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Mapping and Understanding Changes in Tree Cover in Nepal: 1992 to 2016

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Abstract

Since the 1980s, Nepal, one of the poorest countries in the world, has gained worldwide recognition for its successful community forestry program. Researchers, however, have not previously documented the spatially explicit impacts of this forest transition because of the topographic effects, e.g., shading, clouds, snow, and ice, hindered remote-sensing imagery analysis. This multi-disciplinary research project used United States Geological Survey (USGS) Landsat 5, 7, and 8 surface reflected-correct imagery from 1988 to 2016 that were available in Google Earth Engine to map forest cover change across the country. We then used a Random Forest (machine learning method) and multilevel regression analyses to assess associations between changes in forest cover and physiographic and socio-economic variables. We found that between 1992 and 2016, forest cover in Nepal almost doubled. Among other variables, being a member of a community-forestry user group, and receiving remittance income from children who had migrated elsewhere to work had a positive impact on forest cover.

Key words: Community forestry, forest regeneration, Google Earth Engine, migration and land use

INTRODUCTION

In the 1970s and early 80s, numerous authors attributed deforestation in Nepal to uncontrolled use of forestlands by a rapidly growing rural population (Eckholm 1976; Bishop 1978; Hoffpauir 1978). In the 1990s, other authors began to document examples of successful conservation and forest management efforts (see Messerschmidt 1990; Stone 1990; Fisher 1991). What happened? Were the reports in the 1970s and early 1980s erroneous, or did they fail to predict how Nepali farmers would react to forest degradation and to shortages of forest products? Mather (1990) proposed the term "forest transition" to describe a trajectory of change where initial forest loss is followed by recovery as a country undergoes social and economic changes. Rudel *et al.* (2005) distinguished two forest transition pathways: an economic development path and a forest scarcity path. The economic development pathway is associated with industrialisation and the movement of people from rural areas and towards non-farming livelihoods. The forest scarcity pathway is associated with a scarcity of forest products and higher timber prices, which cause landowners to invest in tree planting and forest management. Forest scarcity also induces governments to implement policies that restrict forest exploitation, create protected areas, promote community management practices, and invest in forestry research and reforestation programs. Rudel *et al.* (2005) suggested that the forest scarcity pathway might be more prominent in densely populated and poorer countries of Asia, whereas the economic development pathway may be more prevalent in the richer and less densely populated countries of the Americas.

In 1988, Nepal's Department of Forests (DoF) identified 61 per cent of the nation's total forest area (3.5 million ha) as forest that could be transferred legally to local communities and managed for their benefit (Acharya 2002). Today, community forests occupy nearly 23 per cent of Nepal's total forest area (1.2 million ha), the management of which involves over 19,500 community forest user groups comprising 1.6 million households and nearly 40 per cent of Nepal's population (DoF 2012). Scientists have not documented the spatially explicit impacts of this transition in forest management in part because of the difficulty of mapping forest cover in mountainous environments topographic effects, e.g., shading, the presence of clouds, snow, and ice, and the inaccessibility of areas of rugged terrain for ground truth data collection hinders remote sensing analysis. Indeed, only three national scale forest surveys have been conducted in Nepal using Landsat imagery—1990 imagery (Uddin 1990), 2010 imagery (Uddin 2015), 2010-2014 imagery (GoN 2015). Mapping Nepal's forest transition through time and developing a comprehensive understanding of factors underlying observed changes in forest cover are critical if Nepal is to improve upon its already successful resource initiative.

While scholars have yet to quantify changes in Nepal's tree cover, they have written extensively about the country's community forest program (e.g., Agrawal and Gibson 1999; Agrawal and Ostrom 2001; Chakraborty 2001; Gautam *et al.* 2004; Joshi *et al.* 2013; Poudel *et al.* 2013; MoFSC 2013; Birch *et al.* 2014). Numerous case studies have also used remote sensing and aerial imagery to map changes in forest cover at regional (i.e., sub-national) and village scales (e.g., Millette *et al.* 1995; Jackson *et al.* 1998; Gautam *et al.* 2002, 2003, 2004; Nagendra *et al.* 2004, 2005, 2008; Ostrom and Nagendra 2006; Panta *et al.* 2008; Niraula *et al.* 2013). However, these studies only offer a mosaic of disjointed assessments of forest dynamics based on disparate methods and data. Without a methodologically cohesive, updated national map of forest cover change, scientists cannot identify the socio-economic variables associated with successful community forest efforts.

