Between socio-economic drivers and policy response: spatial and temporal patterns of tree cover change in Nepal

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Despite the local and global importance of forests, deforestation driven by various socio-economic and biophysical factors continues in many countries. In Nepal, in response to massive deforestation, the community forestry program has been implemented to reduce deforestation and support livelihoods. After four decades of its inception, the effectiveness of this program on forest cover change remains mostly unknown. This study analyses the spatial and temporal patterns of tree cover change along with a few socio-economic drivers of tree cover change to examine the effectiveness of the community forestry program for conserving forests or in reducing deforestation. We also investigate the socio-economic factors and policy responses as manifested through the community forestry program responsible for the tree cover change at the district level. The total tree cover area in the year 2000 in Nepal was ~ 4,746,000 hectares, and our analysis reveals that between 2001 and 2016, Nepal has lost ~46,000 ha and gained ~12,300 ha of areas covered by trees with a substantial spatial and temporal variations. After accounting socio-economic drivers of forest cover change, our analysis showed that districts with the larger number of community forests had a minimum loss in tree cover, while districts with higher proportion of vegetation covered by community forests had a maximum gain in tree cover. This indicates a positive contribution of the community forestry program to reducing deforestation and increasing tree cover.

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Abstract

Despite the local and global importance of forests, deforestation driven by various socio-economic and biophysical factors continues in many countries. In Nepal, in response to massive deforestation, the community forestry program has been implemented to reduce deforestation and support livelihoods. After four decades of its inception, the effectiveness of this program on forest cover change remains mostly unknown. This study analyses the spatial and temporal patterns of tree cover change along with a few socio-economic drivers of tree cover change to examine the effectiveness of the community forestry program for conserving forests or in reducing deforestation. We also investigate the socio-economic factors and policy responses as manifested through the community forestry program responsible for the tree cover change at the district level. The total tree cover area in the year 2000 in Nepal was ~ 4,746,000 hectares, and our analysis reveals that between 2001 and 2016, Nepal has lost ~46,000 ha and gained ~12,300 ha of areas covered by trees with a substantial spatial and temporal variations. After accounting socio-economic drivers of forest cover change, our analysis showed that districts with the larger number of community forests had a minimum loss in tree cover, while districts with higher proportion of vegetation covered by community forests had a maximum gain in tree cover. This indicates a positive contribution of the community forestry program to reducing deforestation and increasing tree cover.

Introduction

Forests play multiple roles in climate regulation, protection from extreme events, water filtration, carbon sequestration, and biodiversity habitat apart from providing provisioning ecosystem services such as food, timber, and medicines (Lambrechts et al., 2009; Anderegg et al., 2013).

Forests regulate regional and global climate through evapotranspiration, which in turn affects the precipitation regime and the water cycle (Chagnon and Bras, 2005). About 45% of carbon found in terrestrial ecosystems is stored in forests, and forests sequester more than 25% of annual anthropogenic carbon emissions from the atmosphere (Pan et al., 2011). Forests, with the majority of the world's terrestrial species of plants, animals, and microorganisms, are also one of the richest biological areas on Earth (Lindenmayer et al., 2000). Furthermore, about 1.3 billion people, primarily in developing countries, rely on forests for their subsistence livelihoods and a significant part of cash income (Wasiq and Ahmad, 2004).

Despite the important and critical role forests' play in maintaining essential functions of our planet and in human welfare, the process of converting forested land to other land uses such as cropland, pasture, mining, and urban areas is persistent (Keenan et al., 2015). Although the rate of deforestation has slowed down in recent years, it is still alarmingly high (FAO, 2010). About 13 million hectares (ha) of forests were lost annually from 2010 to 2015 at the global scale, and the extent of forest loss is higher in tropical countries (Hansen et al., 2013; FAO, 2015), where biological diversity as well as reliance on forests for subsistence level livelihoods, are the highest. Deforestation has caused degradation of quality and amount of ecosystem services around the world reducing biodiversity, undermining the flood retention capacity and soil stability as well as producing negative impacts on local livelihoods and regional economies (Wagner et al., 2015). The global deforestation is causing a significant amount of carbon emission (8-10% of total) contributing to global climate change and environmental degradation affecting human wellbeing (Le Quéré, 2016; Lambrechts et al., 2009). Therefore, efforts for accurate monitoring of forests at different scales have received particular attention in recent years (FAO, 2015; Shimada et al., 2014).

Forest cover change and its drivers

Deforestation is influenced by a wide range of factors such as agricultural expansion, insecure land tenure, international markets, colonization, infrastructure and road building, urbanization, mining, grazing, uncontrolled fire, political unrest, fuelwood extraction, and timber logging (Angelsen and Kaimowitz, 1999; Geist and Lambin, 2002; Rudel et al., 2009; Ferretti-Gallon and Busch, 2014). Various demographic, socioeconomic, biophysical, political, cultural, and technological drivers, acting individually or synergistically, stimulate the anthropogenic activities of the agents (i.e., small farmers, ranchers, plantations, loggers) causing deforestation or forest degradation (Angelsen and Kaimowitz, 1999; Kissinger et al., 2012). For example, increase in human population requires more land for food, space, and other commodities resulting in the conversion of forest areas into agriculture or other land uses (Kanninen et al., 2007). A synthesis of more than 140 economic models analyzing the causes of tropical deforestation showed that more roads, higher agricultural prices, lower wages and a shortage of off-farm employment lead to more deforestation, while the effect of technical change, agricultural input prices, household income levels and tenure security on deforestation is unknown, and the role of macroeconomic factors such as population growth, poverty reduction, national income, economic growth, and foreign debt on deforestation is ambiguous (Angelsen and Kaimowitz, 1999). However, the drivers of deforestation vary across geographical locations and historical contexts; over the last 50 years, the agents of deforestation have changed (Laurance and Balmford, 2013). Historically, forests were cleared for crops or livestock, and small farmers were considered as a major driver of deforestation. Conversely, after economic globalization since 1990, forests have been cleared for massive agricultural expansion, road building, wood extraction, and infrastructure development (Rudel et al., 2009; Laurance and Balmford, 2013). A large-scale agriculture expansion for cattle ranching, soybean and palm oil production, and timber logging is causing deforestation in many countries such as Brazil and Indonesia (Brown et al., 2005; Morton et al., 2006; Arima et al., 2011).

