

Article

# Assessment of Land-Use/Land-Cover Change and Forest Fragmentation in the Garhwal Himalayan Region of India

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**Abstract:** The Garhwal Himalaya has experienced extensive deforestation and forest fragmentation, but data and documentation detailing this transformation of the Himalaya are limited. The aim of this study is to analyse the observed changes in land cover and forest fragmentation that occurred between 1976 and 2014 in the Garhwal Himalayan region in India. Three images from Landsat 2 Multispectral Scanner System (MSS), Landsat 5 Thematic Mapper (TM), and Landsat 8 Operational Land Imager (OLI) were used to extract the land cover maps. A cross-tabulation detection method in the geographic information system (GIS) module was used to detect land cover changes during the 1st period (1976–1998) and 2nd period (1998–2014). The landscape fragmentation tool LFT v2.0 was used to construct a forest fragmentation map and analyse the forest fragmentation pattern and change during the 1st period (1976–1998) and 2nd period (1998–2014). The overall annual rate of change in the forest cover was observed to be 0.22% and 0.27% in the 1st period (1976–1998) and 2nd period (1998–2014), respectively. The forest fragmentation analysis shows that a large core forest has decreased throughout the study period. The total area of forest patches also increased from 1976 to 2014, which are completely degraded forests. The results indicate that anthropogenic activities are the main causes of the loss of forest cover and forest fragmentation, but that natural factors also contributed. An increase in the area of scrub and barren land also contributed to the accumulation of wasteland or non-forest land in this region. Determining the trend and the rate of land cover conversion is necessary for development planners to establish a rational land use policy.

**Keywords:** land cover changes; forest fragmentation; Garhwal Himalaya; remote sensing; GIS

## 1. Introduction

Mountains are among the most fragile environments on Earth. Many mountain ecosystems, including the Himalayan mountains, which are among the most unstable and fragile mountain areas in the world, are strongly affected by drivers of global change such as land use changes and climate change [1–6]. Environmental degradation such as deforestation and degradation of the Himalayan forests are major environmental issues of global significance and some of the most intensively studied land use change processes [1,7,8]. Despite the fact that the Indian Himalayas are recognized global biodiversity hotspots, forest cover is under pressure from extensive and rapid land cover change due to anthropogenic and natural drivers [9,10]. At the same time, the Himalayan region is vulnerable to numerous types of hazards such as landslides, extreme rainfall events, floods, and forest fires, which further deteriorate the mountain landscape and forest ecosystem [11–13].

Forest loss and fragmentation are distinct but related phenomena. Forest loss is simply the conversion of forestland to some other land use, but forest fragmentation occurs when a large region of forest is broken down, or fragmented, into a collection of smaller patches of forest habitat [14,15]. Forest landscapes are at high risk of forest fragmentation because of changes in land cover due to processes such as agricultural intensification, logging, and infrastructure development. These changes have led not only to the loss of habitat and biodiversity, but also to the modification of natural landscapes and ecosystem functions [16–21]. The anthropogenic drivers and their impact on natural resources, biodiversity, habitat loss, and fragmentation of the forest are widely documented across the Hindu Kush Himalaya region [22–28], although non-anthropogenic drivers such as natural hazards also contribute to forest fragmentation, especially in mountain regions such as the Himalayas [29]. However, very few studies have been conducted to understand the correlation between natural hazards and forest fragmentation. Therefore, understanding the link between natural hazards and forest fragmentation at different scales is also important for implementing conservation strategies for proper land management in mountain regions such as the Himalayas.

The Garhwal Himalaya is one of the hotspots of biodiversity situated in the western part of the Uttarakhand Himalaya [30]. Extensive deforestation and fragmentation of the forests in the Garhwal Himalaya have caused serious environmental degradation [1,31,32], which is a critical issue in the Uttarakhand Himalaya and a basic reason for biodiversity loss [32]. According to data from the Ministry of Environment and Forests (MoEF), 44,868 hectares of forest land have been changed to non-forest use in Uttarakhand since 1980, 9500 hectares of which have been converted for the construction of roads, followed by 5500 hectares for hydro-projects and 3100 hectares for transmission lines. Agriculture is the main occupation of the people of the Garhwal Himalaya. About 70% of the population is directly and indirectly employed in the agriculture sector [33], which may lead to the overexploitation of natural resources in the region. Not surprisingly, the fragile nature of the Garhwal Himalaya coupled with increasing human activity poses a serious threat to the natural landscape, especially in the forest ecosystem. Therefore, forest cover has been under pressure over the last few decades in the region.

The present study focuses on the Rudraprayag district of the Uttarakhand state, situated in the Garhwal Himalaya region of India (Figure 1). The Rudraprayag district has been continuously experiencing extensive forest loss, due to agriculture expansion and infrastructure development. The forest in this area has been converted for hydroelectric projects (62.93 hectares), roads (187.52 hectares), or other activities (299.08 hectares) [34]. On the other hand, natural hazards such as floods, landslides, and forest fires have increased over the last few decades and have led to further deterioration of the forest landscape in the study area [10]. For example, a vegetation cover mapping was done at the National Remote Sensing Centre (NRSC) for the flood affected area of the Mandakini river between Kedarnath to Rudraprayag during the 16th and 17th of June 2013. The assessment shows that the vegetation cover had changed at 50 locations. The loss of forest cover was 46 hectares and the loss of grassland cover was 124.9 hectares in the Rudraprayag district. Recently, in 2016, a study was conducted by the Forest Department of Uttarakhand, which was related to the forest fire in Uttarakhand. According to the report, 79 locations experienced forest fires in the forest area, and the loss of forest cover was 157.20 hectares in the forest fire incident in the Rudraprayag district between April and May 2016. These are some examples that have indicated the anthropogenic pressure on natural resources and the natural vulnerability of this region.

The Rudraprayag district has experienced the extensive loss of forest in the past due to human activities and natural hazards, but data and documentation detailing this are limited. The present study is designed to fill this gap and to provide detailed information about land cover change and forest fragmentation in the study area. Satellite remote sensing and the use of geographical information systems (GIS) have emerged as powerful tools to create a spatial inventory of natural resources and play crucial roles in monitoring and analysing spatial and dynamic changes of an area [35]. Therefore,

this study applies satellite remote sensing: (1) to analyse the spatial-temporal trends in land-use/cover change from 1976 to 2014 and (2) to evaluate forest fragmentation due to the land cover change.