Extending over 147,181 km^2, Nepal is preponderantly a mountainous country composed of three distinct physiographic zones or regions, the Mountains, Middle Hills, and Terai (lowland plains). By examining regional forest cover change since 1990 alongside data on social and economic transformations from the 2001 and 2011 national population censuses and the 2011/2012 agricultural census (Khadka *et al.* 2003), it is possible to assess forest-transition hypotheses. These hypotheses include the influence of socio-economic characteristics (i.e., forest resurgence is associated with higher incomes, older populations, less farmland, and higher education) (Meyfroidt and Lambin 2011), location (i.e., forest regeneration is associated with land marginally suited for agriculture and distant from population centers or markets), and condition (i.e., forest scarcity yields improved management and increased tree planting).

This paper describes a project that used a multi-disciplinary research approach to quantify the rate and extent of Nepal's forest transition and identify significantly associated socio-economic variables. However, because the project could not distinguish forests from plantations, orchards, trees growing on fallow land and other trees, the paper will henceforth refer to tree cover instead of forest cover. The project had three overarching objectives: 1) Build a comprehensive, cross-scale database of change in tree cover between 1992 and 2016; 2) Identify the physiographic and socio-economic variables associated with changes in tree cover and quantify their respective influences; and 3) Assess how foreign labor migration and remittances correlate to changes in tree cover across the country.

BACKGROUND

Remotely Sensing Changes in Tree Cover in Nepal

Satellite imagery analysis is a critical tool in mapping the area and pattern of changes in tree cover and understanding the spatially explicit processes contributing to observed changes. In mountainous Nepal, earlier studies have been impeded by the influence of Nepal's mountainous terrain, namely, topographic effects such as variation in solar illumination and shading that produce within-forest spectral variability. An early Landsat TM-based assessment by Millette *et al.* (1995) of three village areas in the Middle Hills readily identified most land covers with the exception of forest. This disparity was largely due to differing solar illumination between slopes: greater solar exposure on south-facing slopes made them more favorable for cultivation, while north-facing slopes were left forested but also more shaded, which impeded classification. Nagendra *et al.* (2005) had difficulty mapping forest cover change over an 11-year period (1989 to 2000) because of variation in the spectral character of forest cover across Landsat images taken months and years apart.

However, recent advances in imagery pre-processing, large volume processing, algorithmic development, and the expanded availability of imagery and complementary geospatial data have been instrumental in supporting highly accurate forest change mapping in mountainous environments (e.g., Brandt *et al.* 2012; Van Den Hoek *et al.* 2014). Of these, the development of fine-scale, global digital elevation models (DEMs) such as the Shuttle Radar Topography Mission (SRTM) (Slater *et al.* 2006) and ASTER DEMs at spatial resolutions of 90 meter and 30 meter, respectively, support the co-registration and ortho-rectification of satellite imagery through automated approaches such as the Automated Precise Ortho-rectification Package (AROP) (Gao *et al.* 2009), ATCOR (Balthazar *et al.* 2012), and related terrain illumination correction approaches (e.g., Tan *et al.* 2013). Ortho-rectification coupled with automated radiometric correction techniques (e.g., Canty *et al.* 2004; Masek *et al.* 2006; Vicente-Serrano *et al.* 2008) yield satellite imagery data that are both geometrically and spectrally faithful to on-the-ground conditions, which is necessary for any forest-cover change mapping effort in mountainous terrain.