Various approaches were adopted globally such as the establishment of protected areas, forest restoration, protection and afforestation activities, and provision of economic incentives to reduce and prevent deforestation or forest degradation (Brooks et al., 2012; Le Saout et al., 2013). Around 15.4% of the world's land area (Deguignet et al., 2014) and about 24% of the total area of Nepal are covered by protected areas (GoN, 2014b), which have contributed to reducing deforestation and conserving forests. As an alternative to strict protection, as practiced in protected areas, community-based conservation initiatives such as community forestry program adopted in Nepal and other developing countries also plays a successful role in forest protection (Brooks et al., 2012; Porter-Bolland et al., 2012). More recently, reforestation has been a global phenomenon, and many developing countries have undergone through a forest transition—a shift from net loss to a net increase of forest cover (Meyfroidt and Lambin, 2011). During 1990-2015, a net loss of the forest area has been slowing down and afforestation has increased at a global scale primarily in 13 tropical countries, forest transition has undergone since 1990 (Sloan and Sayer, 2015). Forest transitions result from various trends such as natural regeneration of forests, forest plantation, and adoption of agroforestry (Meyfroidt and Lambin, 2011). Migration of farmers from rural areas to urban centres and economic shift from agriculture to industry and services stimulate forest recovery and gain (Aide and Grau, 2004). In the context of South Asia including Nepal, reforestation and regrowth of forest are attributed to human drivers particularly to the devolution of forest management to local communities in the form of community forestry (Nagendra, 2009).

Globally, community forest management (CFM) has been considered a promising approach to sustainable forest management over the past few decades (Arnold, 2001). Although CFM has various definitions and interpretations, CFM is a government-approved form of forest management in which the rights, responsibilities, and authority for forest management rest, at least in part, with local communities (Newton et al., 2015). The primary aim of CFM is maintaining ecological sustainability (reduce deforestation, preserve biodiversity) while improving livelihoods of the local community (Bowler et al., 2012). Despite some examples of CFM failures (Tole, 2010; Bowler et al., 2012), in many countries, it has produced successful outcomes such as improvement of forest cover, increase in plantation zones, equity of benefit sharing, or reduction of community poverty (Pagdee et al., 2006). In some tropical countries, the community managed forest plays more important role in maintaining forest cover than protected areas; community forestry has lower deforestation rates than protected areas do (Porter-Bolland et al., 2012). Despite these mixed outcomes, CFM is the widespread approach to forest management in developing countries including Nepal. In the context of climate change, CFM is now viewed as an option to reduce greenhouse gas emission through REDD+ (Reducing Emissions from Deforestation and Forest Degradation), a global climate change mitigation mechanism, which has been under negotiation by the United Nations Framework Convention on Climate Change (UNFCCC) (Agrawal and Angelson, 2009).

Nepal has a promising history of forest management and shows an excellent example of community-based forest conservation globally although the country has only 5.96 million hectares forests (40.36% of the country's land area). Concerned with massive deforestation and forest degradation in the early 1970s, Nepal initiated one of the most extensive community forestry (CF) programs in the world by handing government-controlled forests over to community forestry users groups (CFUGs) formed by local communities through an enactment of the Panchayat Forest Rules (Acharya, 2002). Since then about 1.8 million ha of the forest areas have been handed over to and managed by, 19,361 CFUGs (approximately 1.45 million households or 35% of Nepal's population) under community-based forest management program (DoF, 2015). The community forests provide various ecosystem goods and services to the local communities and help to global communities by sequestering a significant amount of carbon. Nepal has recently jointed to the United Nations collaborative initiative on REDD+ program—one of the leading global efforts to reduce deforestation to mitigate climate change, prepared a Readiness Preparation Proposal (R-PP) and formed REDD+ institutional framework (MoFSC, 2012; UN-REDD, 2014). Finally, under the most recent United Nations Framework Convention on Climate Change (UNFCCC) agreement in Paris to reduce emissions, Nepal's Intended Nationally Determined Contributions (INDCs) to emissions assign a vital role to forests. Nepal aims to enhance forest carbon stock by 5% by 2025 as compared to 2015 levels and decrease mean annual deforestation rates by 0.05% from 0.44% (DFRS, 2015).

Nepal does not have a long-recorded history of deforestation or forest cover change. The initiation of large-scale monitoring of forest cover change occurred only after 1960 although deforestation has been a major issue in Nepal. From 1964 to 1994, about 2.1 million ha of forests were converted to shrubland or other land uses (Acharya et al., 2015). FAO data showed that the annual loss of forest in the period between 2000 and 2005 was 1.39%, which remained stable during 2005-2010 (FAO, 2010). However, forest cover change at the national level has not been assessed in Nepal after the second National Forest Inventory in 1999; therefore, there is no critical information available about forest cover change at the national level in Nepal in recent years (DFRS, 2015). Most of the recent studies on forest cover change were conducted in small areas (Uddin et al., 2015a; Uddin et al., 2015b; Niraula et al., 2013; Poudel et al., 2015). Some recent studies have outlined both drivers and underlying causes of deforestation and forest degradation in Nepal. A total of nine major drivers of deforestation and forest degradation: i) forest fire, ii) overgrazing, iii) unsustainable utilization of forest products, (iv) weak forest management practices, (v) infrastructure development, (vi) urbanization and resettlement, (vii) encroachment, (vii) invasive species, (ix) mining were identified (REDD Implementation Center, 2013). Likewise, population distribution, migration, poverty, high dependency in forest products, insecure forest tenure are major underlying causes of deforestation and forest degradation in Nepal (Acharya et al., 2015). We use available data on the drivers and underlying causes of deforestation and analyse: a) the spatial and temporal patterns of the tree cover change in Nepal from 2001-2014, b) the socio-economic drivers of forest cover change, and c) the effectiveness of community forestry programs on the tree cover dynamics. Our efforts mark the first attempt to analyse the tree cover change for the entire country (albeit at the district level), relate this loss and gain to socio-economic drivers, and identify policy-relevant interventions (community forestry) needed to stem deforestation and forest conservation.

Materials and Methods

Study area

Nepal provides an excellent case study to understand the effectiveness of community-based institutions on forest conservation as a significant portion of the forests of this country is managed by local communities. The entire country, Nepal (figure 1) with a geographical area of 147,181 km^2, was divided into five physiographic zones—High Himal, High Mountain, Hill, Siwalik, and Terai—based on climate, soil, elevation, topography, vegetation and forest types (LRMP, 1986). Forest and agriculture sectors have the highest contributions to the national gross domestic product (GDP), contributing 26.1% share of the total GDP of Nepal (CBS, 2015b). About 69% of the employed population in Nepal is engaged in agriculture, forestry, and fishing (CBS, 2015a). The country is politically divided into 75 districts; the district is the lowest spatial unit used here for data analysis, as most of the demographic, socio-economic, and environmental data are available only at the district level in Nepal. We believe that district-level analyses do not compromise data availability and spatial accuracy.

