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Studies on land-use/land-cover change and forest fragmentation with the implications for landslide occurrence in the Garhwal Himalaya, India

（インド，ガルワール・ヒマラヤにおける土地利用・土地被覆変化および地すべり発生と関連した森林の分断化に関する研究）

Amit Kumar BATAR

Long abstract

1. Background and purpose

Mountain ecosystems are continuously experiencing extensive land-use and land-cover (LULC) changes, due to natural and anthropogenic processes (Klein, 2001; Agarwal et al., 2002; Liu et al., 2003). These changes have not only led to modifications in forest ecosystem, but also to the conversion of land cover, with serious environmental implications (Hansen et al., 2001; Lung and Schaab, 2010). Changes in forest cover due can result in a variety of negative environmental consequences (Malek et al., 2015). For example, deforestation can affect the vegetation composition, forest fragmentation and water balance and can increase erosion rates (Glade, 2003; Ghimire et al., 2013). This leads to increased environmental risks, such as landslide occurrence, and can have strong impacts on the human well-being on a larger scale (Tasser et al., 2003; Papathoma-Kohle and Glade, 2013).

The Garhwal Himalaya situated in the western part of the Uttarakhand Himalaya is one of the hotspots of biodiversity (Chandra et al., 2010). Extensive deforestation and forest fragmentation in the Garhwal Himalaya have caused serious environmental degradation (Ives and Messerli, 1989; Roy and Tomar, 2000), which is a critical issue in the Uttarakhand Himalaya and the basic reason for biodiversity loss (Sharma and Roy, 2007). During the three decades from 1967 to 1997, the forest cover in the Garhwal Himalaya has altered drastically due to increasing population pressure, increased agricultural activities and extraction of natural resources (Wakeel et al., 2005). Not surprisingly, the fragile nature of the Garhwal Himalaya, coupled with increasing human activity, poses a serious threat to the natural landscape, especially for the forest ecosystem. Therefore, forest cover has been under pressure over the past few decades in the region.

The present study focuses on the Rudraprayag district of the Uttarakhand state, situated in the Garhwal Himalaya (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 utilized for hydroelectric projects (62.93 hectares), roads (187.52 hectares), and other activities (299.08 hectares) (Srivastava, 2017). On the other hand, natural hazards such as floods, landslides, and forest fires have increased over the last few decades and may lead to further deterioration of the forest landscape in the study area (Gupta et al., 2013).

The present study area is believed to have experienced extensive deforestation and forest fragmentation due to anthropogenic and natural drivers, but the data and documentation detailing this transformation are limited. Previous studies have examined forest fragmentation and landslide occurrence separately, and forest fragmentation has been believed to cause landslides. However, there is no study to understand the correlation between forest fragmentation and landslide occurrence. Therefore, understanding the link between forest fragmentation and landslide occurrence is important in the mountains such as the Himalaya.

2. Study area

The study area, i.e., the Rudraprayag district is a part of a vulnerable zone in the Garhwal Himalaya of the Uttarakhand state of India. It extends from 30° 12’ 58” N to 30° 48’ 47” N latitude and 78° 50’ 07” E to 79° 22’ 34” E longitude. The geographical area of the Rudraprayag district is around 1936.06 km^2. The district is bounded by Uttarkashi in the north, Chamoli in the east, Tehri Garhwal in the west and Pauri Garhwal in the south. The altitude varies from 546 to 6840 m above sea level (Figure 1). Mandakini is the major river of the Rudraprayag district, with a catchment area of 1641.64 km^2, and it has many tributaries. It originates from the Chorabari glacier (3895 m) (Figure 1). The mean air temperature in winter (December to February) varies from 8.32 to 13.15°C and that in summer (May to July) from 27.75 to 32.54°C. The overall average rainfall in the district is 1485 mm. Most of the rainfall (70–80% of annual precipitation) occurs from June to September. According to the 1991, 2001 and 2011 census, the Rudraprayag district had populations of 198,672 persons, 227,439 persons, and 236,857 persons, respectively, and its population growth rate over the decades of 1991 to 2001 and 2001 to 2011 was 14.4% and 4.14%, respectively.