## 2. Materials and Methods

### 2.1. Study Area

The study area, i.e., the Rudraprayag district, is an area of the vulnerable zone in the Garhwal Himalaya region of the Uttarakhand state in India. It extends from  $30^{\circ}12'58''$  N to  $30^{\circ}48'47''$  N latitude and  $78^{\circ}50'07''$  E to  $79^{\circ}22'34''$  E longitude. The geographical area of the Rudraprayag district is around  $1936.06 \text{ km}^2$  (Figure 1). As per the report of the Disaster Mitigation and Management Centre (DMMC), the Rudraprayag district is a land of deep valleys, high ridges, and steep mountains. It is comprised of two main tectonic units, viz. the Garhwal group and Central Crystalline group, and covers two sections of the Himalaya: the Lesser Himalaya and Greater Himalaya [36,37]. In the study area, rainfall is highly variable depending upon the altitude. In the southern part of the district at Rudraprayag, the average annual rainfall is around 1220 mm, while in the central part at Chandrapuri, the average annual rainfall is 1751 mm, and the rainfall in the northern higher part at Ukhimath is 1995 mm [38]. The overall average rainfall in the district is 1485 mm. Most of the rainfall (70–80% of annual precipitation) occurs from June to September. The mean air temperature in winter (December to February) varies from 8.32 to 13.15 °C and from 27.75 to 32.54 °C in summer (May to July) [38]. The altitude varies from 546 to 6840 m above sea level (Figure 1). Mandakini is the major river of the district, with a catchment area of  $1641.64 \text{ km}^2$ , and it has many tributaries. It originates from the Chorabari glacier (3895 m) (Figure 1).

The Kedarnath wildlife sanctuary has a total area of  $975 \text{ km}^2$  out of which  $645 \text{ km}^2$  is situated in the Rudraprayag district (Figure 1). It is one of the largest protected areas in Uttarakhand. Over 175 villages are located along the southern boundary of the sanctuary, whose inhabitants depend substantially on its resources for fuel wood, fodder, medicinal plants, and pastures for livestock grazing [39]. Agriculture is the primary occupation of the people. Agricultural activities are restricted on river terraces, gentle hill slopes, and intermountain valleys. The Rudraprayag district is famous for one of the most recognized pilgrim sites (Kedarnath Temple) in India. Therefore, tourism is another important livelihood option for the local people during the tourist season in the Rudraprayag district. The population of the Rudraprayag district is increasing, but, compared to the other districts of Uttarakhand, it is low. According to the 1991, 2001, and 2011 census, the Rudraprayag district had a population of 198,672 persons, 227,439 persons, and 236,857 persons, respectively, and its population growth rate over the decades of 1991–2001 and 2001–2011 was 14.4% and 4.14%, respectively. According to the 2001 and 2011 census, the population density was 115 persons per  $\text{km}^2$  and 119 persons per  $\text{km}^2$ , respectively.

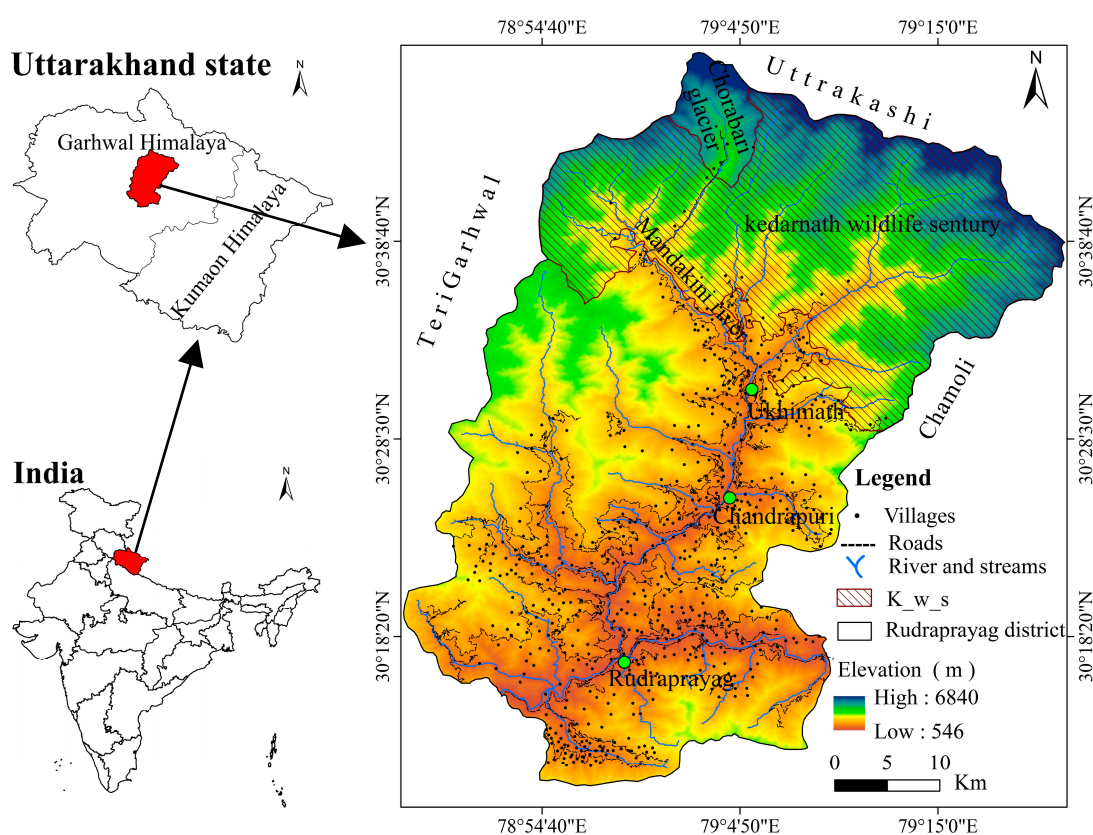


Figure 1. Location and extent of the Rudraprayag district, Uttarakhand, India.