Tree cover data

We used a subset of global tree cover data provided by global forest watch (Hansen et al., 2013, updated every year). The global forest watch offers the highest resolution datasets (30m ground resolution) of tree cover using Google Earth Engine and Landsat's satellite imagery for the entire globe. The data show both the extent and change of tree cover globally (Hansen et al., 2013). We called it tree cover, however; it is synonymously called forest cover. Unfortunately, there is no shared definition of forests globally. Generally, forests are defined for specific purposes, based on views, concepts, and priorities (Chazdon et al., 2016). Three common criteria: canopy cover, intact-area, and the height of the trees are commonly used for defining forests, but these criteria are not uniformly used by different agencies and countries. For example, Food and Agriculture Organization of the United Nations (FAO) uses 5 m for the height of trees, 10% crown cover and 0.5 ha for minimum size of forest (Lambrechts et al., 2009) whereas United Nations Framework Convention on Climate Change (UNFCC) calls forests for area of 0.05-1 ha with 10-30% canopy and >2-5m tall trees (Sasaki and Putz, 2009). These differences in definitions and methodologies used to map and monitor forests often lead to differing results (Lambrechts et al., 2009). Furthermore, the definition and assessment issues have handicapped the efforts to understand the tree cover dynamics (Rudel et al., 2016). The definition of tree cover adopted for this study was 'all the vegetation area greater than 5 meters in height with the canopy cover of at least 30%' as used by Hansen et al. (2013) since we used Hansen's data from the Global Forest Watch. We disaggregated tree cover change (loss and gain) data for the 75 districts and five physiographic zones of Nepal.

Drivers of tree cover change and policy responses

According to Angelsen and Kaimowitz (1999), the framework of deforestation should consider five types of variables (the magnitude and location of deforestation as a dependent variable, the agents of deforestation, the choice variables, agents' decision parameters, the macroeconomic variables, and policy instruments) in the models of deforestation. We selected a list of potential factors of deforestation and forest degradation in the context of Nepal after carefully reviewing the literature on global and local drivers of—and causes to—forest cover change, while also considering the availability of data. We did not consider some factors associated with deforestation and forest degradation identified by previous studies (Angelsen and Kaimowitz, 1999) as relevant to Nepal. For example, some of the immediate causes of deforestation listed by Angelsen and Kaimowitz (1999) such as agriculture prices, prices of agricultural inputs and credit and underlying causes of deforestation such as timber prices, external debt, trade and structural adjustment may be associated with deforestation in Nepal but the data is not available.

Data on various factors associated with deforestation and forest degradation such as demographic (population, population density, migration), economic (number of poor people, poverty incidence, poor people density, livestock number, livestock density), social (human development index, fuelwood collection), and environmental (fire, road length, elevation, slope) along with the policy response variables (number of community forest user groups and the share of the major vegetation area covered by community forest) were gathered from various sources (Table 1). In the following paragraphs, we provide our justification for selecting these factors.

The population is widely seen as an underlying driver of deforestation (Angelsen and Kaimowitz, 1999; Kissinger et al., 2012). In the natural resource-dependent country like Nepal, population growth increases demand for natural resources primarily forests and requires more lands for habitation. As the population grows, more people are living in the cities, and urbanization is considered as one of the major drivers of deforestation in Nepal (REDD Implementation Center, 2013). A high unemployment rate coupled with population growth has accelerated both domestic and international migrations in Nepal, and the country has emerged as a remittance-dependent economy shaped by the earnings of labour migrants for foreign employment. Remittance contributes around 29% to the Gross Domestic Product (GDP) of Nepal, making the nation top third among the countries in terms of remittance contributions to GDP (World Bank, 2016). Migration particularly labour migration, has resulted in land abandonment and the conversion of agricultural land into other land use such as forests, shrubs or fallow in some areas (Paudel et al., 2014). Therefore, total population, population density, and migration are considered as dependent variables in our model. We used the most recent national population census as a demographic variable (CBS, 2012). We also included the data on out-migration (the number of people migrated abroad for employment as there is no data on internal migration available) (GoN, 2014a).

Human development index, which measures income, health, and education, is linked with deforestation and hence incorporated in our model; countries with low HDI has a high rate of deforestation and vice versa (Jha and Bawa, 2006). Although income and poverty are correlated, poverty is a multidimensional social phenomenon (Anand and Sen, 1997). There is a high rate of poverty in naturally forest-dense areas, and poverty is considered as an important underlying cause of forest conversion by smallholders (Chakravarty et al., 2012). However, the linkage between poverty and forest degradation is ambiguous (Angelsen and Kaimowitz, 1999) and the natural resource degradation may depend on a complex range of choices and tradeoffs available to the poor (Barbier, 2010). Nepal still has a large number of people living in poverty and has a low score in HDI. Therefore, we accounted for HDI and poverty in our model. District wise figures of HDI, number of poor people, and poverty incidence were obtained from the latest human development report (NCP/UNDP, 2014).

Overgrazing is considered as one of the major drivers of forest loss and degradation in Nepal (Acharya et al., 2015; REDD Implementation Center, 2013). Grazing in the forested areas and stripping trees to provide fodder for animals are common in many parts of Nepal. Therefore, we considered this as a variable to our model. The most recent data of livestock were acquired from the statistical information on Nepalese Agriculture (GoN, 2012a). Since the populations of pig, poultry, and fowl do not have a direct impact through grazing on forests, we excluded them from the populations of cattle, buffalo, sheep, and goat and used as the livestock number. We calculated the livestock ratio by dividing the livestock number with the extent of the major vegetation cover of each district assuming the pressure of these livestock exerts mainly on vegetation. The vegetation area (cumulative area of forests, shrubs, grasslands and sparse vegetation) for a district was calculated by using a global land cover share map, version 1.0 (Latham et al., 2014).

Although fire can be a helpful tool for forest management, it can be a significant cause of deforestation if abused (Chakravarty et al., 2012). Forest fire induced by humans is one of the key drivers of forest degradation in Nepal (Matin et al., 2017). We gathered the district wise and temporal data of forest fire from Martin et al. (2017). Their analysis is based on the active fire data from MODIS satellites dating from 2003 to 2013.

