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Characterizing fragmentation trends of the Himalayan forests in the Kumaon region of Uttarakhand, India

Anusheema Chakraborty [a,*], Aniruddha Ghosh [b], Kamna Sachdeva [a], P.K. Joshi [c]

[a] Department of Natural Resources, TERI University, New Delhi 110070, India
[b] Department of Environmental Science and Policy, University of California, Davis, CA 95616, USA
[c] School of Environmental Sciences, Jawaharlal Nehru University, New Delhi 110067, India

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ABSTRACT

Forest fragmentation is a major conservation issue, which includes interdependent components of forest loss and changes in their spatial patterns. Over the years, the Himalayan forests have experienced major changes, but data and documentation on patterns and causes of forest fragmentation are limited. In this study, we analyzed temporal changes (1990–2014) of forest loss and fragmentation using Landsat imageries in the Kumaon division of Uttarakhand state, India. To assess mechanisms causing forest fragmentation, we investigated changes in following quantitative parameters describing forest fragmentation: (i) forest area density (P_f), (ii) overall forest connectivity (P_{ff}), (iii) anthropogenic fragmentation (P_{fa}), and (iv) natural fragmentation (P_{fn}). We found that this region is undergoing intensive forest fragmentation, shifting from forest-dominated landscapes to fragmented forests intermixed with agricultural lands and urban settlements. Overall, intact forest patches decreased between 1990 and 2009 (1442 km^2), followed by a small gain from 2009 to 2014 (260 km^2). In lower altitudes, anthropogenic activities caused fragmentation; while in higher altitudes, fragmentation can be attributed to natural causes. All districts within the region show a decreasing trend of forest cover area, with the highest rate of forest cover loss for the low-lying district of Udham Singh Nagar and the lowest rate for the high-lying district of Bageshwar. This trend can be associated with increasing population density in low-lying districts than high-lying districts. Our results emphasize on delineating spatial trends of forest loss and fragmentation to support the identification of conservation sites. The findings can further help in developing forest policies for maintaining local livelihood options in the Himalayan region.

1. Introduction

Humans have ascertained their presence by changing naturally occurring landscapes and management practices that have transformed large proportions of the Earth's land surface (Foley et al., 2005). Although, forest patches can naturally occur as a part of the process of forest expansion or in case of forest succession over grasslands (Matte et al., 2015); however, in the recent years, anthropogenic factors such as clearing, burning, logging, along with intensified agricultural practices and expanding urban centres, have resulted in extensive forest loss and fragmentation all across the globe (Haddad et al., 2015).

Forest loss and fragmentation are the primary causes of ecosystem degradation worldwide (Newman et al., 2014). Forest fragmentation is a progressive continuous process which reduces intact forest cover areas, increases forest edges and isolates remaining patches in a forested landscape (Carranza et al., 2015). Fragmentation adversely impacts the supply and flow of ecosystem services (Uddin et al., 2015), modifies the ecosystem structure and functioning (Rocha-Santos et al., 2016), and greatly influences the native biodiversity (Gibson et al., 2013), by altering their optimal range of preferred habitats (van Langevelde, 2015). Furthermore, forest fragmentation affects essential ecosystem processes such as carbon and water balance (Dantas de Paula et al., 2015), which leads to increased variation of microclimatic changes in forest edges and surrounding interior forest patches (Li et al., 2010). Such changes around the forest edges modify the size of core habitats and facilitate the establishment of invasive alien species towards interior forest fragments (Reddy et al., 2013). Globally, around 70% of the forest cover is within 1 km of the forest's edge, which is either indirectly or directly subjected to the degrading effects of fragmentation (Haddad et al., 2015). Well-connected forest landscapes can enhance population viability for many species (Beier and Noss, 1998). Therefore, identification of the fragmenting landscapes and the underlying processes causing fragmentation, along with their regular monitoring to improve ecological connectivity between natural forests patches is very crucial. By categorising the processes behind forest fragmentation, either caused by natural disturbances (naturally occurring land cover types) or anthropogenic disturbances (artificially created land use types), it can

* Corresponding author.
E-mail address: anusheema@gmail.com (A. Chakraborty).

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help in prioritizing forest management practices. The forest areas experiencing fragmentation due to anthropogenic activities are susceptible to enhanced fragmentation than forests fragmented by natural causes (Li et al., 2010). It, therefore, becomes imperative to investigate the causes of forest fragmentation as it will provide crucial inputs for forest management and land-use policies.

Over the span of twelve years (2000 − 2012), the total global forest area has witnessed a net loss of about 1.71 million km^2 (3.2% of all forest area), while a net loss of about 3.76 million km^2 (9.9%) of interior forest area has been estimated (Riitters et al., 2015). Especially in the tropics, the extent of forest loss and fragmentation has affected many naturally occurring forests (Aide et al., 2012; Carranza et al., 2015; Tewari et al., 2014). Studies to separate forest fragmentation into natural and anthropogenic components has been attempted at global scale (Riitters et al., 2002; Wade et al., 2003), regional scale (Dong et al., 2014) and national scale for countries including, China and the USA (Li et al., 2010). India has suffered a net loss of total forest area of up to 243,447 km^2 (28% of total forest area) over the last eight (1930–2013) decades (Reddy et al., 2015). Scientific research community working on forests in India has primarily focused on studying spatial patterns of forest and non-forest areas, by delineating forest areas into categories such as high, moderate, low or intact areas based on forest fragmentation index (Roy et al., 2013), and using landscape indices such as patch size, edge density, and number of patches (Reddy et al., 2013). However, separation of forest fragmentation into anthropogenic and natural components has not been attempted so far. Up till now, despite the importance of systematic analysis of human versus natural sources of forest fragmentation, it has received relatively little attention in the Indian context.