2.2. Data Used

In this study, three cloud free satellite images from Landsat 2 (MSS), Landsat 5 (TM), and Landsat 8 (OLI) from the USGS (United States Geological Survey) server for land cover maps were used. These images were selected on the basis of their availability and the quality of the datasets for the study area. Table 1 summarizes the details of the satellite data used in this study.

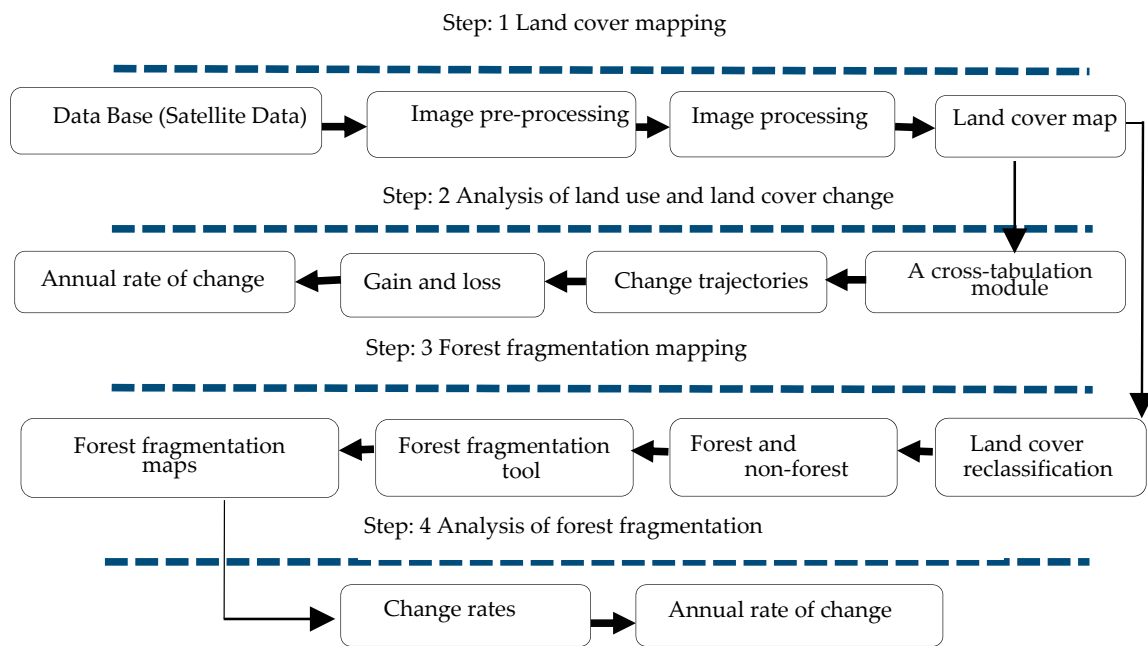
Table 1. Details of the satellite data used in this study.

Satellite	Sensor	Path/Row	Spatial Resolution (M)	Date of Acquisition	Sources
Landsat 2	MSS	156/39	60	19/11/1976	USGS
Landsat 5	TM	146/39	30	12/11/1998	USGS
Landsat 8	OLI	146/39	30	24/11/2014	USGS

OLI: Operational Land Imager; USGS: United States Geological Survey. MSS: Multispectral Scanner System; TM: Thematic Mapper.

2.3. Methods

Figure 2 shows the overall methodological framework. Land cover maps were derived based on Landsat images for the years 1976, 1998, and 2014, using supervised classification with the maximum likelihood method. Then, land cover maps were analysed to understand the changes in land-use and land-cover, using the cross-tabulation module detection method in Arc GIS. Finally, all land cover maps were converted to forest and non-forest areas to detect forest fragmentation areas, using the landscape fragmentation tool (LFT v2.0). The details of the procedure are given in the following sections.



**Figure 2.** Overall methodological framework for the study.

### 2.3.1. Land Cover Classification Scheme

Due to the mountainous topography of the study area, image preprocessing of the satellite images was necessary to reduce or eliminate differences between the two dates due to atmospheric or sensor variations [40,41]. Therefore, the Fast Line-of-sight Atmospheric Analysis of Spectral Hypercube (FLAASH<sup>®</sup>) model was applied to improve radiometric and atmospheric correction in this study using the software ENVI 5.1. The FLAASH model technique was applied for handling particularly stressing atmospheric condition, such as the presence of clouds and surface reflectance. For geometric registration, the 2014 image was geo-referenced using ground control points by GPS and Google Earth. Then, the images of 1976 and 1998 were matched with the geometrically corrected OLI images from 2014 by means of an image-to-image matching method, provided by the ERDAS Imagine software. Afterwards, all images were re-sampled using the nearest neighbor technique with a root mean square error of less than  $\pm 0.5$  pixel per image to a 30 m resolution with the common Universal Transverse Mercator (UTM) 44N zone.

A classification scheme was developed based on ancillary information (Table 2), fieldwork, local knowledge, and visual interpretation of each class of land cover. The visual interpretation was completed using ArcGIS to obtain a training set for each class that was completed based on field observation and Google Earth. In addition, unsupervised classification and NDVI (Normalized Difference Vegetation Index) determination were also applied before the supervised classification to aid in the identification of dominant land-cover types and improve the classification accuracy. Then, supervised classifications using the maximum likelihood method were performed in ERDAS IMAGINE for the 1976, 1998, and 2014 Landsat images. For each class, 20 ground-truth polygons were digitized based on a visual analysis of the locations on Google Earth and on the image itself. To improve classification, training polygons with confusing spectral signatures were discarded, and new ones were created based on a visual analysis of the locations on Google Earth and on the image itself. Afterwards, the maximum likelihood algorithm was run again [42]. The identified nine land cover classes included dense forest, open forest, pasture land, agriculture land, built-up area, scrub land, barren land, water bodies, and snow and glacier.

**Table 2.** Land-cover classification scheme.

Land Cover	Description
Dense forest	All lands with tree canopy density of 40–70% and above
Open forest	All lands with tree canopy density of 10% and more but less than 40%
Scrub land	Degraded forest lands with canopy density less than 10%
Non-forest	Lands not included in any of the above class such as agriculture, built-up, barren, pasture, water bodies, snow/glacier

Source: Forest survey of India, Dehradun, India state of forest report (2011) [43].