Fuelwood gathering is considered as one of the causes of deforestation and forest degradation in tropical areas (Chakravarty et al., 2012). In rural areas of Nepal, wood derived from natural forests is one of the most critical sources of fuelwood (Christensen et al., 2009). Fuelwood contributes about 70% of the total energy supply for the rural population of Nepal (Kandel et al., 2016). Therefore, we included fuelwood gathering as a variable in our model. We collected district wise data of the total number of households used fuelwood for cooking from the national population and housing census (CBS, 2012).

Proximity to the roads affects forest condition; forests closer to roads in the distance are more likely to be cleared (Liu et al., 1993; Lambin, 1997). In rural Nepal, there has been a prolific growth of earthen road expansion in recent years. Due to the mountainous topography, steep slopes, and weak soils, these poorly constructed rural roads have increased the probability of landslides especially during the heavy monsoonal rainfall (Leibundgut et al., 2016). Therefore, road buildings may have an impact on the condition of forests and we considered the length of the road as a variable in our model. The data on road was collected from the Department of Roads, Nepal (GoN, 2012b). We also used digital elevation data (DEM) from Shuttle Radar Topographic Mission (SRTM) (http://srtm.csi.cgiar.org/) and calculated slope from DEM in ArcGIS to use in our model.

We used the total number of CFUGs and the proportion of the vegetation area covered by community forests in a district as a proxy to measure the effectiveness of community forestry programs. The data on the number and area of CFUGs were obtained from the Management Information System maintained by the Department of Forests, Nepal (DoF, 2015). To normalize the non-forested area effect, the total area of community forests in a district was divided by the major vegetation area of that district because the government handed over only the area covered by potential vegetation (forests, grasslands, shrubs, and sparse vegetation areas) to the local community as the community forests.

Data analysis

We analysed the net change (loss and gain) of tree cover for each district over a 15-year period from 2001 to 2016. Because protected areas cover a significant area of Nepal (about 24% of the total land area) and have a separate management system, the geographical areas covered by protected areas were excluded in further analysis to determine the impacts of the drivers of deforestation and effectiveness of the community forestry program on the gain and loss of tree cover. We build two models; in the first model, the proportion of forest loss was used as a dependent variable and in the second, proportion of forest gain. The demographic, economic, social, and environmental variables were used as independent variables in both models. After testing our data with the assumptions required for multiple linear regressions (heteroscedasticity, normality, outliers, multicollinearity), we conducted the ordinary least square (OLS) regression analysis to predict the impact of independent variables on the dependent variables. We examined multicollinearity among predictor variables (Supplementary figure 1) and eliminated highly correlated ($r > 0.75$) four variables resulting in 12 independent variables for the initial models. We used stepwise model selection method on R software package to select the final model (R Core Team, 2017). The initial models were evaluated by using Akaike Information Criteria (AIC), the commonly applied criterion to compare models for the goodness of fit and the model with the smallest AIC was chosen as the best-fit model (Burnham et al., 2004).

As the socio-economic data were available at the district level, we choose 75 districts as study units. We conducted area-based correction for the dependent variables (tree cover loss and gain) to normalize the effect of the district size. Rather than using total area of tree cover loss and gain, we used proportions of forest that were lost or gained in the district as dependent variable in the regression models.

We also quantified the spatial pattern of tree cover loss to observe the spatial association between roads and the loss and gain of tree cover, using the GIS-based buffering approach, from one to five-kilometre distance from the current road networks. We counted the total number of pixels of tree cover loss and gain within a range from one to five kilometres from the roads and calculated the total areas. Since we have temporal data of forest fire incidence and forest fire is considered a major driver of deforestation and forest degradation in Nepal, we also compared annual trends of tree cover loss with the trends of the forest fire.

We visually compared the tree cover loss data with the high-resolution images of the Google Earth Pro. We first identified 132 larger patches of tree cover loss and randomly selected 50 patches by overlaying 1 km^2 grids on the layer of tree cover loss. We visually compared the images captured around 2001 with the images captured around 2016 in those loss patches using the Google Earth Pro. About 71.7% time, the tree cover loss patches matched with actual loss of tree cover (Supplementary figure 2).

Results

Spatial pattern of forest cover change

The total tree cover area in the year 2000 in Nepal was 4,746,000 hectares. Nepal has lost 46,000 ha and has gained 12,200 ha areas of tree cover over the last 15 years from 2001-2016. However, a substantial spatial variation was observed among physiographic zones, and districts; maximum loss of tree cover in Siwalik (28%, 13,000 ha) followed by Hill (26%, 12,100 ha) and Terai (22%, 9,900 ha), Middle mountain (21%, 98,00 ha) and High mountain (2%, 1,100 ha). Regarding tree cover gain, the Hill region gained the highest area of 6,200 ha (51%) followed by Siwalik 3,000 ha (25%), Terai 2,100 ha (17%), Middle mountain 830 ha (7%), and High mountain 70 ha (1%).

A major loss in tree cover was observed in Kailali (6%, 2,270 ha), Dang (5%, 2,090 ha), Sarlahi (4%, 1,730 ha), Rautahat (3%, 1,260 ha) and Nawalparasi (3%, 1,180 ha) districts whereas Kaski (0.09%, 34 ha) and Bhaktapur (0.1%, 42 ha) lost comparatively a smaller area of tree (Figure 2). In terms of gain in tree cover, Dang with 880 ha (7%) forest gain was at the top position followed by Nawalparasi (7%, 830 ha), Tanahun (6%, 650 ha), Palpa (6%, 620 ha) and Kailali (5%, 600 ha) districts while Manang (0.01%, 1 ha), Kaski (0.01%, 1 ha) and Darchula (0.01%, 1 ha) gained a lesser forest area. The maximum loss and gain of tree cover were observed within the five-kilometre distance from the roads; the area of forest cover loss and gain decreased as the distance from the roads increased (Figure 3a).

Temporal pattern of forest cover change

Over 2001-2016, the maximum loss in tree cover (6,180 ha) occurred in the year 2009 and the minimum (1,040 ha) in the year 2015 (Figure 3b). Likewise, in different physiographic regions, the maximum loss of tree cover in Terai occurred in 2009, Siwalik in 2011, Hill in 2012, Middle mountain and High mountain in 2009. A significant correlation was observed between the annual incidence of the forest fire with the annual loss of tree cover ($r=0.60$, $P = 0.049$), the maximum resemblance in the trends was found after 2008 (Figure 3c).

