLand30 dataset is derived from over 10,000 images from Landsat Thematic Mapper (TM), Enhanced Thematic Mapper plus (ETM<sub>p</sub>), and the HJ-1 (Chinese Environmental Disaster Alleviation Satellite).

Apart from a few recent studies [40, 41], these data are still not exploited effectively, regardless of being a potential source of understanding the landscape and land cover change. In the present study area, 4 tiles for each period (N43 25 2000 LC 030; N43 30 2000 LC 030; N44 25 2000 LC 030; N44 30 2000 LC 030; N43 25 2010 LC 030; N43 30 2010 LC 030; N44 25 2010 LC 030; N44 30 2010 LC 030) of Glo-

beLand30 were used; this dataset is available in raster format with WGS84 (World Geodetic System 1984) reference system and UTM (Universal Transverse Mercator) projection. The GlobeLand30 dataset classifies land cover into ten categories, viz. artificial surfaces, bare ground, cultivated land, forests, grassland, shrubland, wetlands, water bodies, tundra, and permanent snow/ice.

### 2.3 Land cover Change Analyses

Tabulate Area Tool in ArcGIS 10.5 was used to quantify land use and land cover change (LULC) [42]. The results highlight the changes in the LULC classes, and these changes were compared to quantify the gains and losses between 2000 and 2010. The gain and loss were calculated by subtracting the persistence from the column total and the row total, respectively.

### 2.4 Fragmentation Analyses

The Landscape Fragmentation Tool (LFT v2.0) was developed by Center for Land Use Education and Research, University of Connecticut [28]. The land cover maps for the years 2000 and 2010 were reclassified into forest and non-forest classes. The fragmentation tool classifies forest class into four main categories: patch, edge, perforated, and core [28]. We have considered 100 m as an edge width, as it is a default value used in general purpose analyses [28, 43]. The forest areas were classified into: (i) “intact” forest—the forest that is relatively distant from the non-forest boundary; (ii) “patch” forest—small forest area surrounded by non-forested area; (iii) “perforated” forest—transition zone between the intact forest and perforations; (iv) “edge” forest—transition zone between the intact forest and large non-forest land; and (v) “non-forest” [28].

### 2.5 LULC and Forest Fragmentation Change Analyses

The annual rate of change was calculated by comparing the area of different classes (land cover and fragmentation) at two different periods. The annual rate of change was derived from the formula [44].

$$r = \frac{1}{(t_2 - t_1)} X \ln\left(\frac{a_2}{a_1}\right) \quad (1)$$

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

### 3 Results

#### 3.1 Land cover Changes

The land use pattern of Uttarakhand is governed by its characteristic topography. There are steep variations in the gradient of the land surface while moving from south to north, starting from the Gangetic plains to the mountainous snow-covered peaks. The study result shows that in both the time period (2000 and 2010), the forest class occupies the majority of the state with 46.47% (24141.55 km<sup>2</sup>) and 45.46% (23617.93 km<sup>2</sup>), respectively, followed by cultivated land with 26.31% (13667.28 km<sup>2</sup>) and 26.22% (13624.13 km<sup>2</sup>) (Fig. 3.).

Table 1 shows both positive and negative changes occurred in the land use/cover pattern in the state. Over the decade period from 2000 to 2010, the forests have reduced from 24141.55 to 23617.93 km<sup>2</sup> that equates to 523.61 km<sup>2</sup> and 1.01% of the total area of the state. The cultivated lands have reduced from 13667.28 to 13624.13 km<sup>2</sup> that equates to 43.15 km<sup>2</sup>. Interestingly, the grasslands have increased from 5322.61 to 5832.38 km<sup>2</sup>, which is an increase of 509.77 km<sup>2</sup>. The artificial surfaces have increased from 257.81 to 360.74 km<sup>2</sup>, which is 102.93 km<sup>2</sup>. The water body has also increased from 246.08 to 274.23 km<sup>2</sup>. Figure 4 illustrates the magnitude of change in different land categories. A total of 1638.80 km<sup>2</sup> of the forest area have been converted into other land cover types classes (Table 2). Table 3 shows a total of 1115.20 km<sup>2</sup> of other land cover types converted to forest. Between 2000 and 2010,