Regardless of the alarming trend of deforestation in the Indian Himalayan region (Mishra and Chaudhuri, 2015), quantitative analysis of the potential impacts are limited. The conflicting management practices of conservation and unbridled utilization of surrounding forests and forest-based resources are identified as major hurdles in achieving socio-economic development and sustainable flow of ecological resources in this region (Nautiyal, 2011). Given that the Himalayan forests have shown a great degree of variation with past legacies of local forest management practices, changes over recent decades has been extremely drastic, primarily driven by human activities (Arya and Ram, 2011). Such changes in forested areas are resulting in severe ecological deterioration (Pandit et al., 2006). The forests in the central Himalayan region are highly fragmented (Rao and Pant, 2001; Rathore et al., 1997; Wakeel et al., 2005), as compared to the north-western and eastern Himalayan region (Reddy et al., 2013). Regional localized studies also highlight central Himalayan region witnessing an increase in fragmented forest areas over the years (Munsi et al., 2010; Sharma et al., 2008; Sharma and Roy, 2007).

In the light of consideration of the current state of affairs in the central Himalayan region, the study focuses on forest fragmentation mechanisms and categorisation of their subsequent causes as either natural or anthropogenic components in the Kumaon division of the Uttarakhand state, India. The specific objectives of the study are to: (i) assess changes in the spatial extents and configuration of forests by identifying regions where deforestation has occurred, (ii) characterize the patterns of forest fragmentation for four time periods (1990, 1999, 2009 and 2014) using Riitters' fragmentation model, and (iii) quantify anthropogenic and natural components of forest fragmentation over the years. Furthermore, the study addresses the altitudinal variation of temporal patterns of forest fragmentation to facilitate forest conservation and land use management practices in this region.

2. Study area

The Kumaon division in the state of Uttarakhand falls in the central Himalayan region and has a total area of 20,397 km^2 (Fig. 1). The study area is mostly mountainous and consists of a forest-dominated landscape. This region shows great variation in elevation, climate and vegetation types. It is bounded on the north by China, on the east by Nepal, on the south by the state of Uttar Pradesh, and on the west by the Garhwal division. Due to the steep altitudinal gradient from south to north, there is significant diversity in the natural vegetation of this region (Singh and Mal, 2014).

The Kumaon division consists of six (6) districts: Almora, Bageshwar, Champawat, Nainital, Pithoragarh, and Udham Singh Nagar (Fig. 2). All districts have witnessed an increasing decadal population growth (2001 − 2011), except for Almora (Census, 2011). The likely cause could be increasing out-migration from Almora. The population growth is more in the low-lying districts and comparatively less in the high-lying districts. The relationship between geographical area and population density shows Pithoragarh (68 persons/km^2) with lowest populated density, while Udham Singh Nagar has highest population density (649 persons/km^2), followed by Nainital district (225 persons/km^2).

The forests in the Himalayan region in their current state are highly disturbed; although, forests in the Himalayan hills were mostly 'a no man's land' in the olden times. The first inkling with regard to utilization of forests was perhaps by G. W. Traill's 1823 revenue settlement, popularly known as the '*assi saal bandobast*' (80 years' settlement), where villagers could exercise the rights of pasture and wood extraction on forests and wastelands (Negi et al., 1997). During the British colonial period (1815– 1947) in India, uncontrolled timber extractions of Sal (*Shorea robusta*) were attempted in the more accessible forested areas. The historical plantation of pine trees (*Pinus* spp.) to commercially extract timber for a continued period in the 1900s, has further degraded the forest structure and composition in the region (Schreier et al., 1994). For a major portion of the Himalayan mountain system, rural communities actively indulge in collection of leaf litter as manure and lopping of branches for fuelwood, along with annual ground burning in the pine forests to allow good fodder growth (Rao and Pant, 2001). The majority of local communities in these temperate and subtemperate hilly regions of Himalaya operate mixed crop-livestock farming systems (Tulachan and Neupane, 1999). Most households have different species of livestock, which are conventionally fed through grazing on depleting natural ranges of forests (Biswas et al., 1994). The uncontrolled grazing by the agricultural livestock removes regenerating seedlings and saplings, mostly through browsing and trampling, and consequently reduces the natural regeneration capacity of the forests (Nautiyal et al., 2004).

Thus, the degraded status of the Himalayan forests is the result of forest utilization practices from traditional usage by local communities and government legislations. Therefore, for implementing any forest conservation and planning initiative in the Himalayan region, it is essential to plunge deeper into the historical facts from which forest management has evolved over the past centuries.

3. Materials and methods

3.1. Data source and image classification

We used Landsat images from the year 1990, 1999, 2009 and 2013–2014 (henceforth, written as 2014) to generate corresponding annual land use land cover (LULC) maps for Kumaon division. For each year mentioned above, two seasonal (pre-monsoon from February to March and post-monsoon from October to November) cloud-free Landsat images were used to create the annual map. Seasonal images improved the separability of various vegetation types due to changes in phenology. The details of the Landsat images used for the study are provided in the supplementary material (1).

The Himalayan region is often considered inconsistent with different mapping efforts (Uddin et al., 2015). However, we believe consistency in land classification systems can be achieved only with similar desired objectives of any study and characteristics of input data used, which could limit comparability between different regions. Originally, we