Drivers of change in tree cover

We observed the associations between policy response variables (proportion of the major vegetation area covered by community forest and number of CFUGs) and the proportion of tree cover loss and gain by incorporating the effects of demographic factors, economic, social, and environmental factors. The predictor variables identified by the AIC criterion are: a proportion of area covered by community forests, number of community forests, population, HDI, and number of migrants for the tree cover loss model. Likewise, a proportion of area covered by community forests, number of CFUGs, number of poor people, fuelwood, and fire were retained for tree cover gain model (Table 2). According to our model, the proportion of tree cover loss in a district is significant and negatively correlated with the number of community forests in the district suggesting the districts with a higher number of community forests have a lower amount of forest loss (Table 2). Similarly, population and number of migrants have significantly positive association while HDI was significant, and negatively correlated with the tree cover loss.

Similarly, the area of tree cover gain was significant and positively associated with the proportion of the major vegetation area covered by community forests demonstrating that districts with a higher the proportion of community forests have a more significant area of tree cover gain. Likewise, forest fire showed a significant and positive relationship with the tree cover gain.

Discussion

In this study, we disaggregated tree cover (both extent and change) into five physiographic zones and 75 districts of Nepal to compare spatial patterns of tree cover gain and loss. We also observed the temporal profile of the loss in tree cover at two scales, national and regional (physiographic zones). Furthermore, this study identified the demographic, social, economic, and environmental factors of tree cover change and measured the effectiveness of the community forestry program in changing the dynamics of tree cover. Our results are highly relevant to address the socio-economic drivers of tree-cover change as well as to witness the effectiveness of the community forestry program of Nepal.

Our results on various degree of tree cover loss and gain at district level correspond with the localized studies, which found decrease in forest cover in some areas (Uddin et al., 2015a; Uddin et al., 2015b) as well as increase in forest cover in others (Niraula et al., 2013; Paudel et al., 2015). However, loss of tree cover is more prominent than gain in Nepal at the national scale. This study also confirms the widespread anticipation of the spatial pattern of forest cover change in various physiographic zones; higher rate of deforestation and forest degradation in Siwalik and Terai and the regeneration of forest in the Hill and Middle mountain region (GoN, 2014b). The Terai and Siwalik regions comprise mainly tropical Sal and Mixed Broad-Leaved forest and Hill encompasses Hill Sal forest, Schima-Castanopsis forest, Chir Pine and Chir Pine-Broad Leaved forests whereas High Mountain region has temperate forests such as Cypress, Rhododendron, Spruce, and Oak Forests (Barnekow Lillesø et al., 2005). From the commercial point of view, Terai and Siwalik regions have forests with maximum market value and are hence highly prone to commercial exploitation (Acharya et al., 2015). In contrast, Terai region has the lowest proportion (7%) of community forests while Hill and mountain have 75% and 16% respectively (GoN, 2013). The total incidence of forest-fire as a whole has a significant and negative impact on the forest, and the relationship can be observed in the temporal pattern in which the annual incidences of forest fire correspond with the annual loss in tree cover. Furthermore, forest-fire is also considered a primary cause of forest disturbance of Nepal (DFRS, 2015) and about 452,000 ha of land areas including forests were burned in Nepal from 2003 to 2012 (FAO, 2015).

Our results indicate that the community forestry program played a crucial role in reducing deforestation (tree cover loss) and increasing the forest area (tree cover gain) at the district level. The significant and negative association between the proportion of tree cover loss and the number of community forest shows that districts with a higher number of community forests have lesser areas of loss in tree cover. Similarly, the significant and positive association between the tree cover gain and the percentage of community-forested area in the district indicates a higher proportion of community forests in the districts has a greater gain in tree cover. Community forests combine a mixture of plantation and natural forests, and in most cases, local communities protect the community-owned forests allowing natural regeneration and growth (GoN, 2013). Nevertheless, the tree cover data (Hansen et al., 2012) used here do not distinguish between trees in plantations and natural forests. Therefore, it is not possible to differentiate between regenerating forests due to plantations or from the natural forests. Our study validates the local level studies (Niraula et al., 2013; Gautam et al., 2004; Gautam et al., 2002) and widespread perception that community forestry has a positive impact on the forest cover change by reducing the loss and increasing the gain in forest areas at the district level. Furthermore, an analysis of the CFGUs reports based on the perception of the user groups at national level showed that 79% of the CFUGs reported an overall increase in tree density in the community forests (GoN, 2013). However, there are other factors that are statistically associated with the forest cover loss such as population; a higher numbers of people and a larger the number of migrant workers in a district, greater the areas of forest loss. The positive association between forest loss and population makes more sense as the growing population increases demands for natural resources creating more pressure to forests. In the rural regions of Nepal, the dependency of the local people on the natural resources particularly on forests is very high. This result is consistent with Angelsen and Kaimowitz, 1999; Jha and Bawa, 2006; Ernst et al., 2013; Khuc et al., 2018). Significant and negative association between the tree cover loss and HDI values indicates the districts with higher levels of development has lesser tree cover loss. Studies found that HDI as a crucial predictor of forest transition (Redo et al., 2012) and a lower rate of deforestation (Jha and Bawa, 2006). Lack of development and economic opportunities in the districts with low HDI may make people rely heavily on forest resources for subsistence use (Angelsen et al., 2014; Belcher et al., 2015) that might lead to the extraction of more forest resources causing deforestation and forest degradation.

Road length is another variable, which has contributed significantly to both forest loss and gain suggesting that accessibility is a crucial factor for forest cover change (loss and gain) (Angelsen et al., 1999; Nelson et al., 2001; Newman et al., 2014). Construction of the road might lead to the cutting of trees and facilitate forest encroachment. Due to the steepness in the hilly areas, construction of unplanned earthen roads triggers landslides causing loss of vegetation (Leibundgut et al., 2016). Furthermore, roads were recently built in many rural villages of Nepal, and most of the community forests are located near villages in Nepal. Therefore, spatial concomitance might lead to a positive relationship between forest cover loss and road network. Despite the positive correlation between temporal trends of the number of forest fire incidences and tree cover loss, we also found a positive association between forest fire days and tree cover gain. The forest fire has both positive and negative impacts; the fire not only destroys forests and increases deforestation, but also facilitates germination, and helps the establishment of commercial timber species by eliminating growth-inhibiting vine loads (Cochrane, 2003). More detail study is necessary to understand the impacts of fire on tree cover change in Nepal as in this study, the unit of analysis is district and the precise localities of forest fire and the tree cover gain in a district might be different.