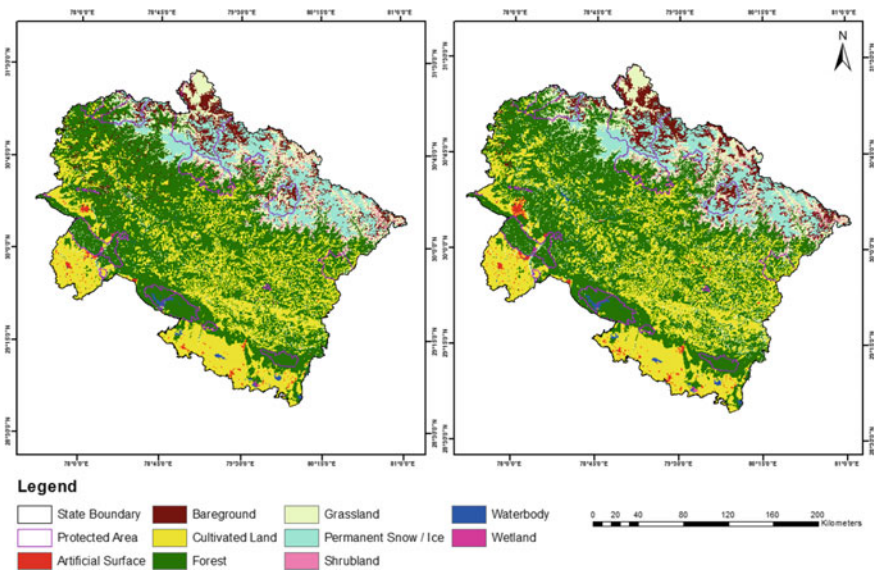
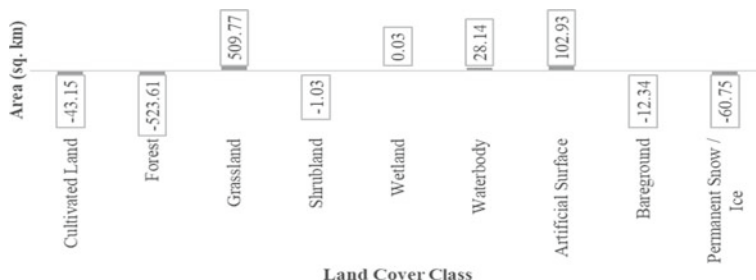


Fig. 3 Land use status of Uttarakhand (A. 2000; B. 2010)

**Table 1** Area of different land cover units in Uttarakhand

Land use/land cover type	Area in 2000		Area in 2010		Change km <sup>2</sup>
	km <sup>2</sup>	%	km <sup>2</sup>	%	
Cultivated land	13667.28	26.31	13624.13	26.22	-43.15
Forest	24141.55	46.47	23617.93	45.46	-523.61
Grassland	5322.61	10.24	5832.38	11.23	509.77
Shrub land	750.39	1.44	749.36	1.44	-1.03
Wetland	13.74	0.03	13.77	0.03	0.03
Water body	246.08	0.47	274.23	0.53	28.14
Artificial surface	257.81	0.50	360.74	0.69	102.93
Bare ground	3029.67	5.83	3017.33	5.81	-12.34
Permanent snow/Ice	4525.64	8.71	4464.89	8.59	-60.75



**Fig. 4** Magnitude of land use change between 2000 to 2010

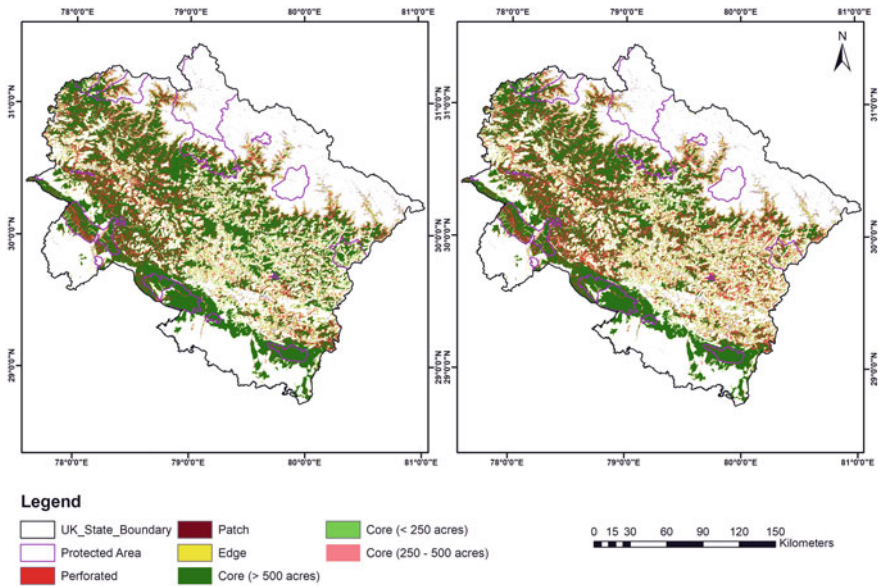
**Table 2** Land use/cover in deforested areas

S.no	Cover type	Area (km <sup>2</sup> )	%
1	Grassland	1130.29	68.97
2	Cultivated land	342.60	20.91
3	Shrub land	76.85	4.69
4	Bare ground	41.44	2.53
5	Water body	36.68	2.24
6	Others	10.95	0.67
	Total	1638.80	

the percentage change of forest is -1.01% with a net annual deforestation rate(*r*) of 0.0022%.