### 2.3.2. Accuracy Assessment

Accuracy assessment is important in validating the digitally classified images. It is the procedure used to compare the classification results to the geographical reference data that are assumed to be true [44]. Due to the mountainous topography of the study area, ground reference data were collected from Google Earth with limited ground GPS points. To assess the accuracy of the classification, field visits were made to the study area with the help of local guides, located randomly below 3000 m elevation (as the elevations above this were not accessible due to difficult terrain), using a handheld Garmin Global Positioning System (GPS; 12-channel Garmin eTrex 30-Summit mode). The accuracy assessment of the 1976 and 1998 images were not possible due to lack of data availability and a clear Google Earth image archive. Therefore, an accuracy assessment was performed for the 2014 image only. For the 2014 image, a total of 270 (30 pixels from each class) testing pixels were generated at random throughout the study area. The testing pixels were compared with the classified map. To evaluate the user's and the producer's accuracy an error matrix was applied, to compare the relationship between the classified map and reference data [45]. As a result, the producer's accuracy, user's accuracy, overall accuracy, and kappa coefficient were computed for the final land cover maps produced.

### 2.3.3. Land-Use and Land-Cover (LULC) Change Analysis

A cross-tabulation module detection method was used to detect land-use and land-cover change (LULC) in ArcGIS [46], through which a LULC change matrix was produced. This matrix provides essential information about the nature and spatial distribution of land use changes [47]. A change matrix enables the main types of changes or directions in the study area. Then, the change in LULC was analysed to depict gains and losses for the two time periods. The change matrices of the 1st period (1976–1998) and the 2nd period (1998–2014) were also used to drive the gains and losses for land-cover categories. The gains for each class were derived by subtracting the persistence from the column total, and the losses were computed by subtracting the persistence from the row total.

### 2.3.4. Assessment of Forest Fragmentation

The ArcGIS Landscape Fragmentation tool (LFT v2.0) was used to create the forest fragmentation maps [48]. The input data of this tool, i.e., forest and non-forest data, were derived from the land cover maps. The land cover maps for the years 1976, 1998, and 2014 were reclassified into forest and non-forest classes using the ArcGIS spatial analyst. Scrub land was not included in the forest class (Table 2). Based on the forest and non-forest classes, the LFT v2.0 tool classifies a forest pattern into four main categories: patch, edge, perforated, and core [48]. Edge-width is the distance over which non-forest land cover can degrade forest land covers, although the edge-width varies by species and can range from 50 m to several 100 m. However, 100 m is often used as a general edge-width [48]. Therefore, using a specified edge width of 100 m, the forest fragmented areas were classified in five categories: (i) "core" forest—the inner part of the forest region that is relatively distant from the non-forest boundary; (ii) "patch" forest—small forest area surrounded by non-forested land cover which does not contain any core pixel forests; (iii) "perforated" forest—transition zone boundaries between the core forest and relatively small perforations; (iv) "edge" forest—transition zone boundaries

between the core forest and large non-forest land cover region; and (v) “non-forest”—not pertaining to forest [48,49].

### 2.3.5. Annual Rate of Change of LULC and Forest Fragmentation

The annual rate of change for each class of LULC and an annual fragment creation rate were calculated using the following formula proposed by [50]:

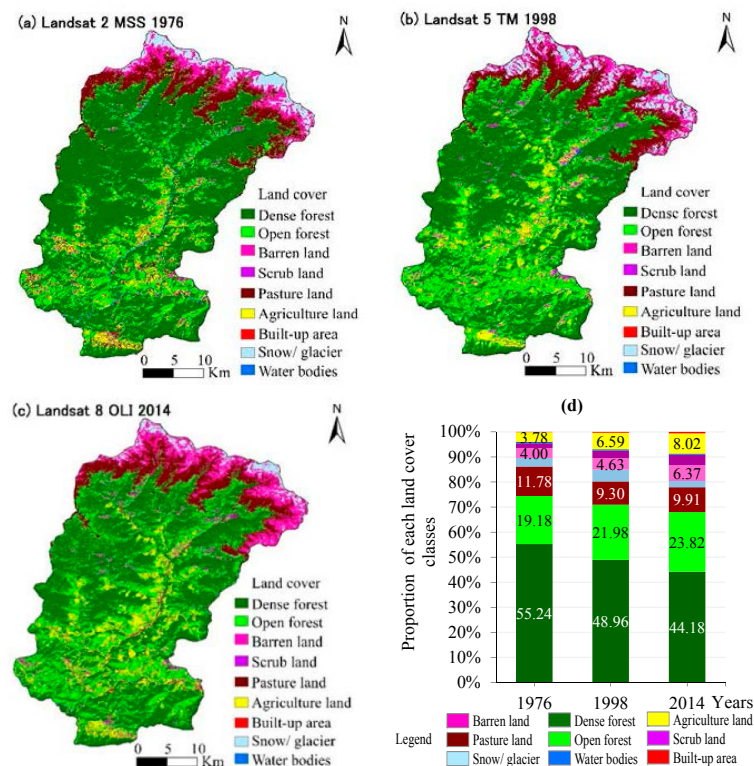
$$r = \left( \frac{1}{t_2 - t_1} \right) \times \ln \left( \frac{A_2}{A_1} \right), \tag{1}$$

where  $r$  is the change for each class per year,  $A_2$  and  $A_1$  are the class areas at the end and the beginning, respectively, for the period being evaluated, and  $t$  is the number of years spanning that period.

## 3. Results

### 3.1. Land Cover Maps and Status

The land cover maps for the years 1976, 1998, and 2014 based on Landsat 2 (MSS), Landsat 5 (TM), and Landsat 8 (OLI) satellite data were prepared with nine land-cover types, namely, dense forest, open forest, pasture land, snow and glacier, barren land, scrub land, agriculture land, water bodies, and built-up area. Figure 3 shows the final output of the supervised classification, which consists of three classified maps of the Rudraprayag district, for 1976, 1998, and 2014 and a comparison in terms of the total area for each land cover category.



**Figure 3.** Land-cover map for the year (a) 1976; (b) 1998; and (c) 2014; and (d) comparison of land use and land cover classes by percentage of the total study area (study area = 936.06 km<sup>2</sup>).