Conclusion

This study has compromised the spatial accuracy of the higher resolution of data with the availability of data at some extends. An analysis at a finer spatial scale would have produced a more nuanced view. Unfortunately, there is no spatial information (maps with boundary) available for all the CFUGs in Nepal. Although the analysis at the village development committees (VDCs), the lowest political unit of Nepal could provide more detail overview of tree cover change, the information on socio-economic drivers is available only at a district level. Despite this shortcoming due to limitations in data availability, our study has highlighted the different factors of deforestation and the effectiveness of the major forest conservation policy in Nepal albeit at a coarse scale. Because of these limitations, the inference of a robust causal relationship between the dependent and independent variables is rather difficult. Globally, the data of tree cover loss provided by Hansen et al. (2013) was correct only 75% of the time (Weisse and Petersen, 2015) and the data do not differentiate temporary and permanent loss of tree cover between natural forests or tree plantations (Harris et al., 2016). The quality of socio-economic data of developing countries is often criticized (Meyfroidt and Lambin, 2008). Given our limited understanding of the forest cover change in Nepal, the results of this study are useful in formulating policies and programs to address the drivers of deforestation and persistently improve the existing policy on community forestry. We hope that future research with a higher resolution of demographic and socio-economic data (at the scale of community forest) can provide more nuanced results and may identify additional factors associated with forest cover change in Nepal.

Despite some shortcomings due to limitations in data availability and quality, this paper analyses the spatial and temporal patterns of tree cover loss and gain in the light of socio-economic drivers and effectiveness of one of the major forest conservation policies of Nepal. This study addresses a long-term standing policy question regarding the effectiveness of community forestry programs and reveals the likely socio-economic drivers of tree cover change in Nepal. Our results confirm that both the extent of community forestry and the number of CFUGs have positive impacts on the forests. Districts with a higher number of community forests have a minimum loss in tree cover, and the districts with a higher percentage of community forest area have a maximum gain in tree cover. Although the community forestry program has a positive impact on the forest cover by reducing the forest loss and increasing the gain, the other drivers of forest loss have been leading to the overall decline in forest area in Nepal. Nepal lost almost 46,000 ha forest area while Nepal gained roughly 12,300 ha over 2001-2016. Therefore, in order to conserve forest areas in Nepal, the current policy can be continued and improved if necessary, coupled with addressing the underlying cause of deforestation.

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Table 1 (on next page)

Description of the variables used in the model

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Table 1. Description of the variables used in the study

Variables	Description	Unit	Data source
Ncfug	Number of community forestry user groups (CFUGs). CFUG is a community based local institution that has right to manage and govern community forests in Nepal's community forestry program.	Number	Community Forestry National Database Department of Forest, Government of Nepal (DoF, 2015) http://dof.gov.np/image/data/Community%20Forestry/Detail%20FUG%20All.pdf
Rcfug	Percentage of major vegetation area (cumulative of trees, grasslands, shrubs and sparse vegetation areas potential to be community forests) in the district covered by community forests.	Percentage	Calculated based on the land cover map and area of community forest in the district
P2011	Total population in 2011 based on population census.	Number	Central Bureau of Statistics, Government of Nepal (CBS, 2012) http://cbs.gov.np/image/data/Population/District%20Level%20Detail%20Report/Household_Tables.pdf
Pdensity	Population density in 2011 (calculated by dividing population	Number/km^2	Central Bureau of Statistics (CBS),

	with the area of a district outside the protected areas)		Government of Nepal (CBS, 2012) http://cbs.gov.np/image/data/Population/District%20Level%20Detail%20Report/Household_Tables.pdf
Pincid	Poverty incidence (Headcount index value). Poverty incidence is share of population having an income or consumption below the poverty line.	Percentage	National Planning Commission, Government of Nepal (NPC/UNDP, 2014) http://www.hdr.undp.org/sites/default/files/nepal_nhdr_2014-final.pdf
Ppop	Absolute number of poor people under poverty threshold.	Number	National Planning Commission, Government of Nepal (NPC/UNDP, 2014) http://www.hdr.undp.org/sites/default/files/nepal_nhdr_2014-final.pdf
Ppopdensity	Density of poor people (calculated by dividing population of absolute number of poor people with the area of a district	Number/km^2	Calculated here

	outside the protected areas)		
Livest	Total number of livestock (sum of total cattle, buffalo, sheep and goat)	Number	Promotion and Statistics Division, Ministry of Agricultural Development, Government of Nepal (GoN, 2012a) http://www.moad.gov.np/en/publication?PublicationSearch%5Bcategory_id%5D=13&PublicationSearch%5Btitle%5D=&PublicationSearch%5Badded_date%5D=
Rlivest	Ratio of total number of livestock with the extent of the major vegetation area in a district	Number/km^2	Calculated here
Hdi	Human development index (Composite index of life expectancy, education and per capita income)		National Planning Commission, Government of Nepal (NPC/UNDP, 2014) http://www.hdr.undp.org/sites/default/files/nepal_nhdr_2014-final.pdf
Rlength	Total length of roads	Km/100km	Department of Roads, Government of Nepal (GoN, 2012b) http://dor.gov.np/home/page/road-statics-

			2013-14-1
Fire	Total number of fire incidence from 2001 to 2013	Number	Disaster Information Management System, The United Nations Office for Disaster Risk Reduction (UNISDR, 2016) http://www.desinventar.net/DesInventar/profiletab.jsp?countrycode=npl&continue=y
Nmigrant	Number of migrants from the district gone to overseas for employment (2008-2014)	Number	Department of Foreign Employment, Government of Nepal (GoN 2014) https://asiafoundation.org/resources/pdfs/MigrationReportbyGovernmentofNepal.pdf
Fuelwood	Total number of households using fuelwood for cooking	Number	National Population and Housing Census (National Report), Central Bureau of Statistics (CBS), Government of Nepal (CBS, 2012) http://cbs.gov.np/sectoral_statistics/population/national_report
Tloss	Net change loss in tree cover from 2001-2016	Hectare	Global Forest Watch (Hansen et al., 2013)

			http://earthenginepartners.appspot.com/science-2013-global-forest/download_v1.4.html
Tgain	Net gain in tree cover from 2001-2016	Hectare	Global Forest Watch (Hansen et al., 2013) http://earthenginepartners.appspot.com/science-2013-global-forest/download_v1.4.html
Elevation	Altitude	Meter	Shuttle Radar Topographic Mission (SRTM) Digital Elevation Data (DEMs) https://lta.cr.usgs.gov/SRTM1Arc
Slope	Slope	Degree	Calculated from elevation in ArcGIS