**Table 3** Other land use/cover areas converted to forest

S.no	Cover type	Area (km <sup>2</sup> )	%
1	Grassland	428.51	38.42
2	Cultivated land	302.65	27.14
3	Bare ground	278.46	24.97
4	Shrubland	84.63	7.59
5	Water body	20.03	1.80
6	Others	0.93	0.09
	Total	1115.20	



**Fig. 5** Fragmentation status of Uttarakhand (A. 2000; B. 2010)

### 3.2 Fragmentation Status

Forest fragmentation analyses revealed a significant decrease in the large intact patch area (>500 acres). In 2000, the large intact patches were dominant, covering 63.41% of the total forest area, but got reduced to 55.25% in 2010 (Fig. 5), followed by edge (15.57%), perforated area (15.09%), small intact (2.84%), patch area (1.86%), and medium intact (1.23%) (Table 4).

However, the edge (16.93%), perforated area (19.92%), small intact (4.07%), patch area (2.27%), and medium intact (1.59%) have increased in 2010. Between 2000 and 2010, the percentage change of the large intact patch was -4.35% with a



**Table 4** Forest fragmentation in area and percentage

Fragmentation class	Area 2000		Area 2010	
	km <sup>2</sup>	%	km <sup>2</sup>	%
Patch	449.55	1.86	536.85	2.27
Edge	3760.01	15.57	3998.44	16.93
Perforated	3642.03	15.09	4704.58	19.92
Intact (<250 acres)	686.35	2.84	960.27	4.07
Intact (250–500 acres)	297.17	1.23	376.32	1.59
Intact (>500 acres)	15309.20	63.41	13049.21	55.25

net annual reduction rate (*r*) of 0.016%. And the percentage change of perforated area was 2.05% with a net annual increase rate (*r*) of 0.026%.

## 4 Discussion

The changes in land cover/land use provide a useful understanding for the landscape pattern and processes. In the present context, it was possible to deduce that the rate of deforestation across space and time is minimal (0.0022%). But the fragmentation process is affecting the intact forests, and there is a significant increase in edge and forest perforation, reflecting that the landscape integrity is suffering. The GlobeLand30 dataset has been recognized as an essential geospatial database by the United Nations Committee of Experts on Global Geospatial Information Management, United Nations Environment Programme, and Global Observation for Forest Cover and Land Dynamics.

This study was to examine the suitability of using GlobeLand30 dataset for mapping large landscapes in the countries with inadequate National and regional land cover maps. The study illustrates the change in the land cover classes and also quantified the changes in the forest class and fragmentation over large landscapes. The results demonstrate that there are minimal changes occurring in different land use/cover type with a very low annual rate of change as compared to studies from other parts of the world [9]. The land cover change analysis shows that there is a decline in the forest (523.61 km<sup>2</sup>), agriculture area (43.15 km<sup>2</sup>), and permanent snow (60.75 km<sup>2</sup>), whereas grassland (509.77 km<sup>2</sup>), artificial surface (102.93 km<sup>2</sup>), and water body (28.14 km<sup>2</sup>) have increased. Also, the results show a reduction in the forest area (1.01%) to be less compared to other similar studies [8, 18, 21, 23], but there is a serious fragmentation happening in the state’s forests. A total of 2259.99 km<sup>2</sup> (4.35%) area of large core forest (>500 acre) have been lost, whereas perforations have increased by 1062.55 km<sup>2</sup> (2.05%) in the forested areas between 2000 and 2010. This information is essential for national and state-level policy making to tackle deforestation and habitat protection. Most global land cover datasets suffer at

details due to their coarser spatial resolution (300 m–1 km) and has limited usability in research and policy deliberation [39, 40, 45]. Given the free availability of GlobeLand30 data with 30-m resolution, the dataset provides more details on land cover patterns and its change over time. This can bring in better understanding of landscape heterogeneities and also will increase the performance of landscape level modeling and predictive simulations.

## 5 Conclusion

This study conducted in one of the states of the Indian Himalayan Region (IHR) advocates that importance of multi-temporal and regional datasets in detecting the landscape changes rapidly and accurately. The results of our study demonstrate that there is no considerable forest decline in the state of Uttarakhand but the visible fragmentation events in the forests are of significant importance. Although the state is covered with 45.47% of forests, only 55% of the total forest fall into a large intact patch (>500 acre) and the remaining 45% falls into other fragmentation classes indicating clear and persistent degradation happening in the Uttarakhand's forests. The integrity and intactness of the forests are of high importance value to the species inhabiting those areas. Perforations in the forests can often lead to isolated patches that can completely lose its connections with the main forest areas and will further be completely lost leading to species extinction. Prioritizing the target areas where maximum changes and forest decline have taken place will aid in better conservation and management practices within the area. Even though this work has shown the present state of forests in Uttarakhand, more detailed analyses on patch metrics will be required to identify the factors that have resulted in the present spatial pattern of the forest.

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