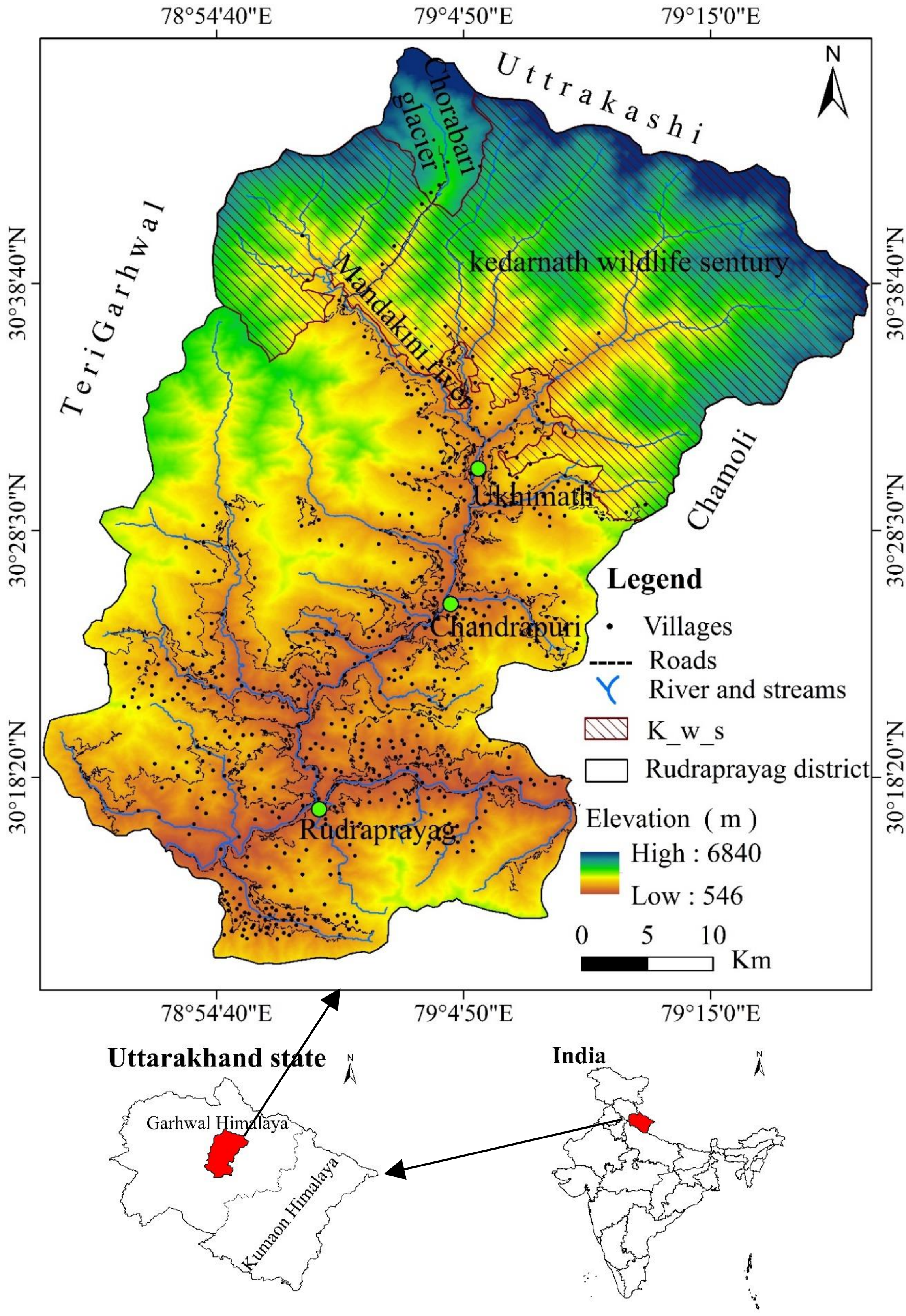

Figure 1. Location and extent of the Rudraprayag district, Uttarakhand, India.

3. Research objectives

The objectives of this study are:

1. To understand the spatial-temporal trends in land-use and land-cover (LULC) change from 1976 to 2014,
2. To evaluate the forest fragmentation due to the LULC change from 1976 to 2014,
3. To establish the relationship between forest fragmentation and the occurrence of landslides, and,
4. To identify the potential change of forest fragmentation with implication for landslide occurrence.