1

Table 2 (on next page)

Coefficients of net change in tree cover

Table 2. Coefficients of tree cover loss and gain

Model 1: Proportion of tree cover loss		**Model 2: Proportion of tree cover gain**	
Variables	Estimate (Std. error)	Variables	Estimate (Std. error)
	4.0660 (1.162)***		-0.4183(0.1700)
Ncfug	-0.0036(0.0008)***	Ncfug	-0.0007 (0.0004)
Rcfug	0.0139(0.0073)***	Rcfug	0.0155 (0.0029)***
P2001	0.000002(0.0000007)**	Ppop	-0.000002(0.000001)
HDI	-7.153(2.609)**	Fuelwood	0.000006(0.000004)
Nmigrant	0.00002(0.000009)*	Fire	0.02562(0.00852)**
	R^2= 0.54, p = < 0.00000	R^2= 0.40, p = < 0.00000	

*p=0.05,**p=0.01, ***p=0.001

1

Figure 1

Study area showing the tree cover loss in different districts of Nepal.

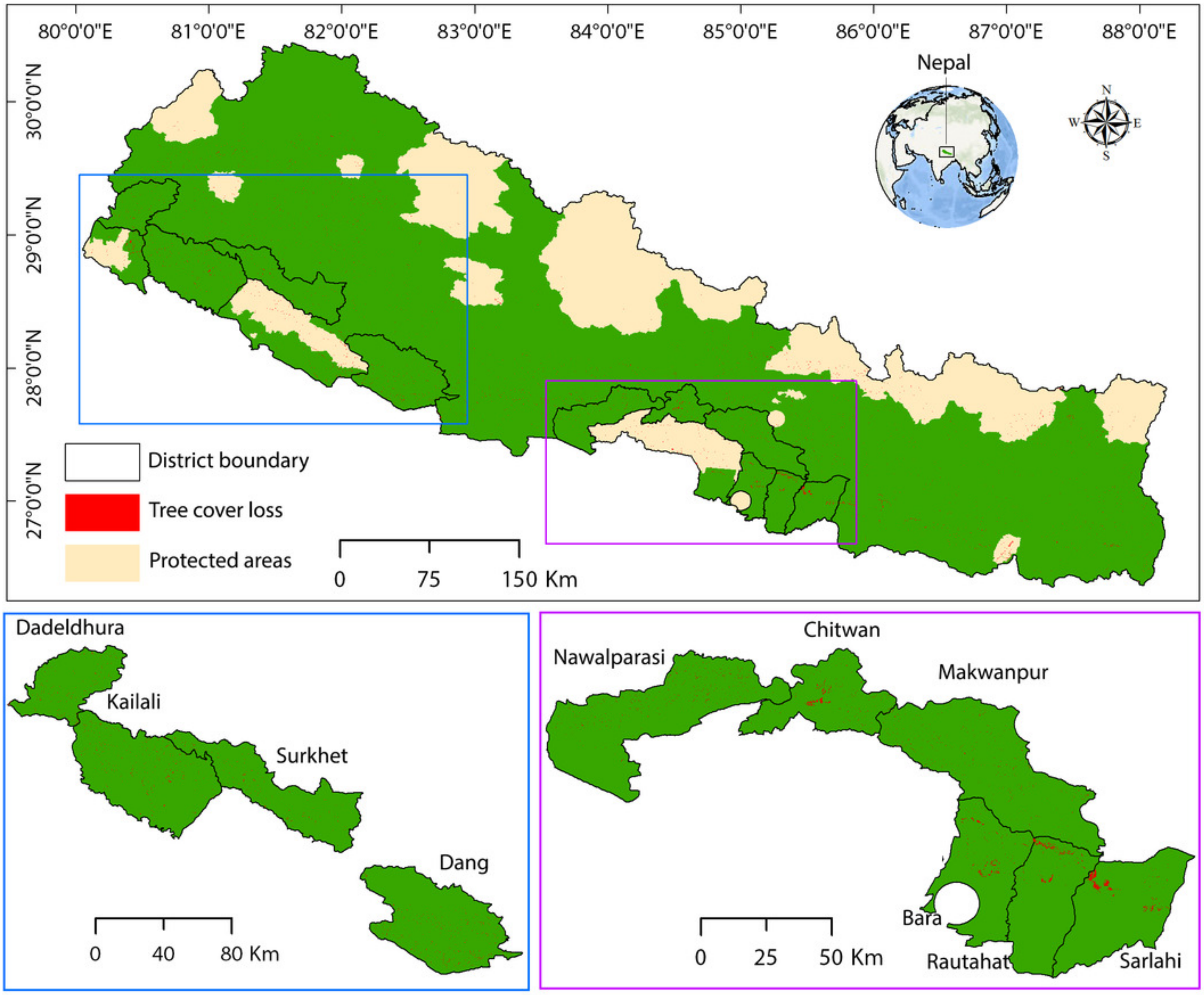

Figure 2

Extent of tree cover change in different districts of Nepal.