Nepal's persistent cloud cover and the Scan-Line Corrector (SLC) gaps in Landsat ETM+ imagery acquired after February 2003 impede researchers from producing forest change maps with Landsat time-series imagery. Cloud-masking and multi-date, intra-annual imagery compositing techniques (e.g., Roy *et al.* 2010) are therefore required to produce imagery free of cloud effects, and the same compositing techniques can be used to fill SLC-error gaps. Imagery with excessive (> 50%) cloud cover is often of little value, however, and may result in breaks in temporal imagery coverage. Breaks in Landsat coverage can be addressed in multiple ways: through fusion with cross-scale imagery, e.g., Moderate Resolution Imaging Spectroradiometer (MODIS) or very high resolution (VHR, 1–2 m) commercial imagery; adoption of a forest regrowth or disturbance detection algorithm that is robust to intermittent imagery gaps, such as the Vegetation Change Tracker (VCT) (Huang *et al.* 2010) or LandTrendr (Kennedy *et al.* 2010); or interpolating across missing imagery dates by using a time-series signal processing algorithm such as a Kalman filter or Bayesian minimum mean square error (MMSE) estimator.

Finally, the relative inaccessibility of forests in Nepal impedes the collection of ground truth data necessary for calibrating and validating satellite imagery-based estimates of forest regrowth or disturbance. A ground truth sampling approach must accommodate the diversity of forest conditions, but such a sampling regime is exceptionally time-intensive. To circumvent this, VHR multispectral imagery that provides an incredibly detailed perspective on forest cover over a broad spatial extent as far back as 2000 may be used. Moreover, a pseudo-annual mosaic of VHR imagery across the country can provide an independent assessment of forest cover change sensitive to the spatially diffuse and small-scale regrowth and gain common in Nepal (Fox 2016).

National Censuses and Socio-economic Data

Research has shown the benefits of merging national census (mainly population and agricultural) and socio-economic (household, district, and regional) survey data with remote sensing data to examine the nexus of land-cover change and demographic and socio-economic processes (e.g., Frolking *et al.* 2002; Perz and Skole 2003; Karimi *et al.* 2011; De Espindola *et al.* 2012; Heinimann *et al.* 2013; Saksena *et al.* 2014). For example, Heinimann *et al.* (2013) used village-scale Lao Population and Housing Census data to characterise the pattern of shifting cultivation relative to key socio-economic parameters in northern Laos. Likewise, Saksena *et al.* (2014) used commune-scale data from Vietnam's national censuses as well as MODIS and Landsat imagery to correlate urbanisation with the incidence of avian influenza.

In Nepal, the Central Bureau of Statistics (CBS) collects data through decadal census surveys on demographic, social, economic, and natural resource variables. The CBS compiles and distributes these data at district, municipality, and Village Development Committee (VDC-prior to

2017 this was the smallest administrative unit in the country) levels (Sharma *et al.* 2013). In 2003, the CBS and the International Centre for Integrated Mountain Development (ICIMOD) produced a district-scale map based on demographic, social, and economic variables derived from the 2001 Population Census (Khadka *et al.* 2003). These data provide the means to interpret forest dynamics in Nepal with local and regional socio-economic drivers. For example, Adhikari and Hobley (2011) found that income was positively associated with fuelwood collection – wealthier households collect more fuelwood than poorer households do – and education was negatively associated with fuelwood consumption since higher levels of education provide a wider range of employment opportunities and reduce forest dependency. Gunatilake (1998) also found that family education level is negatively related to forest dependency. Households with large numbers of livestock spent more time collecting grass and fodder from community forests. Data on income, education, and number of livestock are available in the national demographic and agricultural censuses at district and VDC scales.