### 3.2. Accuracy Assessment

Table 3 shows the error matrix with the user’s accuracy, producer’s accuracy, and kappa coefficient. The overall accuracy was calculated from the error matrix (Table 3) by dividing the correctly classified

pixel by the total number of the pixels, i.e.,  $(240/267) \times 100 = 89.88\%$ . Therefore, the total accuracy was 89.88% for the 2014 classified map. Furthermore, the Kappa coefficient was calculated for the 2014 classified map at 0.8818 (88.18%).

**Table 3.** Cross-tabulation error matrix of classified vs. reference data for 2014.

Classified Image	Reference Data									
	Dense Forest	Open Forest	Pasture Land	Snow/Glacier	Barren Land	Scrub Land	Water Bodies	Agriculture Land	Built-up Area	Row Totals
Dense forest	28	1								29
Open forest	1	25						1	1	28
Pasture land			26		1	2		1		30
Snow /glacier				30	1					31
Barren land					27		1			28
Scrub land		1	3			26		1	1	33
Water bodies					1		29			30
Agriculture land	1	2	1			1		26	3	34
Built-up area		1						1	23	25
Column totals	30	30	30	30	30	29	30	30	26	267
User’s accuracy	96.55	89.29	86.67	96.77	87.10	81.25	96.67	76.47	92.00	
Producer’s accuracy	93.33	83.33	86.67	100	90.00	89	96.67	86.67	82.14	
Total accuracy						89.88%				
Kappa statistics						88.18%				

### 3.3. Land-Use and Land-Cover (LULC) Change

Table 4 summarizes the results of the land cover, change rate, and annual rate of change in area of each class for the Rudraprayag district. Forest area (dense forest and open forest) was the main land cover in 1976 with 74.42% of the total area of the Rudraprayag district, followed by pasture land (11.78%), barren land (4.00%), agriculture land (3.78%), and scrub land (1.89%). The area of dense forest decreased from 55.24% (1069.51 km<sup>2</sup>) in 1976 to 44.18% (855.39 km<sup>2</sup>) in 2014. On the other hand, open forest increased from 19.18% (371.3 km<sup>2</sup>) in 1976 to 23.82% (461.08 km<sup>2</sup>) in 2014. The area of pasture decreased from 11.78% (227.98 km<sup>2</sup>) in 1976 to 9.91% (191.78 km<sup>2</sup>) in 2014. Agriculture and built-up areas progressively increased from 3.78% and 0.14% in 1976 to 8.02% and 0.62% in 2014, respectively. Barren and scrub land areas also progressively increased from 4.0% and 1.89% in 1976 to 6.37% and 4.12% in 2014, respectively. Due to climatic or seasonal variation, the areas under snow and glacier and water bodies decreased from 3.38% (65.5 km<sup>2</sup>) and 0.61% (11.86 km<sup>2</sup>) in 1976 to 2.51% (48.61 km<sup>2</sup>) and 0.46% (8.94 km<sup>2</sup>) in 2014, respectively.

The overall annual rate of change in the declining phase of forest cover (dense and open forest) was observed at about 0.22% and 0.27% during the 1st period (1976–1998) and 2nd period (1998–2014), respectively. Another declining annual rate of change was observed for pasture land and snow and glacier during the 1st period (1976–1998), while water bodies and snow and glacier were observed to be in decline during the 2nd period (1998–2014). Other land cover classes experienced an expansion at both time intervals.

**Table 4.** Land cover area, percentage, change, and annual rate of change of the Rudraprayag district.

Land-Cover Type	1976		1998		2014		Change (1976–1998)	Change (1998–2014)	Annual Rate of Change (1976–1998)	Annual Rate of Change (1998–2014)
	km <sup>2</sup>	% <sup>a</sup>	km <sup>2</sup>	% <sup>a</sup>	km <sup>2</sup>	% <sup>a</sup>	% <sup>b</sup>	% <sup>b</sup>	% <sup>c</sup>	% <sup>c</sup>
Dense forest	1069.51	55.24	947.96	48.96	855.39	44.18	−6.27	−4.78	−0.55	−0.64
Open forest	371.3	19.18	425.53	21.98	461.08	23.82	2.80	1.83	0.62	0.50
Pasture land	227.98	11.78	180.1	9.30	191.78	9.91	−2.47	0.60	−1.07	0.39
Snow /glacier	65.5	3.38	91.09	4.70	48.61	2.51	1.32	−2.19	1.50	−3.93
Barren land	77.37	4.00	89.58	4.63	123.33	6.37	0.63	1.74	0.67	2.00
Scrub land	36.54	1.89	57.31	2.96	79.70	4.12	1.07	1.15	2.05	2.06
Water bodies	11.86	0.61	10.45	0.54	8.94	0.46	−0.07	−0.08	−0.58	−0.98
Agriculture land	73.22	3.78	127.51	6.59	155.34	8.02	2.80	1.44	2.52	1.23
Built-up area	2.78	0.14	6.53	0.34	11.91	0.62	0.19	0.28	3.88	3.75
Total area	1936.06	100.00	1936.06	100.00	1936.06	100.00				

<sup>a</sup> Percentage of each class out of the total area; <sup>b</sup> Percentage change in the component; <sup>c</sup> Percentage of the annual rate of change in each class.



### 3.4. Land-Use and Land-Cover (LULC) Change Trajectories

Tables 5 and 6 show the conversion of the land cover in the form of a change matrix for the 1st period (1976–1998) and 2nd period (1998–2014). In the 1st period (1976–1998), there was a major conversion from forest cover (dense and open forest) to agriculture land (44.79 km<sup>2</sup>), from forest to scrub land (25.33 km<sup>2</sup>), from forest to barren land (5.86 km<sup>2</sup>), and from forest to built-up area (2.18 km<sup>2</sup>). In the same period, a change from snow and glacier to barren land, from pasture to agriculture land, and from barren land to snow and glacier were also observed. On the other hand, the 2nd period (1998–2014) showed a further major loss of forest cover (dense and open forest), being converted to agriculture land (39.8 km<sup>2</sup>), scrub land (29.95 km<sup>2</sup>), built-up area (4.13 km<sup>2</sup>), barren land (3.51 km<sup>2</sup>), and pasture land (5.13 km<sup>2</sup>). During the same time period, another major change from snow and glacier to barren land was also observed. A few areas were converted to forest in the study area during both periods.