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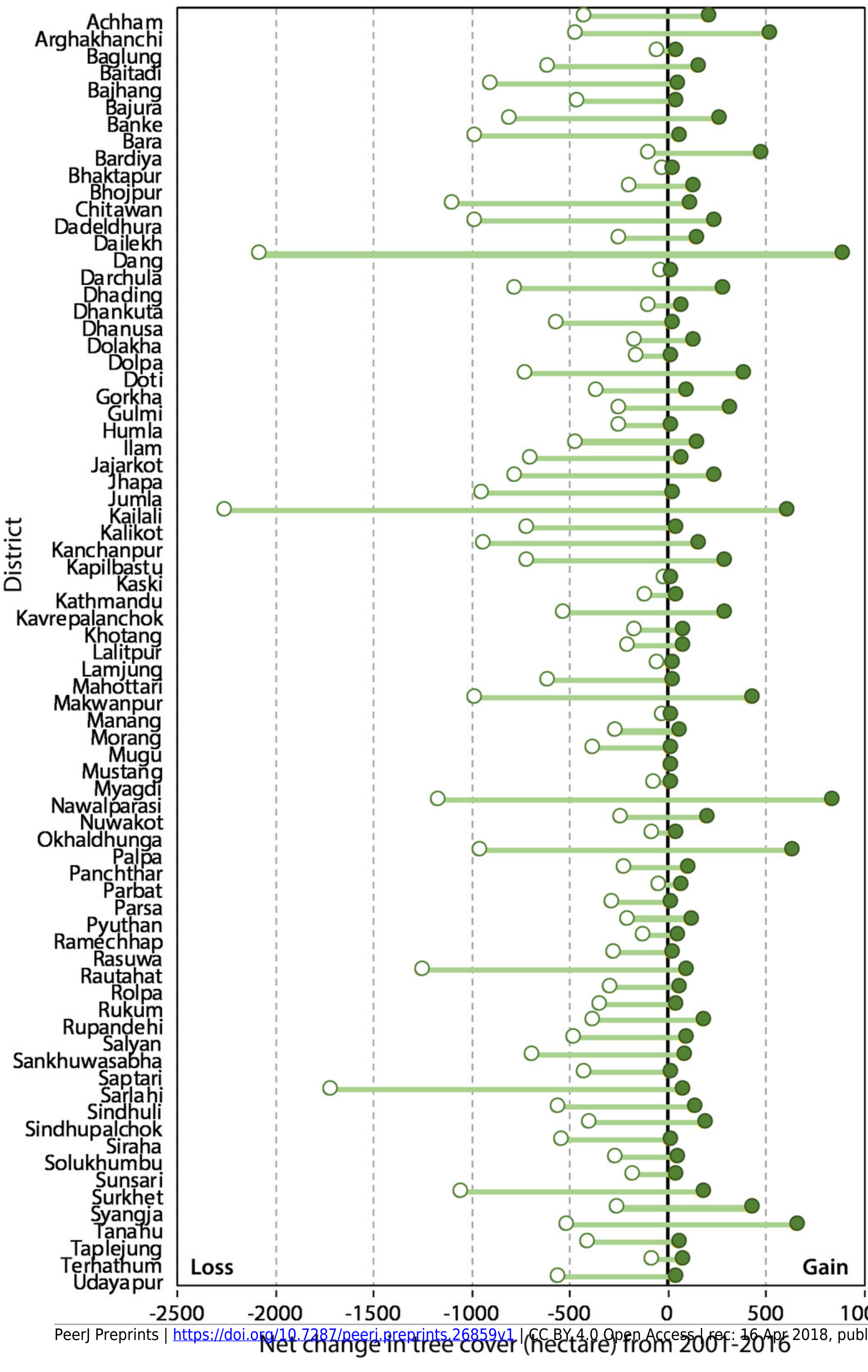

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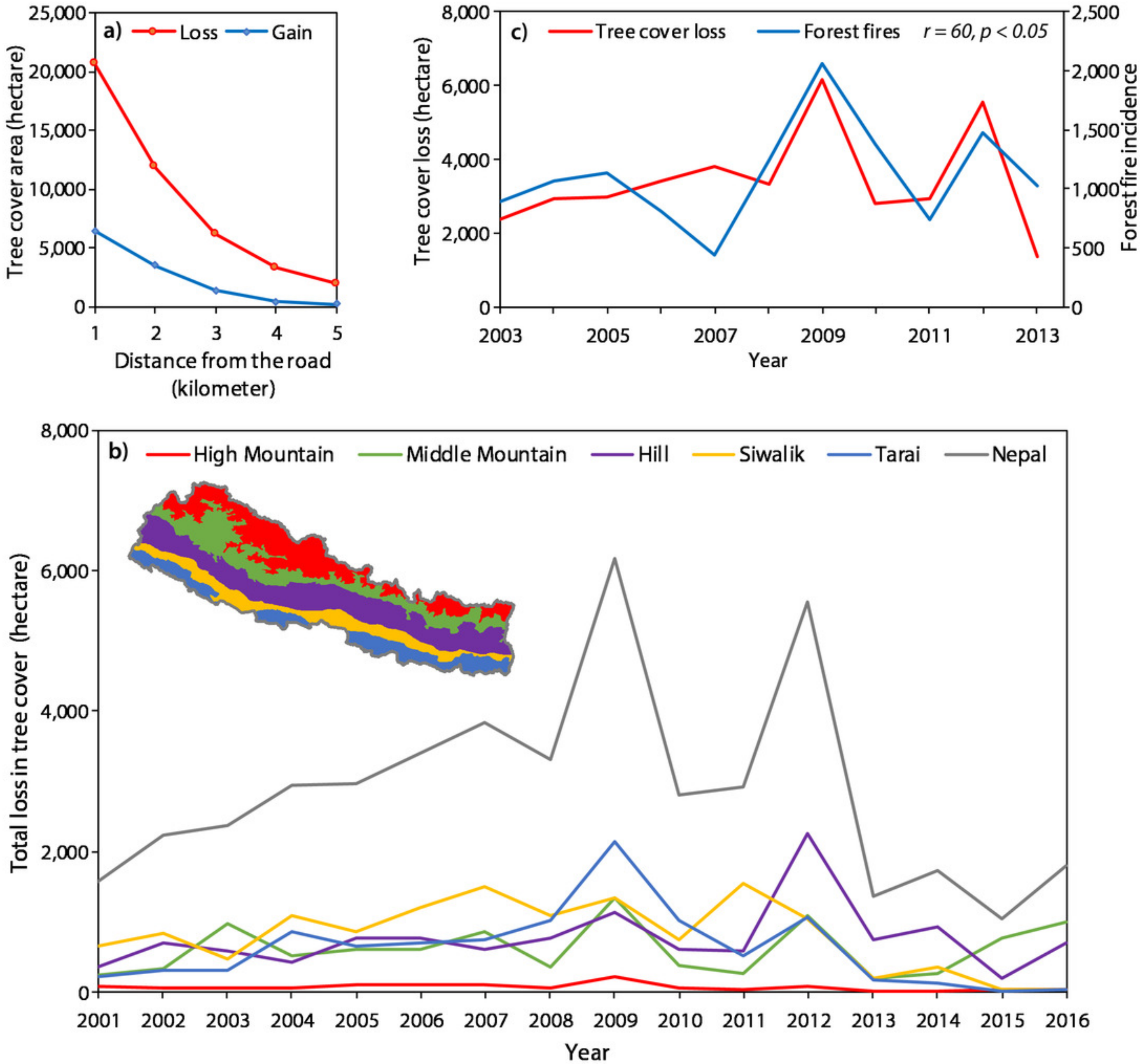
Figure 3

a) Tree cover loss and gain in distance from the road, b) Temporal pattern of tree cover loss in five physiographic regions of Nepal, c) Temporal pattern of tree cover loss with respect to forest fire incidence.



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