METHODS

Building a Comprehensive, Cross-scale Database of Forest-Cover Change in Nepal Over the Last 24 years

Satellite Image Collection and Pre-processing: Nepal overlaps 13 Landsat footprints, (139041, 139042, 140041, 140042, 141040, 141041, 142040, 142041, 143039, 143040, 143041, 144039, 144040, 144041) (Figure 1). In this study we used all Landsat 5, 7 and 8 surface reflected-corrected imagery from 1992-2016 that were accessible through Google Earth Engine. Images taken during Nepal's growing season-July to August – with a Scene Cloud Cover Score of less 80 per cent were used to generate cloud free seasonal composite images. The C Function Mask (CFMask) algorithm (Gorelick *et al.* 2017) was used to select mostly cloud-free imagery and was combined with the Simple Cloud Score algorithm (Gorelick *et al.* 2017) to mask clouds and cloud shadows. Finally, reflectance values from Landsat 5, 7, and 8 were harmonised using the method outlined by Roy *et al.* (2016) to ensure consistent spectral values year-to-year, sensor-to-sensor.

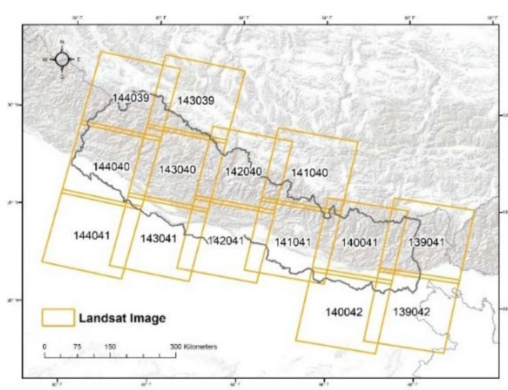

Figure 1: A Map of the Spatial Distribution of the 13 Landsat Scenes that Cover Nepal

The landsat time-series composites across Nepal were topographically corrected before the analysis of the Landsat data began (Hurni *et al.* 2019). After evaluating multiple topographic correction approaches and found that the effectiveness of a given correction approach varied across Landsat bands. For this reason, we used different topographic correction approaches for different bands: we used the

Variable Empirical Coefficient Algorithm (VECA) (Gao and Zhang 2009) for the Blue band and the Statistical-Empirical correction (S-E) Teillet *et al.* 1982) for all other bands. After topographic correction, reflectance was more consistent over the forests of Nepal as well as over our full study period regardless of illumination conditions at the various times of image acquisition.

Annual Tree Cover Classification: A number of spectral metrics were generated to guide the identification of tree cover across the country. In addition to the standard multispectral bands, we measured NDVI, EVI, NBR, brightness, greenness, wetness, and tasseled cap angle as well as topographic metrics including elevation, slope, and aspect to improve our discrimination of forest from non-forest. Since some years' composites were missing image information due to SLC errors or excessive cloud cover, we performed a linear interpolation across the full time series of imagery, pixel by pixel, to estimate values of missing pixels based on the spectral values of the pixel before and after the year with missing data. These linearly interpolated annual composites were the foundational imagery for our subsequent image classification.

To generate a training dataset representative of tree and non-tree conditions across Nepal, we started with a stratified random sample of forest and non-forest sites based on ICIMOD's 1990 (Uddin 1990) and 2010 (Uddin 2015) forest cover maps. We visually validated the ICIMOD-recorded land cover at each randomly sampled site and removed any erroneously classified sites, leaving approximately 2,100 locations labeled as 'tree' or 'non-tree'. At these sites, we then extracted spectral and topographic values from our 1990 and 2010 Landsat image composites at 1990 or 2010 ICIMOD-labeled sites, respectively, and then pooled 1990 and 2010 training data together into a single dataset appropriate for classifying any year in our study period. Finally, we trained and validated a one-thousand-tree RandomForest classifier on these labeled sites.

Identifying the Physiographic and Socio-economic Variables Associated with Tree Cover Change and Quantifying their Respective Influences

The quantitative relationships between tree cover dynamics and physiographic and socio-economic variables were assessed. Different physiographic variables were considered including elevation, slope, aspect, soil type, and distance from roads, settlements, and markets influence a given area's suitability for trees or other competing land uses such as agriculture or development. Just as the remoteness of a tree patch affects its accessibility, so too do socio-economic characteristics of a community affect the community's potential for successful tree management. Our initial hypotheses included the following: 1) tree resurgence is positively associated with higher incomes and higher education; 2) tree resurgence is negatively associated with older populations, less farmland, and more livestock; 3) tree resurgence is positively associated with land marginally suited for agriculture and distant from population centers or markets; 4) tree resurgence is positively associated with the formation of Community Forest User Groups; and 5) tree resurgence is positively associated with out-migration and remittance income.