4. Research methodology

4.1 Data base

Remote sensing satellite data are suitable for poorly researched area with less data availability, and can provide detailed assessment. This study, therefore, used satellite remote sensing and geographic information system (GIS) to create a spatial inventory of land-use and land-cover (LULC), and to examine forest fragmentation and landslides in the Garhwal Himalaya. Then, an evaluation on how potential change of forest fragmentation would result in changes of landslide susceptibility and vice versa.

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 land cover. A cross-tabulation detection method in a GIS module was used to detect land cover changes during the 1st period (1976–1998) and the 2nd period (1998–2014). The landscape fragmentation tool LFT v2.0 was used to prepare a forest fragmentation map and to analyze the patterns and changes of the forest fragmentation during the 1st period (1976–1998) and the 2nd period (1998–2014). Using the weight-of-evidence (WOE) model, the relationship between the forest fragmentation and the landslide occurrence was established to identify the potential change of forest fragmentation and landslide susceptibility in the study area. Table 1 summarizes the details of the satellite data used in this study.

Table 1. Details of satellite data used in this study

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

* OLI: Operational Land Imager, **USGS: United States Geological Survey

4.2 Methods

Figure 2 shows the overall methodological framework. Land-cover maps were derived based on Landsat images of 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 LULC, using the cross-tabulation module detection method in Arc GIS and annual rate of change for each class of LULC. Regarding forest fragmentation mapping, 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). In order to apply WOE method, past patch forests and past landslides were considered as an evidence for forest fragmentation probability and landslide susceptibility maps, respectively. Patch forests were extracted from forest fragmentation map from 1976 to 2014 using analyst tools in ArcGIS. Landslide polygon inventory data were derived from two sources. First, landslide point locations were extracted as a reference based on ancillary information, i.e., open data sources from BHUVAN (Indian earth observation visualization) developed by ISRO, which provides location and distribution of landslides. Second, we used Google Earth® archive to extract landslide polygons. Thus, taking the advantage of all these free access open data sources with ground truth investigation, we prepared landslide inventory from 2011 to 2013. Afterward, using the WOE model, forest fragmentation probability and landslide susceptibility maps were derived. Finally, to identify the potential change of area, forest fragmentation probability in zone of landslide susceptibility were analysed using the reclassify method, raster calculator and zonal statistics in ArcGIS.