**Table 5.** Land-Use and Land-Cover (LULC) change matrix between 1976 and 1998.

Land-Cover Type (km <sup>2</sup> )	Dense Forest	Open Forest	Pasture Land	Snow/Glacier	Barren Land	Scrub Land	Water Bodies	Agriculture Land	Built-up Area	Total (1998)
Dense forest	<b>928.26</b>	13.35	0.73	0	0.08	1.71	0	3.83	0	948.00
Open forest	130.43	<b>284.7</b>	1.62	0	0.4	3.09	0	5.28	0	425.50
Pasture land	0.48	4.85	<b>150.07</b>	0	19.61	2.45	0.18	2.46	0	180.10
Snow/glacier	0.02	0.55	32.85	<b>38.84</b>	18.83	0	0	0	0	91.09
Barren land	0.42	5.44	16.9	26.16	<b>36.94</b>	1.07	2.23	0.42	0	89.58
Scrub land	3.54	21.79	2.06	0	0.27	<b>21.41</b>	0	8.24	0	57.31
Water bodies	0	0	0	0.5	0.92	0	<b>8.93</b>	0.1	0	10.45
Agriculture land	6.01	38.78	23.56	0	0.32	6.64	0.45	<b>51.75</b>	0	127.50
Built-up area	0.35	1.83	0.19	0	0	0.17	0.07	1.14	<b>2.78</b>	6.53
Total (1976)	1069.51	371.00	227.98	65.50	77.37	36.50	11.86	73.22	2.78	1936.06

Note: The bold letters indicate that there is no change in the LULC over the time period.

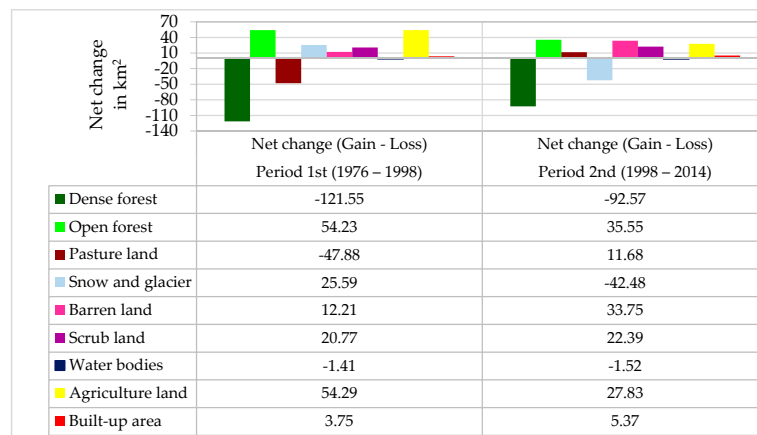
**Table 6.** Land-Use and Land-Cover (LULC) change matrix between 1998 and 2014.

Land-Cover Type (km <sup>2</sup> )	Dense Forest	Open Forest	Pasture Land	Snow/Glacier	Barren Land	Scrub Land	Water Bodies	Agriculture land	Built-up Area	Total (2014)
Dense forest	<b>832.3</b>	17.69	0.52	0	0.35	0.36	0	4.21	0	855.40
Open forest	104.9	<b>336.1</b>	1.15	0	2.16	8.33	0	8.42	0	461.10
Pasture land	0.82	4.31	<b>157</b>	0	23.6	2.72	0.39	3.32	0	191.8
Snow/glacier	0	0	0.93	<b>38.84</b>	8.85	0	0	0	0	48.61
Barren land	0.5	3.01	11.2	52	<b>53.8</b>	0.62	1.68	0.41	0.12	123.30
Scrub land	3.95	26	3.78	0.03	0.03	<b>41.2</b>	0	4.73	0	79.70
Water bodies	0	0	0	0.19	0.49	0.21	<b>7.35</b>	0.2	0.49	8.93
Agriculture land	4.63	35.17	5.75	0	0.32	3.7	0.82	<b>104.42</b>	0.53	155.30
Built-up area	0.92	3.21	0.18	0	0	0.19	0.21	1.8	<b>5.39</b>	11.90
Total (1998)	948.00	425.50	180.10	91.09	90	57.31	10.45	127.50	6.53	1936.06

Note: The bold letters indicate that there is no change in the LULC over the time period.