A RandomForest (a machine learning method) and multilevel regression analyses was conducted to relate socio-economic and physiographic variables to tree cover change to identify the most significant predictors of tree cover loss or regrowth at the VDC level.

RESULTS AND DISCUSSION

Our remote sensing classification had an overall accuracy of 90 per cent with 87 per cent forest user's accuracy. We delineated tree cover gains and losses over our study period, measured the geographic distribution across Nepal's physiographic and administrative regions, and assessed the location of tree cover loss or gain relative to landscape features (e.g., villages, roadways, etc.). In 1992, we mapped 3.88 million ha of tree cover, which is equal to approximately 26.2 per cent of Nepal's land area. We mapped changes in tree cover every year until 2016. In that year, trees cover accounted to 6.63 million ha, an amount equal to approximately 44.9 per cent of Nepal's land area. Hence, during this 24-year period tree cover almost doubled across Nepal.

Table 1 below summarises the results of this research. In terms of first hypothesis, tree resurgence is positively associated with higher incomes and higher education, we found that increase in tree cover is positively associated with per cent of households in the VDC with modern houses and modern sources of water (proxies for wealth), and the per cent of household members who are literate. In terms of the second hypotheses, tree resurgence is negatively associated with older populations, less farmland, and more livestock, we did not find any significant variables. In terms of the third hypotheses, tree resurgence is positively associated with land marginally suited for agriculture and distant from population centers or markets, we found that, the rougher the terrain and north facing slopes (both proxies for marginally suited agriculture) were associated with more tree cover. We also found that accessibility, measured the time required to travel to the district headquarters had a positive association with tree cover (the longer it took to get to the district headquarters the more tree cover). In terms of the fourth hypotheses, tree resurgence is positively associated with the formation of Community Forest User Group, we found that being a member of a community forest user group had a positive association with tree cover. Finally, in terms of the fifth hypothesis, tree resurgence is positively associated with out-migration and remittance income, we found that receiving remittance income from children who had migrated to work elsewhere in Nepal or abroad had a positive impact on tree regeneration.

Table 1: Results from Random Forest and Multilevel Regression Modeling of Physiographic and Socio-economic Variables Associated with Changes in Tree Cover

Nepal	RandomForest	Multilevel Regression	
		75% Accuracy	
% Annual Tree Cover	88% Accuracy Ranking	Coefficient	P value
Regression Intercept		-450.094	0
Terrain Ruggedness	620,162	4.345	0
North facing slopes	43,553	30.114	0
% Hhs CFUG Members	31,193	0.010	0
Distance to Municipality	30,510	-0.001	0
% Modern Houses	25,323	0.073	0
% Hhs with modern water	21,970	-0.027	0
% literacy	19,181	0.024	0.048
% Hhs with migrants	15,817	0.0190	0.004

Hhs = households

CONCLUSION

In summary, this project produced a comprehensive set of maps and datasets at multiple scales that reveal the complex story of tree-cover change in Nepal over the last 24 years. We also produced an integrated database of physiographic and socio-economic data at multiple scales that can be used to explore the drivers of tree-cover change as well as the policy implications of these changes. Finally, we explored the impact both community forest user groups, and out-migration and remittances have on tree cover and implications for the future of tree cover. The project's significance lies in its improved methods for mapping tree cover in mountainous regions, and its integration of methods and datasets for conducting a comprehensive, interdisciplinary assessment of tree dynamics in mountainous regions. Furthermore, the project seeks to understand tree dynamics in Nepal in a way that not only produces insights into the social and ecological transformations of the region but also broadly advances forest transition theory.

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