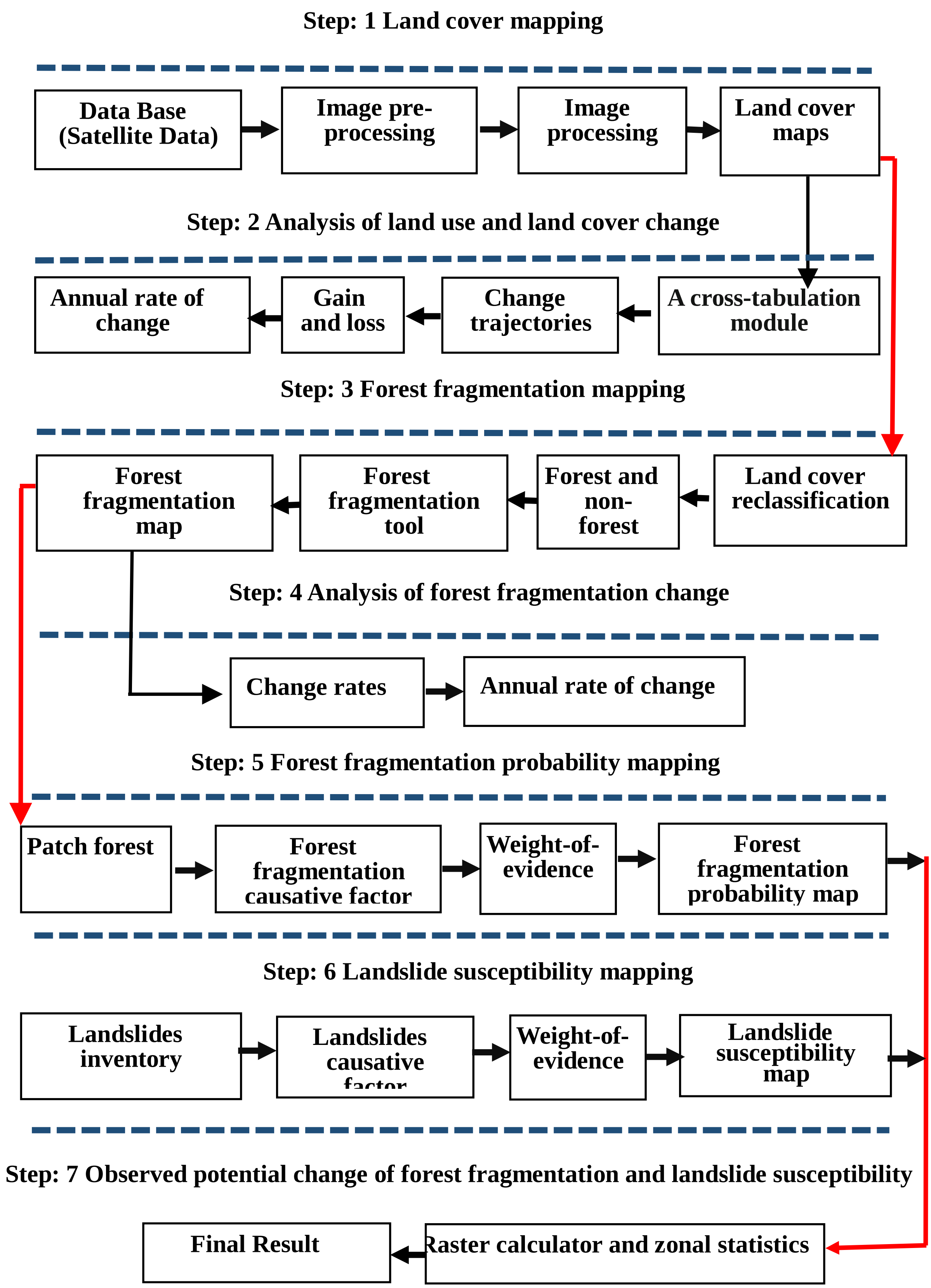

Figure 2. Overall flow chart for study area

5. Results and implications

The results of this research showed that the overall annual rate of decreasing change in the forest cover was 0.22% and 0.27% in the 1st period (1976–1998) and the 2nd period (1998–2014), respectively. Non-forest area, i.e., agriculture land, built-up area, scrub land and barren land, had increased in both periods of time. An increase in the areas of scrub land and barren land also contributed to the accumulation of wasteland in the area. The forest fragmentation analysis showed that a large core forest has decreased throughout the study period. The results of forest fragmentation showed that the increased non-forest and perforated areas were the main cause of the decline in the large core forest. The total area of the forest patches also increased during the study period (1976–2014).

The result of the weighted contrast value showed that the forest fragmentation probability was primarily observed near built-up area (less than 500 m), agriculture land (less than 500 m), roads (less than 1000 m), and streams (less than 500 m) with very gentle and gentle slopes (less than 25 degree) at the lower to middle altitude zone (less than 2000 m). The probability map of the forest fragmentation showed that medium to high probabilities are primarily concentrated near the roads and agriculture land area on very gentle to gentle slopes at the lower altitudes. The probability map of the forest fragmentation also showed that the role of higher altitude zone (more than 2000 m) is less significant, and that factors such as distance to roads, distance to agriculture land, distance to built-up area and slopes are more important. The analysis of the forest fragmentation probability suggested that the area would experience more forest fragmentation in the future due to the increased areas of patch forest and perforated forest, meaning the increase in the forest degradation.

Regarding the landslide susceptibility, the result clearly showed that medium to high landslide susceptibilities had occurred mainly in the non-forest area. The result of the weighted contrast value showed that most of the medium to high landslide susceptibilities are primarily concentrated in the areas adjacent to higher altitudes, steep slopes, and the non-forest area such as scrub land, barren land, and pasture land.

Regarding potential change in the forest fragmentation probability and the landslide susceptibility, the result demonstrated that the forest fragmentation probability was observed in the areas where landslides are less likely to occur. The probability of landslides would not give a major influence on forest fragmentation and vice versa, which was suggested for the first time by the approach with the combination of both forest fragmentation and landslide occurrence.

This study contributes to the understanding of the spatio-temporal trends in LULC change, pattern of forest fragmentation, changes of the forest fragmentation pattern caused by LULC change as well as potential change of forest fragmentation in the zone of landslide susceptibility and vice versa. 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 poorly researched with poor data availability heretofore and, will improve information at the regional and national levels.