### 3.5. Gain and Loss of Land-Use and Land-Cover (LULC)

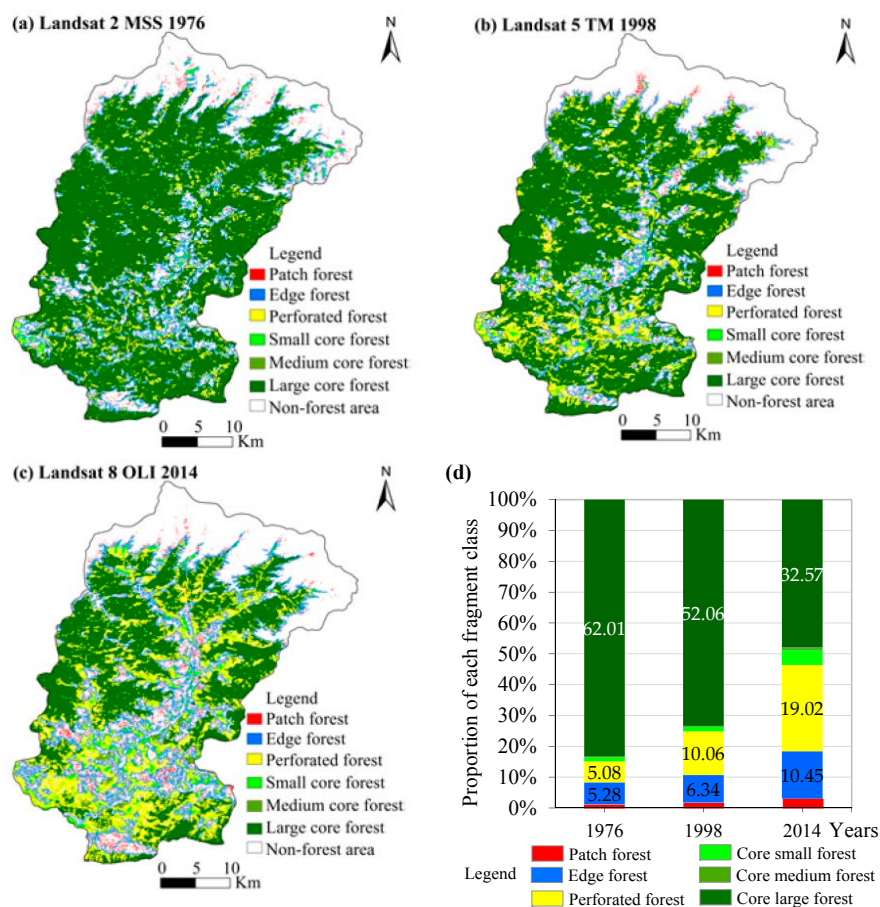
The net change in the form of gains and losses for each class during the 1st period (1976–1998) and the 2nd period (1998–2014) is shown in Figure 4. The highest loss was in the dense forest (121.55 km<sup>2</sup>) during the 1st period, followed by pasture land (47.88 km<sup>2</sup>), and water bodies (1.94 km<sup>2</sup>), while a significant gain was observed in agriculture land (54.29 km<sup>2</sup>), open forest (54.23 km<sup>2</sup>), snow and glacier (25.59 km<sup>2</sup>), scrub land (20.77 km<sup>2</sup>), barren land (12.21 km<sup>2</sup>), built-up area (3.75 km<sup>2</sup>), and water bodies (1.41 km<sup>2</sup>). An overall loss of 67.32 km<sup>2</sup> of forest area (dense and open forest) was observed during the 1st period. On the other hand, the highest loss was observed in dense forest (92.57 km<sup>2</sup>) and snow and glacier (42.48 km<sup>2</sup>), while significant gains were observed in open forest (35.55 km<sup>2</sup>), barren land (33.75 km<sup>2</sup>), agriculture land (27.83 km<sup>2</sup>), scrub land (22.39 km<sup>2</sup>), pasture land (11.68 km<sup>2</sup>), and built-up area (5.37 km<sup>2</sup>) during the 2nd period. An overall loss of 57.03 km<sup>2</sup> of forest area (dense and open forest) was observed during the 2nd period. However, the overall net change was the highest during the 1st period.



**Figure 4.** Net change (i.e., gains minus losses) for each land cover class of the study area for the 1st period (1976–1998) and the 2nd period (1998–2014).

### 3.6. Forest Fragmentation Pattern and Status

The forest fragmentation pattern maps for the years 1976, 1998, and 2014 based on forest and non-forest areas were generated by using LFT v2.0. Forest fragmentation maps with categories such as patch, edge, perforated, small core, medium core, and large core are shown in Figure 5.



**Figure 5.** Maps of the forest fragmentation pattern in the Rudraprayag district for the years (a) 1976; (b) 1998; and (c) 2014; and (d) a comparison of the forest fragment pattern classes by percentage of the total study area (study area = 1936.06 km<sup>2</sup>).

### 3.7. Forest Fragmentation Change

Table 7 summarizes the forest fragmentation change from 1976 to 2014. Forest fragmentation analysis shows a significant decrease in the compact forest area (large core forest) from 1976 to 2014. In 1976, the large core forest was dominant covering 62.01% of the total study area, followed by edge forest (5.28%), perforated forest (5.08%), small core (1.03%), patch forest (0.90%), and medium core (0.12%). Between 1998 and 2014, the large core forest decreased, while medium core, small core, edge, and patch forest continuously increased.

The area of large core forest decreased from 62.01% in 1976 to 32.57% in 2014, showing a component change of 9.95% and 19.49% in the 1st period (1976–1998) and the 2nd period (1998–2014), respectively. The area under patch, edge, perforated, and medium core forest progressively increased from 0.90%, 5.28%, 5.08%, and 0.12% in 1976 to 2.07%, 10.45%, 19.02%, and 0.61% in 2014, respectively, showing a component change of 0.34%, 1.32%, 4.97%, and 0.10% in the 1st period and 0.83%, 4.01%, 8.96%, and 0.38% in the 2nd period, respectively. Small core forest slightly decreased by 1.02% in 1998, and then drastically increased by 3.28% in 2014, showing a decreased change of 0.01% in the 1st period and an increased change of 2.25% in the 2nd period. An overall decrease in forest area from 3.47% in the 1st period to 2.94% in the 2nd period was observed, while an overall increase in non-forest area from 3.47% in the 1st period to 2.94% in the 2nd period was observed.

A declining annual rate of change for large core forest was observed at about 0.79% and 2.93% in the 1st period (1976–1998) and the 2nd period (1998–2014), respectively. Other increasing annual rates of change were observed in patch, edge, perforated, and medium core forests in the 1st period and the 2nd period, although small core forest decreased in the 1st period, and then increased again in the 2nd period. A declining overall annual rate of change for the total forest cover was observed at 0.22% and 0.27% for the 1st period and the 2nd period, respectively. As a result, the overall annual rate of change in non-forest increased from 0.58% in the 1st period to 0.60% in the 2nd period.

**Table 7.** Forest fragmentation in area, percentage, and annual rate of change of each class.

Fragmentation Classes	1976		1998		2014		Change (1976–1998)	Change (1998–2014)	Annual Rate of Change (1976–1998)	Annual Rate of Change (1998–2014)
	km <sup>2</sup>	% <sup>a</sup>	km <sup>2</sup>	% <sup>a</sup>	km <sup>2</sup>	% <sup>a</sup>	% <sup>b</sup>	% <sup>b</sup>	% <sup>c</sup>	% <sup>c</sup>
Patch	17.46	0.90	23.97	1.24	40.13	2.07	0.34	0.83	1.44	3.22
Edge	102.13	5.28	122.76	6.34	202.24	10.45	1.32	4.10	0.83	3.12
Perforated	98.32	5.08	194.69	10.06	368.32	19.02	4.97	8.96	3.11	3.98
Small core	19.91	1.03	19.74	1.02	63.41	3.28	−0.01	2.25	−0.04	7.29
Medium core	2.39	0.12	4.37	0.23	11.76	0.61	0.10	0.38	2.73	6.17
Large core	1200.57	62.01	1007.93	52.06	630.57	32.57	−9.95	−19.49	−0.79	−2.93
Total forest	1440.81	74.41	1373.49	70.94	1316.45	68.00	−3.47	−2.94	−0.22	−0.27
Total non-forest	495.25	25.58	562.57	29.06	619.61	32.00	3.47	2.94	0.58	0.60

<sup>a</sup> Percentage of each class out of the total study area (study area = 1936.06 km<sup>2</sup>); <sup>b</sup> Percentage change in the component; <sup>c</sup> Percentage of the annual rate of change in each class.

## 4. Discussion

### 4.1. Land-Use and Land-Cover (LULC) Change

The results show that significant change in land cover occurred in the Rudraprayag district between 1976 and 2014. The forest was the main land cover in the study area. The overall trend shows that the forest area had decreased and the non-forest area had increased in the Rudraprayag district; the overall loss of the forest was 122.35 km<sup>2</sup> from 1976 to 2014. This result agrees with other studies conducted in the Himalayan region of India [51,52]. The general trends of change showed an increase in agriculture, barren land, built-up area, and scrub land. The local community depends highly on agricultural activity, which would be further expected with a decline in forest cover. Other studies also found similar causes of forest decline in the Hindu Kush Himalaya (HKH) region [49,52–54]. Although natural drivers could also play a role in land cover change, the scope of this study mainly focused on anthropogenic activities. However, the loss of forest cover is particularly serious in mountain regions such as the Himalayas, where the landscape has a complex and fragile environment with

rough terrain, unique topography, and vulnerability to numerous types of natural hazards. Therefore, the impact of natural drivers such as hazards on LULC changes could be further analysed for a more in-depth understanding.

The results displayed in Figure 3 clearly show that the majority of the agricultural activities and built-up areas are distributed along the roads and river channels at lower and middle altitudes. The significant increase in agricultural land and built-up areas contributed to the modification of the forest cover, which indicates the possibility of decrease in the forest cover in the near future. The continuous increase in the area of barren and scrub land contributed to wasteland land or non-forest land in the study area, which could lead to a huge loss in topsoil and further affect the health of the nearby forests. Significant changes in barren land at higher altitudes may also further contribute to an increase in mass movement and soil erosion [13,54,55] during the heavy rainfall season in the Rudraprayag district. A drastic increase in barren land at higher altitudes might also be converted to large run-off during the rainfall season in the steep and narrow channels of the Mandakini valley, which indicates the possibility of increased flood activity in the downstream area [38]. A continued increase in scrub land indicates that the forest land is degraded at a significant rate. Some of the forest, pasture, agriculture, and built-up areas was lost during the heavy flood disaster that took place on the 16th and 17th of June 2013 [10]. The area under water bodies and snow/glaciers also showed a decreasing trend. This could be due to the climatic or seasonal variation (temporal cover of snow) over the time period.

#### 4.2. Forest Fragmentation

Forest fragmentation increased because the large core forest was diminished at a significant rate. A continued decrease in the large core forest and an increase in the perforated forest indicates an increase in forest fragmentation. The increase of patch, small core, and medium core forests is indicative of the continuing disconnect of the forest from the large core forest area. The patch forest increased throughout the study period, completely degraded by the edge effect [48]. The result showed that significant change had occurred in the large core forest due to expansion of the non-forest area. The conversion of vegetation cover to non-forest area by human activity increased forest fragmentation, posing a great threat to biodiversity [32], although the increase in forest fragmentation is related to both natural and anthropogenic drivers [56]. The result of this study suggests that expansion in agricultural and built-up areas is the major driver for forest fragmentation, where topography has played a significant role in the study area. At the same time the study area is highly vulnerable to natural hazards such as heavy floods, landslides, and forest fires. It is also vulnerable to modification of the forest cover and further increase in forest fragmentation, which would further deteriorate the overall forest landscape. Fragmentation and the loss of forest due to the conversion to agriculture and other land use indicate that the available habitat is shrinking [57]. Therefore, the overall changes in forest fragmentation are likely to have a negative impact on the continuity and quantity of the forest land area [58]. The trends of forest fragmentation together with the land cover change have serious impacts on biodiversity, habitat loss, and ecosystem services in this region. Moreover, the pattern of forest fragmentation may vary at a different scale and depend on the spatial scale or resolution of the landscape.

In addition, the upper part of the study area is a protected area classified as a wildlife sanctuary. However, due to the disturbance of continuous human activities such as road development, the upward movement of people to higher elevations for agricultural activity, hydro power projects, and the increase of the built-up area within the sanctuary, the wildlife sanctuary is seriously threatened, which may change the continuity, quantity, and connectivity of the sanctuary and reduce the forest land area as a whole.

## 5. Conclusions

This study assessed changes in land-use/land-cover and forest fragmentation in the Rudraprayag district, Garhwal Himalaya, India. The study area experienced a decrease in forest cover and an increase in agricultural land, barren land, scrub land, and built-up area between 1976 and 2014. Forest cover is likely to decrease further due to commercial exploitation, expansion of agricultural land, and human settlements. The results of the forest fragmentation analysis showed that the increase in the non-forest and perforated areas is the main cause of the decline of the large core forest. The study indicates that expansion in agriculture and the built-up area are the major drivers of forest cover change and fragmentation. The study results also suggested that forest fragmentation coupled with land cover changes may lead to forest degradation with implications for biodiversity, habitat ecosystem services, and people's livelihoods.

This study contributes to the understanding of the pattern of forest fragmentation and influence on the forest fragmentation pattern caused by land cover changes. Finding the areas where changes have occurred will help to fill the gap necessary to lead to prioritization in forest management, conservation, and biodiversity policies. This study will also fill an information gap regarding area classification, which has been heretofore poorly researched with poor data availability and will improve information at the regional and national level. Moreover, improved understanding of the drivers can help reveal the dynamics of LULC change and the forest fragmentation process of the Himalaya region at different scales.

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